THE UNIVERSITY OF MANITOBA

A SIGNAL DETECTION ANALYSIS OF THE EFFECT OF WHITE NOISE INTENSITY ON VISUAL FLICKER SENSITIVITY AND ON RESPONSE BIAS

BY

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DEDICATION

This research is dedicated to the memory of Professor John Peter Zubek who taught me to find out for myself.

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I would like to thank the members of my examining committee, Drs. R. S. Harrison, E. Schludermann, M. Janisse, H. Kelm, and especially Professor A. W. Pressey for the trust they displayed in giving me considerable freedom to explore an obscure phenomenon in accordance with my own philosophy of science.

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Nettie always had faith in me and in this project. My daughter Megan, by continually asking me what I was doing reminded me to find out. My son Brendan arrived late in the project and reminded me to finish.

To all of these people thank you, and I hope I live up to your kind expectations.

Abstract

In spite of several hundred published articles on the topic, the phenomenon of interaction among the sensory modalities has had little impact on the practice and theory of sensory-perceptual psychology. Recognition of these potentially important data has been hampered by conceptual narrowness, a dearth of systematic investigation, a surfeit of apparently contradictory results and methodological inadequacies. A review of the relevant literature indicates that sensory interaction (as reflected in altered sensitivity in one modality as a function of input in another modality) may be under the control of several inadequately investigated stimulus and subject variables. These include intensity of the auxiliary stimulus, temporal relations between the test and auxiliary stimuli, various qualitative aspects of the two stimuli, and state of sensory adaptation of the observer.

One sensory interaction condition which has received an unusual amount of attention is the effect of auditory stimulation on the Critical Flicker Frequency and in particular the effect of the intensity of auditory input on that measure of visual temporal acuity. Results of these investigations are suggestive of an attentional or arousal mechanism as mediator between the modalities. Careful research of a parametric nature is required, however, as research on the variables suffers from incomplete investigation and inadequate methodology.

The present research, employing methodology based on the Theory of Signal Detectability, assessed the effect of a wide range of intensities of white noise on performance in a flicker detection task. Three subjects were exposed to 500 presentations of "flickering" or "fused" light under each of ten auditory conditions. Subjects rated on a four-point scale their confidence that they had observed a "flickering" light. Performance associated with each auditory condition for each subject was determined by deriving Receiver Operating Characteristic curves. In addition indices of sensitivity (d'_e) and of response bias (β'_e) were calculated for each subject under each auditory condition. Results indicated a reliable but complex interaction of intensity of auditory stimulation and visual temporal acuity. Peaks in sensitivity occurred at 40, 70, and 100 dB (SPL) of white noise while lowered acuity was found at 50 and 80 dB (SPL). No response bias was systematically and reliably related to noise level.

Results were discussed in terms of previous research, implications for existing and future theories of sensory interaction, and biological significance of interacting modalities. Suggestions for future research were presented including proposals for two studies designed in conjunction with the present research to determine the contribution of the arousal properties of the auditory stimulus.

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INTRODUCTION

Overview

The functional interdependence of sensory modalities has been the subject of considerable experimental attention during the last one hundred years. As a result, several varieties of intersensory phenomena have been tentatively identified. For convenience, these phenomena may be divided into two broad categories, "higher" and "lower" order intersensory effects (see Ryan, 1940, for a more detailed discussion). "Higher" order interdependence involves the interaction of the products of within-modality processing. In this category may be included multimodal input in concept formation, learning, and memory. "Lower" order intersensory effects involve the modification of processing in one modality as a function of activity in another modality. Multimodal determinants of the perception of space and size are perhaps the best known examples of lower order effects. Less well known, and certainly less well understood, are intersensory effects on very basic sensory-perceptual processes. Recently, intersensory effects have been shown in a reaction-time paradigm by Taylor (1974, Campbell and Taylor, 1975) and others. Taylor argued that improvement in visual reaction time with auditory stimulation represents interaction at the primitive sensory level rather than at the higher process or motor levels. A more direct approach, however, of assessing intersensory effects at the sensory-perceptual level, would be the psychophysical determination of sensitivity or acuity in one modality while a stimulus is presented to another modality.[1] It is not well known that literally hundreds of studies have been carried out employing this "auxiliary stimulation paradigm". These studies on the psychophysical determination of sensory-perceptual interaction between modalities (SI) form the background to the present work.

It is somewhat of a paradox that so large a literature as that on SI has had so little impact on sensory-perceptual psychology. For example, of the many textbooks available in the areas of Sensation and Perception only that of Dember (1965) discusses the possibility of sensory interaction. Similarly, only one major review paper has been published on the topic (London, 1954) and that dealt only with work done by Soviet researchers. The literature is apparently not well known even among researchers who have investigated SI effects, as their references are seldom complete. Another reason for the obscurity of SI may be the rarity of sustained systematic research. Typically, investigators perform a study or two and then abandon the topic. The Soviet research is an exception to this rule. London (1954) states, ". . . western work on sensory interaction has been, in the main, scattered and desultory, whereas in the Soviet Union the subject has been given systematic and sustained attention"[2] (p. 531). The western literature consists of a large number of disconnected but loosely overlapping studies. Interpretation of specific results is difficult as authors rarely take into account many potentially relevant variables and often provide only scanty reports of the experimental situation. Discrepancies between results are difficult to reconcile as studies are seldom designed to be comparable to other related research.

Researchers interested in SI effects, therefore, must try to extract from this unsystematic literature, clues as to the identity of relevant variables. Fortunately, the number of studies is large enough to allow a tentative picture of SI effects to be assembled from deductions and reasonable guesses.

Several interrelated factors seem to underlie the problems outlined above, and before reviewing the SI literature these reasons should be understood. In fact, such an understanding is indispensable if SI is going to be systematically investigated in the future.

There seems to be at least three interrelated reasons why the topic of SI has not become an important problem area in sensory-perceptual psychology. These are: (1) the lack of consistent results both in the experimental questions asked and in the expected answers to those questions; (2) the conceptualization of the sensory modalities as discrete functional entities as encouraged by the histories of sensory physiology and sensory psychology; and (3) an apparent reluctance to speculate on the usefulness to the organism of having modality interdependence at the sensory-perceptual level. Each of these reasons will be briefly examined.

SI research is an area with many apparent discrepancies in results. This may be due to over-simplistic expectations concerning the nature of the effects. Questions guiding research are often of the type: "What is <u>the</u> effect of auditory stimulation on the absolute visual threshold?" Particular parameters of the stimuli and of the subject are not often recognized as possible contributors to differential effects. As a result, researchers expect simple answers such as: "The effect of auditory stimulation on the absolute visual threshold is to lower it." These overly simplistic expectations have caused many researchers to doubt the existence of SI effects. Parametric analysis may lead to the conclusion that such phenomena are extant but complex.

Historical considerations have limited the progress of knowledge concerning intersensory effects. Beginning with Muller's Doctrine of Specific Nerve Energies in 1838 the histories of sensory physiology (and thus sensory psychology) has largely been one of progressive isolation of function (Boring, 1942). Particularly influential have been the speculations of Helmholtz of which Boring (1950) said, "If Muller's theory is a doctrine of specific nerve energies, then Helmholtz's extension of the doctrine is a theory of specific fiber energies" (p. 91). Serious consideration of sensory interdependence goes against the spirit if not the edicts of the Helmholtzian tradition. Gestalt psychology represented a protest against this "isolationist" tendency. As Boring (1942) points out, however, for the Gestaltist, topics such as sensitivity were "swallowed-up" by the more molar concern of object perception.

There is no doubt that the predominant tendency in sensory-perceptual psychology has been to consider the modalities as discrete non-interacting entities. This may soon change, however, as psychologists become more aware of recent evidence from the area of sensory neurophysiology which indicates an unexpected degree and variety of convergence of the sensory systems. For example, a non-specific sensory system involving the reticular formation of the brain stem and mid-brain has been identified (see McCleary & Moore, 1965). This system receives collaterals from the major classical sensory tracts and generally arouses the cortex in response to sensory stimulation (Lindsley, 1961). Fuster (1962) has shown that electrical stimulation of this area in monkeys may result in changes in minimal separation time in a two-flash resolution task. These facts implicate the reticular formation as a candidate for the physiological mediation of SI effects. Other evidence indicates sensory system convergence in classical projection areas of the cortex. For example, the electrophysiological activity of the striate cortex has been reported to be altered at the gross and unit level in response to auditory stimulation (see, for example, Jung, Korhuber, & Fonseca, 1963; Skrebetski & Bomshteyn, 1967, 1968; Ciganek, 1966). The relationship between these neurological data and corresponding psychological phenomena awaits the establishment of unambiguous psychophysical description of those phenomena. As of now there are no general laws of functional interdependence that require neurological explanation. The physiological data should, however, serve to make psychological SI more plausible and so encourage the basic parametric research needed in this area.

The third reason SI research has not reached prominence as a problem area in sensory-perceptual psychology is that there is no obvious usefulness to the organism of interdependence at this basic level of functioning. Most researchers investigating SI effects seem either not to consider the biological significance of an interdependent organization of the sensory system or to consider SI effects as an epiphenomenon. As a result these effects have often been considered to be more curiosities of the laboratory rather than as part of the organism's adaptive process.

These reasons are, of course, complexly interrelated. Unless our conception of the sensory systems is widened to include interdependence, systematic research is not likely to take place, and yet the careful description of an instance of SI is just what is needed to widen the common conception. Until we have good parametric data describing SI effects their biological usefulness cannot be determined--and so on.

As mentioned above, a starting place in resolving these difficulties may be found in careful examination of the existing literature, unsystematic though it may be. The following section surveys the SI literature in an attempt to bring together, from a variety of sources, the most important information concerning the phenomena. As such the review does not exhaust the available literature but is rather an overview of the area, specifically, those variables which appear to be especially important.

Survey of the Variables Affecting SI

Historical Introduction

There is anecdotal evidence concerning SI dating from the 17th century. In 1669 the anatomist Bartholinius (cited by Hartmann, 1934) published his observation that the partially deaf could hear better in light than dark. It was not until 1888 that the first experimental investigations of SI phenomena were published by the

Austrian anatomist Victor Urbantschitsch. The work of Urbantschitsch has been extensively reviewed by Gilbert (1941) and the following discussion is based on that source. Urbantschitsch attempted to establish the heteromodal influence in all pairs of modalities, a task never before or since attempted, though as Gilbert suggests, ". . . it merely made up in scope what it lacked in thoroughness." It is to Urbantschitsch's credit, however, that his work represents a series of related studies. However suspect his results might be on methodological grounds they are therefore of more than historical importance. The results suggest that differential effects may be obtained with different values of several stimulus parameters. For example, he claimed that soft tones increased tactile sensitivity while loud tones inhibited it, and that loud tones initially darken but subsequently brighten the visual field. Qualitative aspects of the auxiliary stimulus were also recognized as determinants of SI effects. Thus high frequency tones were said to make colours brighter while low tones dulled colour intensity. In these demonstrations Urbantschitsch not only suggested the complexity of SI phenomena but he identified several stimulus dimensions as being important. Hundreds of studies later, the questions raised by Urbantschitsch are still in need of investigation.

The Role of Auxiliary Stimulus Intensity

Of all the variables that might affect SI results, there is more evidence concerning the role of the intensity of the auxiliary stimulus than any other. In contrast to the reports of Urbantschitsch, subsequent authors tended to see the effect of this variable as unidirectional. Thus, Heymans in 1904 (cited by Gilbert, 1941) authored the "Law of Inhibition" which stated ". . . the inhibitory power of a stimulus, measured by the intensity of a second stimulus which it can just completely inhibit, is directly proportional to its intensity." Heymans' "Law" described his own data showing electric shock to cause a decline in auditory sensitivity proportional to its strength. Another early study (Jacobson, 1911) found sensitivity to tactile pressure to be proportionally "inhibited" by increasing intensities of auditory stimulation. However, not all early research supported the "Law of Inhibition". Ode (cited by Gilbert, 1941) in 1919 found that weights felt heavier when hot <u>or</u> cold than at room temperature. Olfactory sensitivity was reported to be increased sevenfold in a lighted room over a dark room by Freund and Hofman in 1929 (cited by Hartmann, 1935). Performance on Seashore's auditory tests (Hartmann, 1934) and on a card sorting task that required tactile discrimination (Johnson, 1920) were similarly reported to be better in the light than the dark. Newhall (1923) reported brightness discrimination to be better concomitant with "clicks" than without. As only one intensity value of the auxiliary stimulus was employed in most of the above studies (e.g., the light was either "on" or "off") detailed functional relationships were not established. It is clear, however, that neither Heymans' "Law of Inhibition", nor any other description that is unidirectional describes adequately the heteromodal effect of the intensity of the auxiliary stimulus.

Two papers published in 1934 advanced the hypothesis that the effect of auxiliary stimulus was bidirectional, with the direction of effect being dependent on auxiliary stimulus intensity. Thorne (1934) reported that the probability of detection of a brief flash of light could be improved with a mild simultaneous noise from a buzzer. The detectability was made worse, however, with a loud noise from the buzzer. Thorne interpreted his results as a case of a figure-ground relationship. Vision, being the tested modality, was considered the figure, and audition was conceived of as "ground." Any "ground" of less intensity than the "figure" should enhance perception of the figure, while if the "ground" became very intense there would occur a figure-ground reversal (much as with a Rubin reversible figure). Mild auxiliary stimulation, then, should improve sensitivity in the tested modality while strong auxiliary stimulation would reduce sensitivity. Hartmann (1934), apparently without knowledge of the work of Thorne, also advanced a figure-ground theory of the heteromodal effects of auxiliary stimulus intensity "as figures, the auxiliary stimulus would raise thresholds in accordance with conventional expectations of the results of distraction, but as ground (with the main stimulus as 'figure') it may well produce facilitation."

Thorne and Hartmann, then, were the first since Urbantschitsch to suggest complex interactions in the production and direction of SI effects. Soviet researchers (as reviewed by London, 1954) have also (again apparently independently) noted differential SI effects with different intensities of the auxiliary stimulus. This effect is considered as a case of the "Rule of Inversion" which generally predicts reversed direction of results at different ends of several stimulus and subject continua. Thus, for example, visual sensitivity was found to be enhanced by mild odors and gustatory stimuli, while strong stimuli presented to the same modalities depressed sensitivity. Although the idea of some kind of figure-ground relationship is appealing it is far from established fact. What is required, but has been generally lacking, is the systematic investigation of several levels of auxiliary intensity on the tested modality with all other factors held constant. The one situation that has been studied more than any other in this regard is the effect of many intensities of auditory input on the critical flicker frequency (CFF). This literature will be reviewed in depth in a subsequent section; for now it will suffice to indicate that several investigators have independently concluded that the effect on CFF of increasing auxiliary stimulation intensity is oscillatory. That is, auxiliary stimuli progressively increase heteromodal sensitivity up to a point, then, with further increases in intensity, there results a progressive <u>decrease</u> in sensitivity. Although the role of the intensity of the auxiliary stimulus in determining SI effects is not clear, there is sufficient evidence of the importance of this variable to encourage its future systematic investigation.

<u>The Role of Temporal Aspects of the Stimuli</u>

Urbantschitsch found that a loud tone initially darkens but then lightens the visual field (Gilbert, 1941). This suggests that the temporal relation between the auxiliary and primary stimulus may be important in determining SI effects. Several studies have attempted to give precise statements concerning this relationship.

Child and Wendt (1936, 1938) reported that auditory sensitivity to a tone was enhanced by simultaneous presentation of a flash of light or if the light was presented 0.5 to 1.0 seconds before or after the auditory stimulus. This effect was not found if the auxiliary stimulus was separated from the test stimulus by 2 seconds. Similarly, Kuroki (cited by Gilbert, 1941) found auditory sensitivity to be maximal with simultaneous presentation of light and some increased sensitivity over a darkness condition was found when the light was presented up to 0.33 seconds before or after the test stimulus, but not for longer separations. In contrast, to the above, Pratt (1936) was unable to find changes in visual sensitivity if the auxiliary auditory stimulation followed the test stimulus. This apparent discrepancy may be due to the fact that the roles of test and auxiliary stimuli were reversed in the study of Pratt, or because of a great number of other differences in the studies. Matheson (1967) reinforced the idea that an auxiliary stimulus can act on a stimulus trace when he found that visual afterimages were prolonged when accompanied by auditory stimulation.

Soviet investigation of the temporal variable has dealt mainly with the cumulative effects of auxiliary stimulation (London, 1954). For example, the CFF was found to progressively increase during 15 minutes of exposure to white noise, thereafter it was found to decrease. Another Soviet contribution is the investigation of cessation effects--viz., the changes in sensitivity that accompany cessation of the auxiliary stimulus. Lowered sensitivity, it was reported, upon cessation of the auxiliary stimulus, may go through a hypersensitive phase before returning to baseline level; a hyposensitive period may follow enhancement.

The effect of temporal contiguity interacts with the variable of intensity in the production of SI effects. In fact the effective intensity may be partly determined by the temporal relation of the test and auxiliary stimuli. Gescheider and Niblette (1967) reported decreased sensitivity to tactile pulses to be progressively greater at 30, 50, 70, and 90 dB of an auxiliary "click". Greatest inhibition for each level of intensity was found at simultaneous presentation, with the inhibition approaching zero by 50 msec. The same investigators found similar results when tactile pulses became the auxiliary stimulus to the auditory "click".

The literature on auditory stimulation on the CFF is, in the case of temporal effects (as it is in the case of intensitive effects) particularly instructive. One unique contribution of this literature is the comparison of the effects of steady versus intermittent noise. Again, a thorough review appears in a subsequent section.

The temporal relation between the tested and auxiliary stimuli appears to be an important factor, with simultaneous or near simultaneous presentation optimizing SI effects. This factor may explain many apparent differences among data. For example, Kravkov (1934) claimed that the reason his data (showing changes in visual acuity with hetero-modal stimulation) did not agree with that of Hartmann (1933) was because the latter did not space his trials adequately to allow for "return to baseline". Unfortunately, many such temporal aspects of the experimental situation are typically not reported.

The Role of Qualitative Aspects of the Stimuli

The 1930's saw a great interest in the relations among the senses from Gestalt-oriented psychologists. The literature generated, rather than arising from earlier research, seems to represent a separate tradition. The interest shown by Gestalt psychologists reflected their view of "unity of the senses" in which it is postulated that one set of qualities (e.g., "brightness and roughness") describes perception in all modalities (see Hornbostel, 1938). Attempts were made to alter qualities in one modality by altering the analogous quality in another modality. For example, auditory "brightness" was reported to "follow" visual brightness (Hartmann, 1934) and phi phenomenon was shown to follow intermittent auditory stimulation (Gilbert, 1938).

Qualitative aspects of the stimuli are seen as important determinants of SI effects by Soviet investigators (London, 1954). Evidently, the "Rule of Inversion" applies equally well to qualitative and quantitative variables. It was reported that while white and green light increased auditory sensitivity, red-orange light decreased auditory sensitivity. Peripheral visual sensitivity has also been found to vary under heteromodal stimulation as a function of the wave length of the test stimulus. Auditory stimulation increased sensitivity to green light and decreased sensitivity to red light. No change was reported for extreme violet or yellow wave lengths. The situation is made more complicated by another Soviet study which purports to show a reversal of the above when foveal vision is tested. In addition, odors judged as "pleasant" improved visual sensitivity while "unpleasant" odors depressed sensitivity. Again, the Soviet research must be viewed with caution (see footnote 2), however, these findings of changes with qualitative differences should encourage systematic research.

Other Stimulus Factors

It is probable that a number of other stimulus variables are involved in SI effects. The identification of many of these factors awaits future research. One topic that has only been investigated in one study and yet would seem important is the complexity of the auxiliary stimulus. Matheson (1967) reported that the complexity of the auxiliary auditory stimulus was a factor in determining the vividness of visual afterimages. As with "intensity", increasing complexity was found to progressively facilitate afterimages to a point, and thereafter to decrease the vividness of the afterimage.

Up to this point the search for general laws of SI has ignored possible differences between particular combinations of stimuli. The implicit assumption that the laws of (say) the effect of audition on vision apply equally well to the effect of vision on audition, and so on, may not be warranted. Taylor(1974) has claimed that while auditory input facilitates visual reaction time, the opposite has not been found to be true. The results of the psychophysical data are more complex. With these data the investigator is faced with questions such as: "What is the intensitive equivalent in vision of a 90 dB tone?" One potential tool for the solution of this problem is the cross-modal matching procedure suggested by Stevens (1966). This procedure, however, has not been employed in SI research. Only Honzik (1933) has explicitly suggested that some modalities are more powerful than others as auxiliary stimuli. He claimed that olfaction is stronger than audition in this regard. Again, such questions can only be decided by systematic research.

Subject Variables in SI

There is some evidence that various characteristics of the subject can affect the results of SI research. One such variable is the initial state of sensitivity of the measured modality. In what is the only experimental report of interaction between the gustatory and olfactory modalities, Schultz and Pilgram (1952) found that sensitivity changes to "sour" depended upon the initial state of gustatory adaptation. Subjects having an initially high threshold increased sensitivity in response to an olfactory stimulus; subjects with low thresholds showed no change. Soviet investigators (London, 1954) have also claimed that the initial "degree of excitement" of the primary receptor has an influence on subsequent heteromodal changes. For example, the "Rule of Inversion" is said to hold for dark versus light adapted eyes.

The state of the organism following the ingestion of various drugs may alter SI effects. Kruger (1962) found that chlorpromazine facilitated interaction of a tone on the CFF. A Soviet study reported a reversal of the direction of SI effects with the barbituate "Veronal" (London, 1954). London also reports that hyperventilation and mental activity nullify SI effects. According to other Soviet research, even postural variables have their effects, with maximum effects being found with the subject in the seated position and depression of SI when the subject stands.

Symons (1963) has emphasized certain social factors in the SI experiment as possible confounders in SI research. He cites Schwartz, who was able to increase "visual sensitivity" 310% by verbally reinforcing appropriate responses. Such factors should always be considered as an alternative hypothesis when SI effects are encountered. This is especially true when traditional psychophysical methods have been employed, as it is now well known that non-sensitivity factors enter into traditional "sensitivity" measures. Appropriate measures for controlling this type of confounding are discussed below.

The Effect of Auditory Stimulation on the CFF

The overview of relevant variables in SI phenomena, presented above, is suggestive but not definitive. One useful approach in defining the relevant variables would seem to be an exhaustive analysis of a single combination of test and auxiliary stimuli. Although such an analysis has not been performed, one combination of test and auxiliary stimuli stands out as having received the most systematic attention--the effect of auditory stimulation on the CFF. This attention has resulted in a literature that both mirrors and extends the understanding of SI effects. With the "general overview" as a background, the literature on audition and CFF will be reviewed in detail.

The first study investigating the effect of auditory input on the CFF was that of Von Schiller (1935) who reported that, when an intermittently presented light was put at fusion threshold, concomitant intermittent auditory stimulation would cause the visual stimulus to "flicker wildly". Concomitant stimulation with "smooth" continuous tones, however, led to a more fused light. Although Von Schiller interpreted these results as a case of the Gestalt concept of the "Unity of the Senses" (discussed above) another interpretation is possible. The increased apparent intermittence of the visual stimulus may represent an increased CFF (increased temporal acuity) in response to the intermittent auditory stimulation, and the "smooth" auditory stimulation may have acted to decrease the CFF. Five subsequent studies have investigated the differential effects of steady and interrupted auditory stimulus. Knox (1945, a, b) employing a 50 dB (SPL) tone of 1000 HZ found no differences in the CFF given four auxiliary stimulus conditions: silence, continuous tone, 30 or 15 cps "flutter". The temporal relation of the flutter to the flicker, however, may be an important variable that was neglected in this study. Ogilvie (1956, a, b) reported that when fluttered "white noise" of 80, 90 dB (SPL) was in phase with the flickering light, CFF was found to be higher than the CFF without noise. However, 180^{o} out of phase flutter or fused noise did not result in significant differences in CFF scores from those obtained without the auditory stimulation. This finding was reported with both the monocular and binocular CFF. The results were replicated by Walker and Sawyer (1961) for monocular CFF, without, but not with, an artificial pupil 2mm in diameter. This finding is especially suggestive since Knox employed an artificial pupil (of unreported diameter) but Ogilvie did not. Walker and Sawyer concluded, ". . . the mechanism of sensory interaction might operate through the system controlling the size of the pupil." It is well known that auditory stimulation affects pupil size (see, for example, Dureman and Scholander, 1962) making this suggestion tenable. Unfortunately, the presence or absence of an artificial pupil is generally not reported in the literature, making Walker and Sawyer's hypothesis a matter for future investigation. Another possible explanation of the differences reported above concerns whether the auxiliary stimulus was white noise or a tone. This may be the reason Knox did not find changes in CFF while Ogilvie (1956 a, b), Walker and Sawyer (1961) did. The former employed a tone while the latter used white noise. However, this would not explain why Walker and Sawyer found changes only without an artificial pupil. In addition, there have been reports of both decrements (McCroskey, 1958) and of increments (Miller, 1963) of CFF with white noise. There are also reports of lower (Gorrel, 1953, cited by Miller) and higher (Allen and Schwartz, 1940) CFF's with tones. Also, the direction of results does not seem to be systematically related to the particular frequency of tone involved. Maier, Bevan, and Behar (1961), for example, found that frequencies of 290, 1050, and 3900 HZ did not affect changes in the CFF. It seems probable, then, that tones and noise, or differences in the frequencies of tones are not major determining variables of SI effects.

The intermittence of the auditory stimulus is not the only temporal factor reported to affect the CFF. McCroskey (1958) found that thè CFF was significantly lowered during 19 minutes of white noise stimulation for noise of 85 and 115 dB (SPL) but not for 95 and 105 dB. Buckley (1949, cited by McCroskey, 1958) found a steady decrease in CFF during 16 minutes of exposure to white noise of unspecified intensity. London (1954) reports a Soviet study which claims a progressive increase in CFF during the first 15 minutes of exposure to white noise. Thereafter the effect was said to reverse. These differential results indicate that cumulative effects may be heavily dependent on other variables. Kravkov (1935) studies the effect of a tone of 2100 HZ on central and peripheral CFF during a 40 minute exposure. A gradual increase in central, and decrease in peripheral CFF during the first 30 minutes was reported. Cessation of the stimulus resulted in enhanced peripheral CFF although central CFF showed no such effect.

Allen and Schwartz (1940) determined the monochromatic CFF before and 0, 1.5, 3, 5, and 7 minutes following the cessation of 2 minutes of a monaurally presented tone. Results showed a complex time by wavelength interaction. Eleven of thirteen wavelengths employed showed higher CFF's immediately after the 2 minutes of auxiliary stimulation. At the 1.5 minute post-stimulation test the CFF of most wavelengths were at or near their baseline. Following 3 minutes of "rest" the shorter wavelengths again showed enhanced CFF while the longer (orange-red) wavelengths depressed the CFF. At the "post"-five minute determination all wavelengths again approximated the baseline levels and the "post"-seven minute scores were again differential, with lowered scores for the long and higher scores for the short wavelengths.

These findings suggest that experiments in which the auditory stimulus is simultaneous with the CFF presentation and those that have the tone or noise continuously on for the entire period may yield different results. The variable of the temporal relation between primary and auxiliary stimulation may also explain differences between studies employing simultaneous presentation of the stimuli but different psychophysical methods. For example, the studies of Ogilvie (1956 a, b, discussed above) employed the continuous method of limits with the stimuli lasting 6-12 seconds. Walker and Sawyer (1961), who only partially replicated earlier studies, employed the method of constant stimuli with the stimuli being presented for only 2 seconds. Unfortunately, reports in this area are rarely precise enough to determine all of the temporal variables, and so another problem is left for future research.

One parameter of the test stimulus that has received some experimental attention is the wavelength of the test light. The complex interaction found by Allen and Schwartz (1940) between wavelength and temporal effects has already been mentioned. Soviet researchers have reported the CFF was elevated by an auxiliary stimulus if the test stimulus was white or red, but decreased if green. In a factorial study of auditory input on CFF, Maier, Bevan, and Behar (1961) studied simultaneously the effects of stimulus wavelength and frequency and auditory intensity. Again, the results were complex, with "blue" CFF increasing and "orange-red" decreasing, with increasing tonal intensity. "Green" light CFF showed no change. It is obvious that the role of test light wavelength is not clear. There are a number of other light stimulus parameters that have been shown to affect the CFF (see Brown, 1965, for a review) that have not been investigated in the SI situation. Among these variables are: "on-off" ratio, intensity of "on" portion, wave form, and intensity of an accompanying annulus or lit background (if present).

Many of the apparently discrepant results mentioned above may be due to differences in the intensity of the auxiliary stimulus--a variable that was implicated as important in the "general review". Several experiments have assessed the effect of this variable. Maier et al. (1961), as previously mentioned, found a complex interaction between auditory intensity and test light wavelength. These investigators described the tonal intensity in terms of "phons" and, therefore, this experiment cannot be directly compared to other studies investigating this variable which have designated intensity in dB (SPL). McCroskey (1958) found depression of the CFF with auxiliary white noise of 85, 95, 105, 115, dB (SPL). There were no significant differences between the various levels of auditory intensity. Of special note in this study is the large magnitude of the effect which averaged 2.5 cps. Kruger (1962) found that a 77 dB tone of 1550 cps resulted in a substantial increase in CFF in both of his subjects. Thereafter, further increases led to progressive lowering of CFF in one subject and progressive lowering followed by a slight increase in the other subject. The intensities employed by Kruger were 77, 82, 86, 89, 91, 93, and 96 dB (SPL). Progressive facilitation at low intensities and progressive depression at greater intensities was also found in two unpublished doctoral dissertations from Boston University. Levine (1958, cited by Miller, 1963) found this effect with a 1550 HZ tone over 12 intensities. Munro (1962, cited by Miller, 1963) in the only study in the literature to use a second auxiliary stimulus reported similar results. The familiar initial increase, then decrease, in CFF with increases in auxiliary intensity was evident. The subsequent addition of weights strapped to the wrist caused a reversal towards improved CFF. This result was interpreted as being due to increased overall auxiliary intensity. Miller (1963) has provided one of the most complete studies of the effect of auditory stimulation on the CFF. An 800 HZ tone was presented at the following seven levels of intensity: 15-20, 70, 85.5, 90.5, 95.4, 100, and 109 dB (SPL). The primary difference in results in this study from those previously reporting oscillatory effects was the absence of the decrease relative to baseline that has generally characterized the high intensities. The CFF in this study never gets below the "ambient noise" baseline. This finding is explainable when the intensitive conditions of baseline measurement are examined. Typically, the "without auditory stimulation" baseline is taken in a free field situation in a "quiet room". Such a situation, however, is far from silent, and auxiliary enhancement effects may already be evident. The ambient noise level in Miller's room was estimated to be 46 to 51 dB. This level was further reduced to between 15 and 20 dB (SPL) during baseline testing by means of padded earphones. The results of Miller (1963) indicate that the finding of depressed (relative to baseline) CFF with very intense tones or noise may be an artifact of 'noisy' baseline conditions. Unfortunately, the ambient noise level is very seldom reported, although this would seem to be crucial in deciding whether or not an actual decrement in CFF occurs with high intensities of auditory stimulation. Given Miller's results, a better description of the effect of auditory intensity might be an inverted "U"-shaped curve that does not lead to decreases relative to "silence" condition, rather than a description in terms of oscillation. The actual decibel levels describing ascending and descending portions of the curve may differ among individuals and between experimental conditions. Peaks of sensitivity have been reported as low as 77 and as high as 91 dB. Very high intensities (e.g., 100 dB) seem uniformly to give CFF's lower than this peak.

Towards a Theory of Sensory Interaction

Clearly the most urgent necessity in the area of SI is the acquisition of parametric data which unambiguously describes the role of the variables reviewed above. Until this is done no general theory of SI is possible. It is useful, however, to advance tentative "theories" of SI as such guesses serve to organize the literature and thus increase the plausibility of the phenomena. Such preliminary theoretical efforts may also give direction to those researchers already convinced of the existence but not the importance of SI.

One theoretically suggestive aspect of the SI data is its apparent bidirectionality with changes along stimulus continua. This suggestion is all the more appealing because such descriptions have been arrived at independently by a number of investigators. Thus, the Soviet "Rule of Inversion", Hartmann (1934) and Thorne's (1934) "figure-ground" concept, and descriptions of the effect of auditory intensity on the CFF as "oscillatory" (Miller, 1963; Kruger, 1962) all have in common bidirectionality of SI effects given changes from one extreme to another of some parameter. Although the most evidence exists for bidirectional changes due to auxiliary intensitive changes, similar functions have been described for the factor of auxiliary complexity (Matheson, 1967) and for a great number of stimulus and subject variables investigated by Soviet Researchers (London, 1954). The evidence is far from conclusive (even with the variable of auxiliary intensity), however, it is tempting to suggest that bidirectionality is a "general law" of SI. Tentative acceptance of such a "law" allows further speculation as to the nature of SI effects.

One question that arises is: "Why should several different continua effect SI changes in a similar oscillatory manner?" That is: "Is there a single unifying concept underlying such apparently divergent variables as complexity, intensity, and various qualitative differences in stimuli?" One common aspect of these variables is that changes along their respective continua represent changes in the attentional value of the stimuli. Thus, auditory stimuli of weak intensity also are attentionally weak, while stimuli of high intensities attract much attention. The auxiliary stimulus would also seem to increasingly demand attention with increases in complexity (Matheson, 1967). It may be that all variables that affect SI do so relative to their attentional demands. In doing so they may generate some kind of inverted "U"-shaped or oscillatory pattern of sensitivity or acuity in the tested modality with increases in these demands. On this basis it would be predicted that the effectiveness of a particular parameter as a generator of SI could be determined from such measures of attention as rating scales or patterns of autonomic arousal (see Kahneman, 1973). For example, particular tones (equated for intensity) could be judged for their attentional demands and ranked--it would be predicted that such an ordering would give rise to an inverted "U"-shaped function of (say) CFF. Another characteristic likely to vary in its attentional demands is intermittence of the auxiliary stimulus.

There is some empirical evidence that attentional factors can affect SI research results. Brogden and his colleagues (Gregg & Brogden, 1952 and Thompson, Voss, & Brogden, 1958) found an elevation of auditory threshold when subjects were required to give a verbal response to the auxiliary light, but a decrease in threshold when no such response was required. When subjects were instructed to respond to both tone and light, a slight decrement in the auditory stimulus occurred. However, Knox (1945a) in a study previously discussed, found no effects on CFF whether or not the subject was asked to pay attention to the auxiliary auditory stimulation.

Appealing though the "attentional" hypothesis is at first glance, it seems unlikely that "attention" would generate the type of function discussed above. If a basic "law" of SI is the inverted "U" function along the continuum of a parameter, it would have to be predicted that at some point increases in attentional demands of the auxiliary stimulus would lead to increased sensitivity of the tested modality rather than the intuitively more likely result of lowered sensitivity due to distraction.

Although "attention" may be an important underlying factor, a more parsimonious explanation of the oscillatory function can be achieved by considering the arousal properties of the stimulus parameters. Arousal as used here refers to the general tonic level of excitation that is a background to all sensory processing. Arousal (as used here) differs from attention only in that the latter represents selective or differential excitation. Those variables that were mentioned as varying in their attentional demands could equally well be thought of as varying in their ability to arouse. It seems reasonable that arousal should at low to moderate levels increase general sensitivity and (assuming that arousal would act on the same continuum as the stimulus) there would be less signal required to reach detection (threshold). The idea of arousal facilitating sensitivity has been advanced in a different context by Lindsley (1961) and by Schultz (1965). Very high arousal due to auxiliary stimulation, however, may be disruptive (may act as "noise" obscuring the signal). This situation might be compared with sensory overload--a condition which Lindsley (1961) predicts will result in lowered general sensitivity in an attempt by the organsim to maintain input levels near optimal values. The arousal theory is especially attractive since, as mentioned in a previous section, "cortical arousal" has been shown to occur in response to stimulation of the reticular formation and the reticular formation is known to receive collaterals from all of the classical sensory tracts (McCleary & Moore, 1965). The suggestion of reticular mediation of changes in sensitivity with auxiliary stimulation is made still more tenable by the reports of enhanced temporal acuity in monkeys during mild reticular stimulation (Fuster, 1962).

If the increasing "arousability" of the auxiliary stimulus is reflected in an inverted "U"-shaped function of the sensitivity of the tested modality, SI phenomena may be considered as a case of the "Yerkes-Dodson Law". This law indicates that performance in general progressively improves but then progressively deteriorates with increasing motivation or arousal.

The above discussion assumes the "oscillatory" phenomena is a general law of SI. It would be premature indeed to make such a claim. The most urgent requirement in the area of SI, remains the demonstration and clarification of the phenomena by means of careful systematic research.

Methodological Considerations: The Theory of Signal Detectability and Sensory Interaction

An apt criticism of all the SI research reviewed above is its general failure to take into account non-sensitivity influences on threshold estimates. It is now known that thresholds based on classical psychophysical methods can be influenced by the subject's motivation and expectancy (Swets, Tanner, & Birdsall, 1961). These nonsensory influences may lead to confounding of the threshold by producing response bias. Realization of this shortcoming of the classical methodologies has led to a critical re-examination of the concept of "threshold" (Swets, 1961) and to methodologies based on the Theory of Signal Detectability (TSD, Green & Swets, 1974) which provide independent estimates of sensitivity and response bias. It is quite possible that reports of SI reflect, at least in part, motivational rather than sensitivity effects. That is (in the language of TSD) auxiliary stimulation may alter the subject's "criterion" as well as his sensitivity. Discrepancies between studies, then, may turn out to be due to differences in motivational sets.

In light of the obvious advantages of TSD it is surprising that there have been so few studies of SI employing these procedures. The studies that have been completed using these methods do not demonstrate a single pattern of results indicating the continued importance of systematic parametric research. Zwosta and Zenhausen (1969) reported that subliminal and supraliminal white noise, (-15 and 15 dB SSL), improved sensitivity but did not lead to changes in criteria. Intermediate levels of auditory intensity affected neither d' (sensitivity) nor β (response bias). In a TSD study of the effect of light on absolute sensitivity to white noise, Bothe and Marko (1970), found no consistent changes in either index. These researchers concluded that the effect was "idiosyncratic". In contrast, changes in both d' and B were reported in a study of tactile sensitivity (vibration) with and without a 500 HZ. tone (Gescheider, Kawe, Sager, & Ruffolo, 1974). Auditory stimulation was found to generally enhance tactile sensitivity <u>and</u> to substantially lower response criterion. Finally, in the only TSD assessment of the effect of auditory stimulation on the CFF, Walker (1975), found no sensitivity changes due to exposure to an ultrasonic tone of 108 dB or a 2000 HZ tone at 60 dB (SPL). As a "forced choice" paradigm was employed in this study, no information concerning criteria was obtained.

Sensory interaction effects, if they exist at all, are undoubtedly complex and perhaps subtle. The history of the topic should be sufficient warning that these effects will not be validly demonstrated until the proper questions are asked with the proper methodologies. TSD methodology is certainly the best available methodology and as such should be employed in future SI research.

Summary of Chapter I and Rationale for the Present Research

The question of whether or not functioning in one sensory modality alters the functioning in another modality has been a subject of speculation for several hundred years, and the object of considerable experimental attention for nearly 100 years. Unfortunately, the picture we have of the functional interdependency among the sensory modalities remains unclear. This seems to be so because of at least three interrelated factors. (1) The history of sensory psychology, beginning with the Doctrine of Specific Nerve Energies, has largely been one of progressive isolation of function, while consideration of interdependency effects requires a synthetic conception of the functional organization of the sensory systems. (2) There has been little speculation as to the usefulness of intersensory phenomena to the organism. (3) Finally, interpretation of data has been limited by the researchers' expectations of finding simple interaction effects. It is clear that this assumption prevents an unambiguous interpretation of the typically complex results. Investigations of sensory interdependence have also suffered from methodological inadequacies. The traditional methodologies of sensory psychology fail to eliminate the possibility that intersensory effects are not "sensory" at all, but are attributable to confounding motivational or expectancy factors. Such non-sensory factors as differences in response bias provide reasonable alternative explanations for the seemingly conflicting results often encountered in this area.

It has been repeatedly maintained in this chapter that solution of the problems outlined above awaits systematic research of a parametric nature. SI seems to depend upon a number of inadequately investigated stimulus and subject variables. It is the purpose of the research to be described in the next chapter to systematically investigate the effect of white noise intensity on sensitivity to visual flicker. The parameter of auxiliary stimulus intensity was chosen because previous research indicates that it is an important variable. Visual flicker sensitivity was chosen as the dependent variable because the literature on SI and the CFF is relatively extensive; the results of the present study may be most meaningful when compared to previous similar research.

The present study employed methods based on the Theory of Signal Detectability. One important contribution of the present work was the determination of a psychophysical SI function that is relatively unconfounded by response bias. The separation of sensitivity and response tendencies may be especially important in the present case as it is quite reasonable to expect not only response bias generated by subject motivation and expectation but also response bias that is systematically related to the intensity of noise. That is, in the language of TSD, the amount of signal evidence required for a detection decision (criterion) may systematically vary with the "noiseness" of the environment. Therefore, in addition to unconfounding the sensitivity measurement, the bias determinations may prove to be interesting in its own right.

CHAPTER II

METHOD

The research to be described employed methodology based on the Theory of Signal Detectability (TSD) as described by Swets and Tanner (1974), McNichol (1972) and Pastore and Scheirer (1974). Clark and his associates (Clark, Rutschmann, Link & Brown, 1963; Clark, 1966; Clark, Brown & Rutschmann, 1967) have demonstrated the logic and usefulness of applying TSD methodology to detection of visual flicker. In matters of procedure the present investigation relied heavily on the suggestions of these sources.

The present research consisted of three separate studies--an original parametric assessment of "flicker" sensitivity and response bias associated with several intensities of white noise, and two replications employing two different observers. As the methods employed were highly similar in each case, the general procedures will be presented with the few exceptions to uniformity of treatment clearly noted.

Subjects

Three male graduate students in good health were paid $100 each for their participation as subjects in the present research. Their ages at the time of research were 24 (subject "B. S."), 27 (subject "W. T.") and 32 (subject "D. C."). Audiometric assessment indicated no major hearing impairments in any subject. All subjects, however, showed a small loss (10-15 dB ISO) above 7 kHZ, and two ("B. S." and "D. C.") showed loss of a similar magnitude below 500 HZ. No subject had a history of ear infection or known otological damage. The vision of each subject was mildly myopic. Brown (1965, p. 268) reported, however that, "Variation of optical accommodation and the correction or the lack of it for anomalous refraction have not been found to influence CFF." This contention was confirmed for subjects employed in the present research by comparing CFF (by the Method of Limits) with and without corrective lenses. Two subjects ("B. S." and "W. T.") always wore their corrective lenses during testing while the remaining subject ("D. C.") never did.

Changes in CFF due to noise may be relative to baseline sensitivity ("Law of Initial Values"). It therefore became a subject selection criterion that the observers had similar baseline CFF values (± 5 cps). This was tested by the Methods of Limits under the stimulus parameter settings described below.

One of the subjects ("D. C.") had extensive knowledge of TSD theory and procedure and had many times served as a subject in sensory-perceptual experiments. Another ("W. T.") had little knowledge of TSD but had served as a subject in one previous TSD experiment. The third subject ("B. S.") initially had neither knowledge nor experience with research in this area. This subject, however, served as the observer inmost of the preliminary investigations and so was both knowledgeable and practiced when the actual experimentation began.

Preliminary Sessions

Prior to actual experimentation it was necessary to undertake two types of preliminary work--one concerned empirical assessment of the integrity and practicality of the testing procedures and the other involved the preparation of subjects for the experiment.

Design Development

There are a great many procedures that may be considered in a detection paradigm. The particular methodology employed in a given case depends upon the aims of the experiment and the limitations placed upon the researcher by practical considerations. Among the questions that required empirical answers before the experimental design was finalized in this case were: "The Rating Scale methodology seemed indicated here,[3] but is it a practical procedure for assessing flicker sensitivity?", "If it is how many categories and trials would need to be given for valid results?",[4] "How many blocks of trials in a session and trials in a block could be given before the task becomes fatiguing?", "What kind of intertrial and interblock intervals would be required?". These questions were answered by extensive preliminary investigation. The answers obtained in this manner were incorporated into the testing procedure (see below).

With a workable procedure established, it became possible to investigate questions having a bearing on the interpretation of experimental results. Chief among these were: "Do the earplugs employed in one of the baseline conditions exert a cutaneous SI effect separate from any auditory effect?",[5] and, "What is the probable nature of the Noise and Signal Plus Noise distributions which are assumed by TSD to underlie detection decision?", (see section on choice of indices in Chapter III). The answers to these questions have been incorporated in the interpretation of the present findings.

Subject Training

Preliminary work with the subjects was designed to: (1) Familiarize subjects with the equipment, personnel, and purposes of the study; (2) obtain estimates of subject sensitivity to flicker to be used in the actual experimentation; and (3) train the subject in his experimental task.

Each subject was told the major aims and strategies of the research (including a "short course" in TSD). All questions were answered truthfully as the subjects were considered an integral part of the research team. Early in this familiarization process subjects were asked to obey several important rules concerning their behaviour during the several weeks they were to be engaged as subjects. These rules included keeping regular routines of sleep and exercise, abstaining from excessive alcohol ingestion, not smoking for a minimum of 20 minutes prior to experimentation, and avoiding all medication including "aspirin". The subjects were also told at this time that it was important to begin testing at close to the same time each morning and that they would have to eat something a maximum of three to four hours prior to testing.

The Rating Scale procedures as applied to flicker sensitivity determination, requires the presentation of light which the subject sometimes will judge to be flickering and sometimes will judge to be fused. It was necessary, therefore, to obtain a flicker frequency for each subject that would produce in TSD terminology some "Hits" and some "False Alarms". A first approximation to such a value was obtained by employing the average value in cps of two sets of five pairs of up-down trials of the Method of Limits. Each set was obtained on a different day and all stimulus parameters were those employed in the actual experimentation (see section below). The CFF values obtained for subjects "B. S.", "W. T.", and "D. C." were 17.0, 15.0, and 17.0 cps respectively. These values were well within the ± 5 cps selection criterion.

Next, subjects were trained to a standard criterion of performance in the experimental task. An *a priori* criterion of stable sensitivity was set at d' = 0.5 to 1.0 under experimental conditions. This range of values was chosen because it allowed both improvement and deficit associated with auditory stimulation to be demonstrated.

All subjects required considerable practice before meeting the sensitivity criterion. Subject "B. S.", who had served as the subject for much of the preliminary investigation, required the least training (about 800 trials) to reach asymptotic performance within the criterion range. After about 1000 practice trials the performance of subject "W. T." leveled off substantially below the minimum criterion. Additional training with a on-off frequency lowered to 14.5 cps (0.5 cps below the Method of Limits estimate) and feedback of correctness of response following each trial, quickly (about 200 trials) brought the performance of "W. T." consistently to the required level. Subject "D. C." performed only at chance with the "flickering" light at his threshold estimate of 17.0 cps, even with many hundreds of practice trials. Accordingly the "flickering" light was lowered to 16.0 cps and feedback was given as in the case of "W. T.". About 500 trials presented in this manner were sufficient to raise the performance of "D. C." to a consistently acceptable level.

Apparatus

All testing took place in a double-unit sound-proofed chamber (see Fig. 1) consisting of a (2.24 m x 3.24m x 2.44m high) test room and a (2.05m x 2.84m x 1.83m high) experimental room (Model 1405-aACT, Industrial Acoustics Corporation). The noise and flicker generating apparatus was housed in the test chamber which was separated from the experimental room by three 9.32 cm thick walls each separated by a 27.96 cm air space. The stimuli generating apparatus was connected to the test room by a "jack" panel constructed so as to preserve the acoustical characteristics of the chamber. The test room portion of the chamber was of single-wall construction, while the experimental room consisted of a room within a room separated by a 9.32 cm air space. The floor of the inner room was floated on rubber vibration insulated rails to ensure maximum elimination of structurally borne sounds. Additional characteristics of the experimental room were: two 9.32 cm thick sound-proofed doors, a silent ventilation system, and a sound reduction level of 81 dB for frequencies greater than 600 cps. Finally, ambient noise level with the subject in place was found to be about 45 dB (SPL).

The visual stimulus consisted of a white light presented monocularly to the preferred eye by a cold cathode modulating lamp (Sylvania, type R1131C; Crater diameter 0.236 mm) mounted at the rear of a viewing

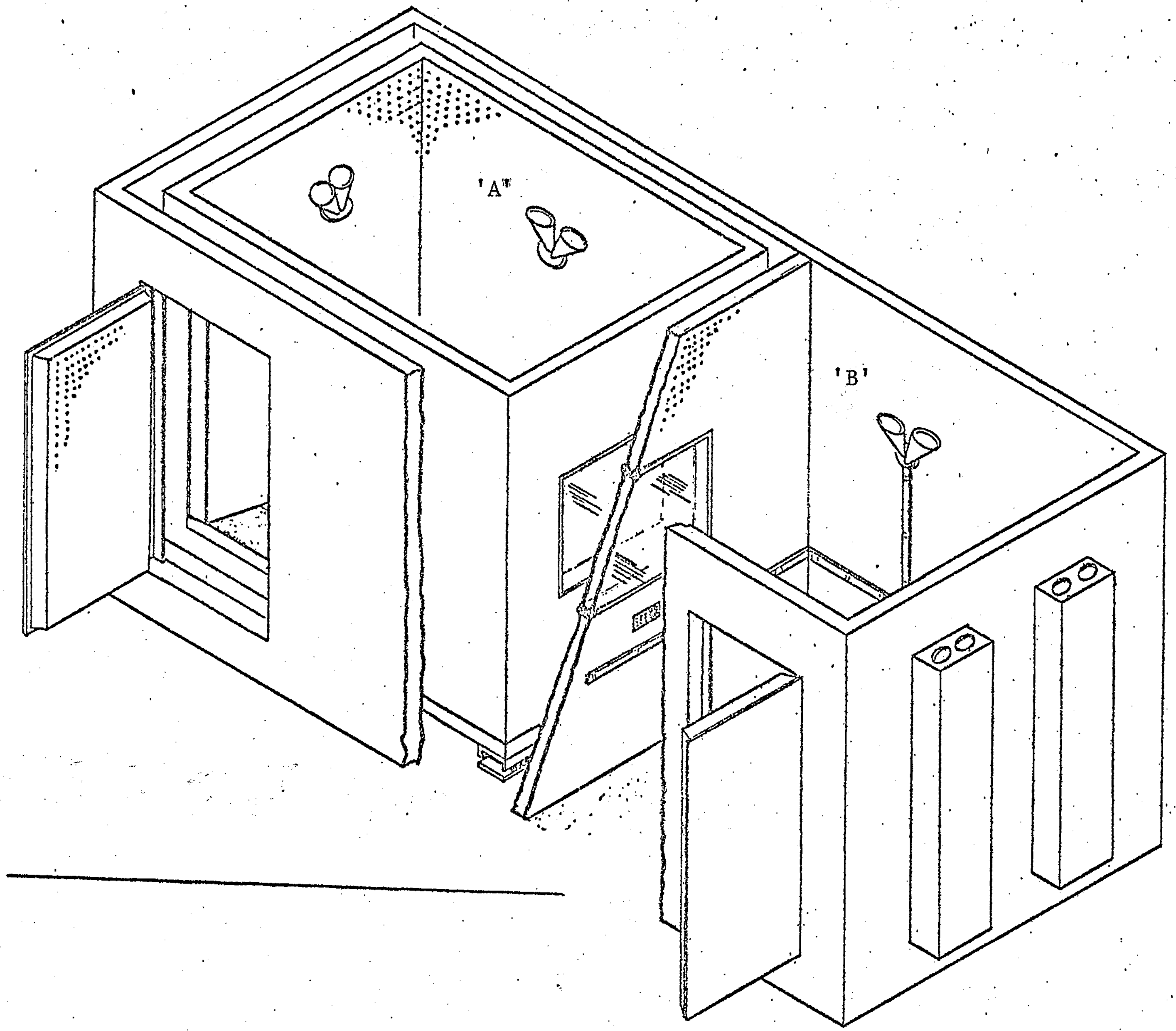

Figure 1. The Experimental ('A') and Test ('B') Chambers.

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chamber (Lafayette, Model 1202 C). The subject was required to centrally fixate the stimulus as it was presented through a 1.25 mm diameter Plexiglas diffuser. The stimulus-to-eye distance was 36.25 cm and the visual angle subtended equalled 2^{o} 10', a value assuring full foveal stimulation. The inside of the viewing chamber was lined with dull black material to eliminate reflectance. The front of the chamber was constructed of molded rubber which closely fit the subject's face thus eliminating extraneous light. The flicker generating apparatus (Grason-Stadler, Model EG66) was set at a light-dark ratio of 0.50 and a lamp luminance during the "on" phase was approximately 35 cd/m^2.

The auditory stimulus was generated by a white noise generator housed in a Bekesy audiometer (Grason-Stadler, Model E800). The spectrum produced by this device falls off only above 10,000 HZ. The intensity range of the generator allows for discrete settings from 20 to 120 dB (SPL), adjustable in 5 dB (SPL) steps. The stimulus was presented binaurally by means of one pair of calibrated air-conduction earphones (Grason-Stadler, MX41/AR) factory calibrated to be used with the above described audiometer. The intensity level produced by the audiometer was recalibrated by means of a Vu meter and calibration controls located on the audiometer control panel before each block of trials.

The presentation of the stimulus was controlled by two Hunter timers set for simultaneous "on"-set and "off"-set and a constant intertrial interval. During testing in the "Headphones and Earplugs" condition a pair of air cushioned earplugs was worn (Willson "Sound silencer", Model (EP-100). These earplugs were found to provide an average attenuation of about 30 dB (SPL) between 125-8000 HZ. Subjects responded to the stimuli by means of a hand held "responding device" wired to the audiometer. When the button on this device was depressed it initiated a loud "click" in the audiometer in the adjacent room. The operation of this device, however, was inaudible to the subject.

Testing Procedure

Testing was completed for each subject in 10 testing sessions held one a day over a 14-day period. Sessions took place in the morning and began at the same time each day for each subject (± 1 hour). Each test session consisted of 500 trials, comprised of five blocks of 100 trials. Each block was characterized by one of ten auditory conditions: "Headphones and Earplugs", "Headphones", or 40, 50, 60, 70, 80, 90, 100, 110 dB (SPL) of white noise presented via headphones.[6] For subject "B. S." the noise levels were quasi-randomly assigned to blocks so that the same level did not appear twice in the same session but did appear a total of five times. A further restriction was that each noise level had to appear at least every other test day. This procedure unfortunately produced a rather "biased" assignment of levels to blocks. For example 70 dB (SPL) was presented by chance in the first block of a session three of its five appearances (see Appendix A for complete details of assignment for subject "B. S."). Subsequent analysis revealed a slight block order effect on sensitivity and a rather large effect on response bias. Figure 2 illustrates these order effects. In this figure greater sensitivity is reflected in

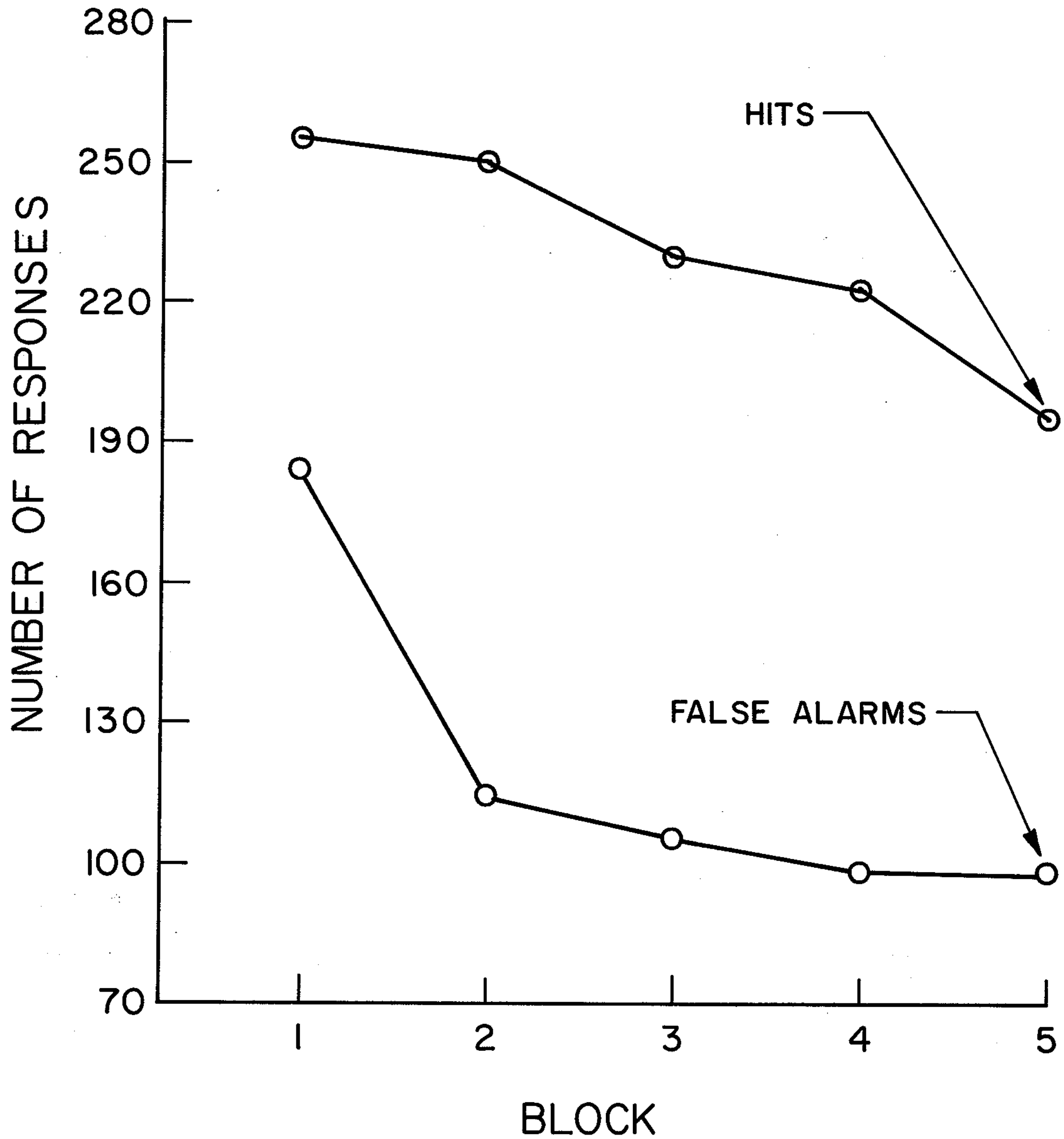

Figure 2. "Hits" and "False Alarms" as a function of block order within the sessions (subject "B. S.")

increased distance between the "Hit" and "False Alarm" curves. Note that the largest effect here is the slightly lowered sensitivity in the first and last blocks. More striking, however, is the obvious decrease in "Yes" responses evidenced by the strong negative slope of both curves. In order to avoid further confounding due to "unlucky" randomization, the assignment procedure was changed slightly for the remaining subjects. The stipulation was added that each level could appear only once in each block order. Any sessional block order effects were, therefore, counterbalanced for these subjects (actual assignments may be found in appendices B and C).

Blocks were separated by a two to 10-minute rest period, the exact elapsed time being subject controlled. Time was also provided for the dark adaptation of the subjects before each block of trials. This was necessary as the subject chamber was dimly lit during the test period but very dark during testing. In order to ensure that the subject began testing for each block at about the same dark adaptation level a small "light leak" between the subject and test room was provided. This "leak" was such that it was visible only after several minutes in the darkened room. Subjects were individually consistent in the duration of this dark adaptation period which averaged five minutes. Dark adaptation <u>during</u> testing was, of course, a consistent function of the experimental visual stimulation and the darkened viewing chamber.

The visual stimulation in a random 50% of the trials of each block was "fused" (150 + cps). On the other 50%, the presentation was "flickering" (presented at the on-off rate determined to be optimal for each subject during preliminary testing). During the 6 second intertrial interval the subject was required to decide his confidence that a flickering light had been presented in accordance with a four-point rating scale ("1" indicating certainty or near certainty the light had been "fused", "2" that it probably was "fused", "3" that it probably was "flickering", and "4" that he was certain or almost certain that the light presented was "flickering"). The subject was then to depress the response button an appropriate number of times. The experimenter used this interval to reset (when necessary) the on-off frequency of the visual stimulus to be presented on the next trial and to record the response of the subject to the preceding trial. Figure 3 depicts the events occurring in one complete trial. Note that no warning signal was provided as is common practice. This was so as it was considered vital that extraneous stimulation be minimized. Subjects were, by the time of actual experimentation, very familiar with the timing involved in the stimulus presentation cycle and at no time was a trial "missed" by a subject.

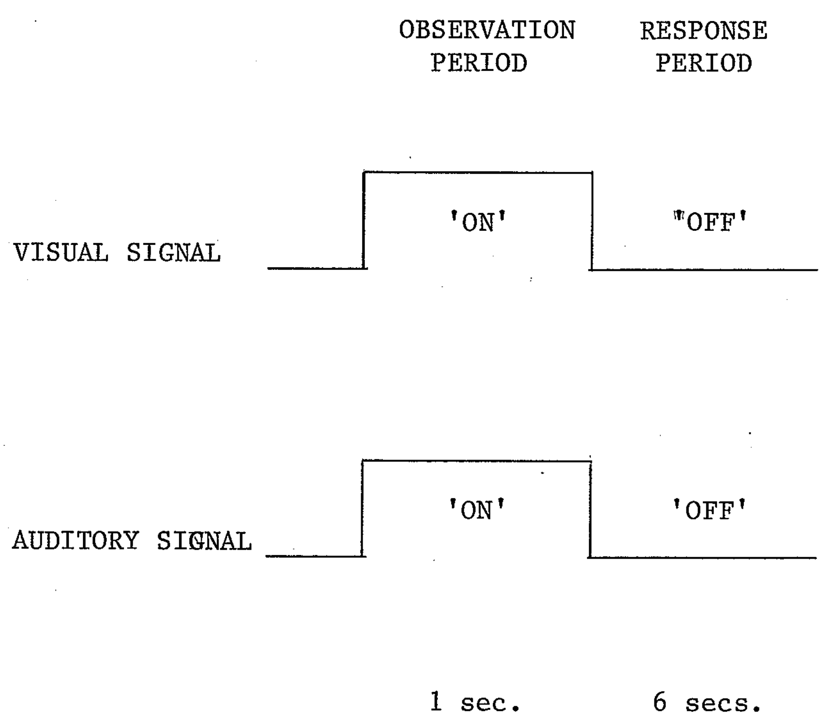

Figure 3. The events in one complete trial.

CHAPTER III

RESULTS

The results of the present investigations are presented in three forms: (1) a tabular summary of subject responses to the visual stimuli associated with each auditory intensity; (2) graphical representation of subject performance in the form of Receiving Operating Characteristic (ROC) and double probability curves for each noise level; and (3) graphical presentation of the indices of sensitivity and response bias as a function of the intensity of the accompanying auditory stimulus. The data analysis procedures presented here rely heavily on the exposition of McNichol (1972, pp. 105-130).

Subject responses to the visual test stimuli for each of the ten auditory conditions are presented in appendices A, B, and C for subjects "B. S.", "W. T.", and "D. C." respectively. In these tables data for each relevant block are presented as cumulative categorical responses for visual stimulus conditions of "flicker" or "fusion". Cumulative proportions of categorical responses associated with "flickering" and "fused" presentations as well as conversion of these to unit normal ('Z') scores are also presented. Finally, the sensitivity index d'_e and the overall response bias index β'_e derived from the response data are recorded in these tables.

ROC curves showing the conditional probability of "Hits" to "False Alarms" for each category appear for each auditory intensity level for each subject in appendices D, E, and F. Also in these appendices are the double probability conversions of the ROC curves.

In both types of figures sensitivity is reflected by the degree of displacement of the function from the positive diagonal. Response bias is reflected in the tendency of points to fall towards the left (few "No" responses--conservative bias) or right side (few "Yes" responses--liberal bias) of the graphs. A better idea of sensitivity and bias effects can be gained, however, by converting the data into quantified indices.

Preliminary Analysis to Determine Proper Indices

It has become common for researchers employing the "Yes-No" and "Rating Scale" procedures to determine d′ and β as measures of sensitivity and response bias respectively. Both of those measures depend for their validity on assumptions concerning parameters of the Noise and Signal distributions assumed to underlie the decision making process. Specifically, both distributions are assumed to be Gaussian and to have equal variances (Swets & Tanner, 1974). Although these assumptions often appear to hold well for auditory tasks, there is increasing evidence that the equal variance assumption holds only rarely when a visual task is involved. Accordingly Pastore and Scheirer (1974) have suggested that researchers either evaluate the assumptions or employ non-parametric alternatives to d′ and β. In the present case it was decided to evaluate the Gaussian and equal variance assumptions.

Techniques of inferring the nature of the underlying distributions have been established. McNichol (1974, p. 85) gives the following evaluative rule: "The ROC curve derived from distributions of signal and noise which are Gaussian will always be a straight line when plotted on double-probability scales. If the variances of these two distributions are equal this line will have a slope of 1." Preliminary investigation had indicated compliance with the first requirement but not the second. Careful examination of the double probability plot ROC curves presented in appendices D, E, and F confirm the preliminary findings. All 30 sets of data points were fitted well by straight lines.[7] The slopes of those lines, however, were not consistently close to unity. An arbitrary <u>a priori</u> decision rule for the evaluation of slope set the critical limits of slope at 0,8 to 1.2. It was decided that any violation of this rule would be reason for not using d′ and β. A total of five such violations occurred with at least one such violation per subject. The mean slopes for subjects "B. S.", "W. T.", and "D. C." were 0.87, 0.99, and 0.91 respectively suggesting that the variance of the signal distribution may have been smaller than that of the noise distribution. Noise intensity, however, did not seem to systematically vary the underlying distributions. Figure 4 illustrates these points.

On the basis of the decision criterion mentioned above the indicies d′ and β could not be employed. Fortunately, indices have been devised to correct for the case of unequal variances where the distributions are thought to be Gaussian. As these measures correct for unequal variances they are also valid for the equal variance case. One such measure for sensitivity is d'_e, which McNichol (1972, p. 89) defines as, ". . . twice the value of Z(S/s) or Z(S/n) ignoring signs

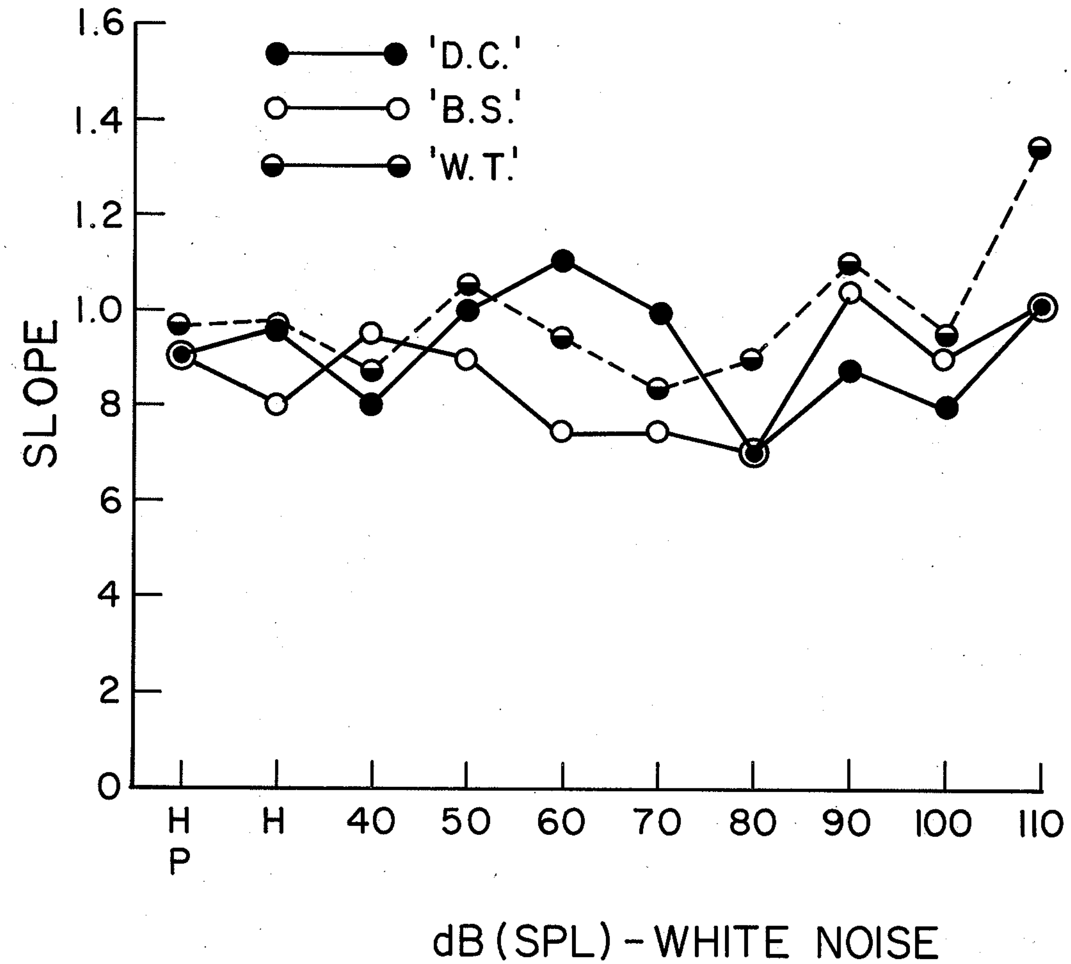

Figure 4. Slopes of double probability ROC plots as a function of intensity of auditory condition

at the point where the ROC curve intersects the negative diagonal." The use of d'_e requires no assumption as to which variance is larger.

McNichol (1972, pp. 93-96) has suggested a comparable index of response bias which corrects for unequal variances. This index, like β, estimates response bias by inferring the relative heights of the overlapping Noise and Signal distributions at the decision cut-off point (χ). Calculation differs only in that the separation between distributions is estimated by a factor corrected for the inequality in variances. McNichol's index, here called β'_e, was employed in the present case. As only an overall index of bias was required for each noise level categories 4 and 3 were collapsed into one "Yes" category while categories 1 and 2 were collapsed into one "No" category. The d'_e and β'_e values associated with each noise level for each subject are presented in appendices A, B, and C.

<u>Effect of Noise Intensity on Flicker Sensitivity</u>[8]

Figure 5 presents d'_e values for each subject as a function of noise condition. It can be seen that there is a great deal of agreement between individual functions. This is true of the shape of the functions and the absolute values attained. All subjects show peaks in sensitivity at 40, 70, and 100 dB (SPL) of white noise. Low sensitivity is uniformly found at the 50 and 90 dB levels. Although there are differences in shape each describes a more or less "Quintic" function. The baseline conditions of "Headphones and Earplugs" and "Headphones" alone yielded no systematic effects on sensitivity although the individual effects were in some cases rather large.[9]

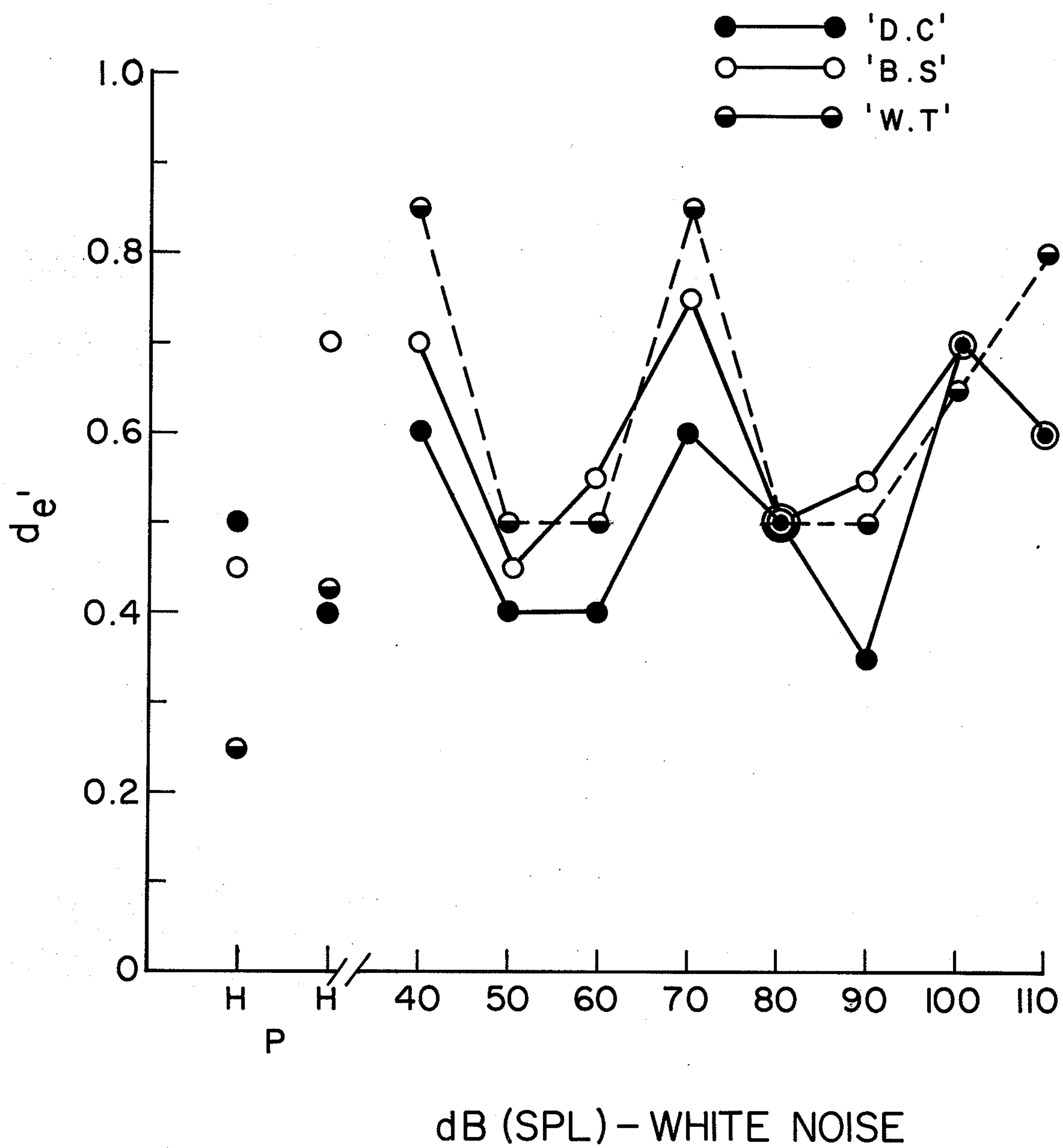

Figure 5. Flicker sensitivity (d'_e) as a function of intensity of auditory condition

Effect of Noise Intensity on Response Bias[8]

Figure 6 illustrates response tendencies of the three subjects as a function of noise intensity. Unlike the sensitivity data there seems here to be little systematic effect of intensity. Two of the subjects ("D. C." and "W. T.") have response tendencies "hovering" around $\beta'_e = 1$ indicating little or no bias. These subjects seem however, to have become slightly more conservative when the decibel level reached 110. Subject "B. S." produced an atypical response bias curve. One interesting aspect is the very conservative nature of his response tendencies at 40 and 70 dB (SPL). In some ways this mirrors the sensitivity findings. The possible confounding effects of "unlucky" random assignment in the case of this subject will be considered in the next chapter. In summary, the response bias associated with noise levels used in the present study can be characterized as largely idiosyncratic.[9]

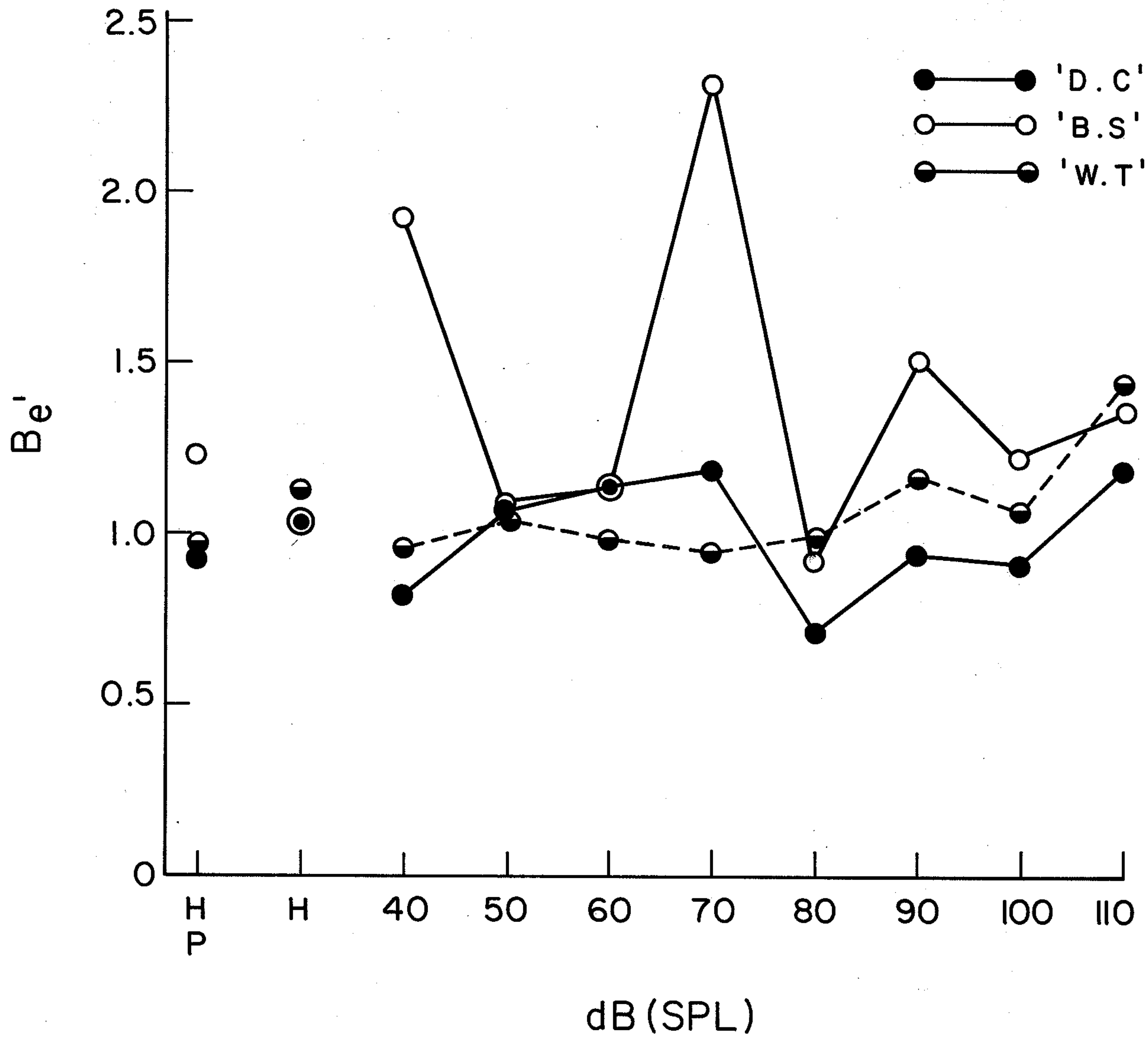

Figure 6. Response bias (β'_e) as a function of intensity of auditory condition

CHAPTER IV

DISCUSSION

The results of the present investigation suggest that there is a complex but genuine effect exerted on sensitivity to visual flicker by white noise. Furthermore, these findings may reflect the nature of basic intersensory organization in man. These conclusions appear to be warranted for several reasons. First, there is obvious consistency in sensitivity estimates for individual subjects over blocks (see appendices A, B, and C). This is so in spite of block order effects, possible differences in sensitivity over days, and the variability due to the small number of trials in a single block. Secondly, although there are large "jumps" or "drops" with small changes in auditory intensity, there are also some orderly changes with intermediate steps. Again these would be unlikely by chance alone. Thirdly, there is a great deal of agreement between the sensitivity functions of individual subjects--not only in shape but in the actual d'_e values. It is highly unlikely that three different subjects could generate so similar complex functions by chance alone. It should be noted, however, that the subjects were not randomly sampled from some population and were similar in several respects (see subject section, Chapter II). Fourthly, the size of effects are moderate and more importantly consistent between subjects. The range of change in d'_e for subjects "B. S.", "D. D.", and "W. T." were respectively 0.3, 0.35, and 0.35. Finally, statistical assessment, though not strictly valid (see Footnote 8) indicated rather significant differences in the sensitivity ranking of the white noise conditions, and a high degree of concordance between subjects.

It is more difficult to evaluate sensitivity changes from baseline. The two baseline conditions show no constant direction or degree of relationship. The cutaneous SI effect of the earplugs is estimated to be a lowering of sensitivity by $d'_e = 0.2$ (see Footnote 5). The adjusted differences between the "Headphones and Earplugs" and "Headphones" conditions are $d'_e = -0.05$, 0.025, and 0.3 for "B. S.", "W. T.", and "D. C." respectively. Thus while two of the subjects showed only slight differences between the two conditions, the third showed a relatively large difference preventing generalizations. It can be said, however, that the baseline levels of sensitivity seem not to determine the sensitivity response to white noise.

Results of the response bias data provide little evidence of either effects of noise generally or differential effects of the noise intensities on response tendencies. The values for two of the subjects ("W. T." and "D. C.") seem to be unsystematically scattered around a β'_e value of 1. Such a value indicates no response bias. The remaining subject ("B. S.") apparently was quite conservative at several intensity levels. The bias data for this subject however may have been confounded by the unique assignment of noise levels to blocks interacting with block order effects evident in Figure 4. It is concluded that any bias effect due to the addition of white noise to the flicker detection task or differential effects of noise intensity are probably small and idiosyncratic.

The present findings of systematic variation in visual temporal acuity with changes in intensity of the auditory stimulus invite comparison with previous research. A thorough review of research concerned with the effects of various intensities of auditory input on the CFF appears in Chapter I. In these studies there appeared to be a peak in sensitivity at moderately intense levels of a tone or noise, 77 to 90.5 dB (SPL). Further increases brought a lowering of sensitivity, relative to that peak and perhaps (Miller, 1963) relative to a condition of minimal auditory stimulation. The present investigation likewise found a peak in sensitivity at an intermediate value of auditory intensity 70 dB (SPL). Also as in the previous research further increases in intensity brought a decrease in sensitivity--but in the present results this was true only up to a point. Sensitivity at 100 dB (SPL) was in the present cases again high while in much of the previous research the downward trend with increased intensity continued. Kruger (1962) however, reported that one of his two subjects showed a slight increase in sensitivity at 96 dB (SPL) from more moderate intensities. Munro (cited by Miller, 1963) reported a reversal towards increased sensitivity when overall auxiliary stimulation was increased.

The present research was the first to assess the effect of low levels of intensity of the auditory input on flicker sensitivity--viz., 40, 50, 60 dB (SPL). This "arm" of the curve changes radically the inverted "U" or oscillatory function described by previous authors.

In summary, as with previous research the present studies generated flicker sensitivity curves with peaks of sensitivity at moderate levels of auditory intensity. The data from auditory intensities of 50 through 90 dB (SPL) generates a curve comparable to previous descriptions. What is added are two other peaks at or near the extremes of intensity of white noise input. One such peak was not expected on the basis of previous research (100 dB). The other was in an intensity region not previously explored (40 dB).

Previous related studies made no attempt to control for response bias. However, in the present study there was no evidence to indicate any response bias effects that were systematic and common to the three subjects. These data, therefore, do not add to the understanding of the findings obtained by means of the traditional psychophysical procedures. Its value lies in the fact that any response bias, regardless of its idiosyncracy has not entered into the sensitivity data. Undoubtedly this has contributed to the high level of agreement in sensitivity data between subjects in this study.

It is difficult to interpret the present results as supporting the theoretical speculations presented in Chapter I. (It is also difficult to relate these results to the properties of known neurological processes.) It was noted there that those speculations were based on insufficient and possibly confounded data. The present research has sampled from a wider range of auditory intensities and has demonstrated considerable agreement employing superior methodology. It seems reasonable, therefore, to examine those theoretical speculations in light of this "best evidence".

It is clear that no simple theory could predict the "quintic" relationship between visual flicker sensitivity and auxiliary auditory intensity observed in the present research. The suggestion that the effect is based on simple arousal is not tenable in light of the present results--nor is the simple attentional hypothesis presented above. Of course the present findings in no way indicate that arousal and attention are not involved in the SI observed here. There may be various kinds of arousals and attentions interacting among other influences. Suggestions are presented below as to a few ways of experimentally sorting out some of these effects.

At the biological level of explanation the present complex results cause another sort of problem. Namely, of what possible use to the organism would be the functional organization of the sensory systems reflected in the present data? It may be that there is some advantage to accentuating visual temporal acuity at 40, 70, and 100 dB (SPL)--but it is not now clear what that advantage may be. It is possible that rather than reflecting an adaptive mechanism, SI (at least in this case) is merely a reflection of the organization of the nervous or information processing system--an epiphenomenon. If SI is such an epiphenomenon the importance of SI research is not diminished, as that research may lead to a better understanding of the organization that does underlie adaptive processes.

One line of research which may contribute to theoretical advances concerns the assessment of any arousal component in the present results. Specifically two studies are suggested, both employing the basic procedures of the research reported here. One would optimize the arousal value of the auditory stimulus by totally randomizing presentation of levels of white noise rather than presenting them in blocks of one hundred. Another would minimize the arousal value of the same stimuli by having the auditory stimulation be a constant background to a block of trials rather than being simultaneously presented with the visual stimulus. With all other factors held constant across investigations (including the present one) the resultant sensitivity curves could be assessed for the contribution of arousal. It would seem that another important line of research would involve the assessment of the effect of the "auxiliary stimulus" on the tested stimulus. A method for assessing the sensitivity of two simultaneously stimulated modalities has been developed in another context by Eijkman and Vendrick (1965). This elegant procedure also has the advantage of TSD methodology.

Variables other than auxiliary stimulus intensity that were implicated as being important in Chapter I, should also be the subject of careful parametric investigation employing TSD methodology. Finally future research should employ several modalities for simultaneous auxiliary stimulation as a step towards establishing ecological validity, as the answer to the question of the usefulness of SI may only be found in a natural environment.

SUMMARY

Visual temporal acuity and response bias were determined under two auditory baseline conditions and eight levels of intensity of white noise. Test procedure and data analysis were performed in accordance with the Rating Scale procedure of the Theory of Signal Detectability. Results indicated that sensitivity, as represented by the index d'_e, described a "quintic" curve as a function of white noise intensity. Two replications of the study with different subjects produced highly similar sensitivity functions. Response bias (β'_e), however, was not found to be reliably related to intensity of white noise.

Some aspects of the sensitivity data are similar to results of previous research attempting to relate Critical Flicker Frequency to the intensity of concomitant auditory stimulation. Simple theories based on the previous research and known neurological processes cannot account for the complexities of the present results. The observed sensory interaction may, therefore, represent a complex of influences one of which may be arousal. The degree of arousal generated by the auditory stimulation may be manipulated in future research, separate from basic stimulus parameters in an attempt to isolate the contributions of this factor. Identification of the biological significance, if any, of sensory interaction awaits systematic study of several implicated variables and efforts towards assessment in ecologically valid environments.

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Footnotes

[1]One alternative paradigm for establishing sensory interdependence is that of measuring changes in sensitivity in non-deprived modalities in response to unimodal sensory deprivation. Extensive study employing this procedure indicates a general compensation effect (in the form of increased sensitivity in the non-deprived modalities). See Duda and Zubek (1965), Pangman and Zubek (1972), Schutte and Zubek (1967), Zubek, Flye, and Aftanas (1964), Zubek, Flye, and Willows (1964), Bross and Zubek (1975a), Bross and Zubek (in press).

[2]London goes on to point out the particular problems with Soviet SI research: "It is true that much of the Soviet work on sensory interaction adheres to standards of execution, reportage, and interpretation that would be quite unacceptable to the western researcher." (1954, p. 531).

[3]There are two established methods for deriving an ROC curve. The "Yes-No" procedure requires experimental manipulation of the criterion in order to generate points along the isosensitivity curve. The other method, the Rating Scale procedure, requires the subject to rate his confidence that he has detected a signal. The categories are assumed to be directly analogous to criteria in the "Yes-No" procedure. The great advantages of the Rating Scale procedure for the present purposes is its efficiency and the fact that overall (collapsed) criterion is free to respond to expectancy, motivational and systematic effects associated with the intensity of the auditory stimuli.

[4]When a Rating Scale detection task is employed, as in the present case, the number of response categories used is an important factor. On one hand a minimum of four categories are required where assumptions concerning the underlying distributions must be checked by means of an ROC curve. This is so since four categories yield only three empirically determined data points, and three points are the minimum from which to construct an ROC curve. On the other hand, the number of categories must not be so large that a subject may not be able to make distinctions between what they represent. The case of too many categories may result in some not being used often enough to determine "Hit" and "False Alarm" rates. When this happens, the points on the ROC curve representing a particular category cannot be established and the curve becomes invalid (see McNichol, 1972, p. 102). It is important therefore to establish empirically the number of categories that are likely to be used consistently by subjects.

Extensive investigation with subject "B. S." involving hundreds of trials indicated that only four categories could be used with consistency. As that subject was known to be atypically conservative in his response tendencies it was considered that the other subjects could also use four categories and that number was chosen for the actual experiment.

[5]The "Headphones and Earplugs" condition is different from every other condition employed in this research, not only because of the noise level associated with it, but also because the earplugs exert

added cutaneous pressure to the ear. It is quite possible that this pressure could cause an interaction effect itself in addition to any auditory effect.

In order to test this possibility the following preliminary study was undertaken. A pair of earplugs identical to those used in actual experimentation were hollowed out so that they provided little apparent sound attenuation but exerted pressure indistinguishable from intact plugs. Audiometric assessment of one subject was completed with and without the plugs and the audiograms were found to overlap. Sensitivity to flicker was then established (by means described in the text) without earplugs and with hollowed earplugs. The results of 200 trials in each condition indicated slightly greater sensitivity without than with the plugs ($d'_{ew} = 0.95$, $d'_{ew/o} = 1.14$). It was concluded that cutaneous SI due to the earplugs might account for less sensitivity in the earplug condition on the other of 0.2 d'_e.

[6]In Chapter I it was mentioned that theoretical interpretation of a particular result may rest on the choice of a baseline. Accordingly it was decided that two baselines would be employed in the present investigation. One consisted of the ambient noise in the sound attenuated chamber (about 45 dB (SPL)) as it was further attenuated by the headphones employed in the presentation of the auditory stimuli. The other included, in addition to the headphones, earplugs. The headphones were estimated to attenuate the ambient level by 15 to 20 dB, resulting in a baseline condition of approximately 25 to 20 dB (SPL). Audiometric assessment indicated that the earplugs

attenuated most audible frequencies about 30 dB. As it was not possible to assess these values precisely, only an ordinal relationship is claimed. The "Headphones and Earplugs" condition was, however, designed to be as "silent" as practically possible. The "Headphones" condition should be roughly comparable to the more precisely controlled auditory environments of previous research (e.g., Miller, 1962).

[7]The usual "lease squares" method of fitting a line to data points could not be employed in the present case. This is so because the ROC data points obtained by the Rating Scale procedure are cumulative across categories (viz.--the data point for category 3 is based on responses in category 4 as well as 3) and so are not independent. The lines were therefore fitted by eye.

[8]A Friedman Two-Way Analysis of Variance for Ranked Data run on the sensitivities associated with the eight levels of white noise for the three subjects proved to be significant ($\chi^2_r = 17.2$, $p. < .02$, $df = 7$). Further analysis revealed that the average intercorrelation between subjects was high ($\bar{r} = 0.83$) indicating good agreement on the rankings. A Friedman test on the ranked response bias data revealed no significant differences over the auditory intensities ($\chi^2_r = 7.88$, $p. > .4$, $df = 7$).

These data analyses should, however, be viewed with caution for at least three reasons. First the investigations presented here were always considered by the experimenter to represent three separate experiments. Secondly, the assignment of noise levels to blocks was completely random in no subject. Thirdly, the assignment procedure was somewhat different for one subject "B. S." than the others.

[9]As a matter of interest (and as an informal test of the robustness of d' and β to the violations of the equal variance assumption evident here) the following indices of sensitivity were calculated in addition to d'_e: d', ΔM, and the non-parametric index P(A). β was also determined. Perhaps surprisingly all indices of sensitivity yielded functions of sensitivity to auditory intensity similar to Figure 5. In no case was the relative order of the indices changed. The same was true in a comparison of β with β'_e values.

APPENDIX A

Tables 1.0 to 1.9

Summary of response by Rating Scale to "flickering" and "fused" light by subject "B. S." for each of ten auditory conditions

Table 1.0

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: HEADPHONES AND EARPLUGS

Session	Block	cps Flicker Fused	Cumulative Responses by Category 4	3	2	1
2	3	17.0 150.0+	3 0	26 14	44 34	50 50
4	5	17.0 150.0+	1 0	11 6	24 20	50 50
6	2	17.0 150.0+	3 0	28 16	42 31	50 50
7	1	17.0 150.0+	1 1	12 12	28 23	50 50
8	4	17.0 150.0+	1 0	27 12	41 26	50 50
TOTALS	14.5	17.0 150.0+	5 1	104 60	179 134	250 250
PROPORTION/'Z'		17.0 150.0+	0.02/2.054 0.004/2.762	0.416/0.202 0.24/0.706	0.716/-0.583 0.536/-0.101	

$d'_e = 0.45$	$\beta'_e = 1.23$

Table 1.1

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: HEADPHONES

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	4	17.0 150.0+	2 0	25 11	41 31	50 50
4	2	17.0 150.0+	1 0	22 12	37 22	50 50
5	4	17.0 150.0+	2 0	25 12	39 32	50 50
7	1	17.0 150.0+	5 1	24 10	41 35	50 50
9	2	17.0 150.0+	2 0	28 13	39 33	50 50
TOTALS		17.0 150.0+	12 1	125 58	197 153	250 250
PROPORTION/Z'		17.0 150.0+	0.048/1.645 0.004/2.652	0.5/0.00 0.232/0.739	0.788/-0.807 0.612/-0.279	

$d'_e = 0.7$	$\beta'_e = 1.04$

Table 1.2

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: 40 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	3	17.0 150.0+	1 2	25 12	43 32	50 50
4	4	17.0 150.0+	0 0	14 7	28 20	50 50
6	3	17.0 150.0+	1 0	27 16	43 36	50 50
8	2	17.0 150.0+	3 0	22 11	35 28	50 50
9	2	17.0 150.0+	3 0	31 8	40 33	50 50
TOTALS		17.0 150.0+	8 2	120 54	189 149	250 250
PROPORTION/'Z'		17.0 150.0+	0.032/1.881 0.008/2.326	0.48/0.05 0.216/0.772	0.756/-0.706 0.596/-0.253	

$d'_e = 0.7$	$\beta'_e = 1.93$

Table 1.3

SUMMARY OF RESULTS

SUBJECT: "B.CS."

CONDITION: 50 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	5	17.0 150.0+	1 1	13 21	36 35	50 50
3	4	17.0 150.0+	3 0	23 12	42 28	50 50
5	1	17.0 150.0+	6 0	26 9	43 28	50 50
7	2	17.0 150.0+	2 1	14 10	30 26	50 50
9	4	17.0 150.0+	3 0	27 12	42 27	50 50
TOTALS		17.0 150.0+	15 2	103 64	193 144	250 250
PROPORTION/'Z'		17.0 150.0+	0.06/1.555 0.008/2.326	0.412/0.228 0.256/0.643	0.772/-0.739 0.576/-0.202	

$d'_e = 0.45$	$\beta'_e = 1.09$

Table 1.4

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: 60 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	2	17.0 150.0+	4 0	27 13	42 38	50 50
3	4	17.0 150.0+	1 1	19 7	28 24	50 50
5	3	17.0 150.0+	6 1	22 6	33 25	50 50
8	1	17.0 150.0+	4 0	25 13	44 39	50 50
9	5	17.0 150.0+	3 1	21 6	38 35	50 50
TOTALS		17.0 150.0+	18 1	104 6	185 35	250 250
PROPORTION/'Z'		17.0 150.0+	0.072/1.476 0.012/2.326	0.416/0.202 0.18/0.915	0.74/-0.643 0.644/-0.359	

$d'_e = 0.55$	$\beta_e = 1.12$

Table 1.5

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: 70 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	1	17.0 150.0+	2 0	28 9	44 35	50 50
3	1	17.0 150.0+	2 0	22 13	37 33	50 50
6	1	17.0 150.0+	6 1	29 7	43 32	50 50
7	5	17.0 150.0+	1 0	26 11	40 34	50 50
9	3	17.0 150.0+	1 1	31 14	45 31	50 50
TOTALS		17.0 150.0+	12 2	146 54	209 165	250 250
PROPORTION/'Z'		17.0 150.0+	0.048/1.645 0.008/2.326	0.584/-0.202 0.216/0.772	0.836/-0.995 0.66/-0.413	

$d'_e = 0.75$	$\beta'_e = 2.32$

Table 1.6

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: 80 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	5	17.0 150.0+	5 0	19 9	36 31	50 50
3	5	17.0 150.0+	2 0	8 11	14 22	50 50
5	2	17.0 150.0+	3 0	25 7	35 25	50 50
7	4	17.0 150.0+	1 0	23 17	42 34	50 50
9	1	17.0 150.0+	5 1	31 13	43 33	50 50
TOTALS		17.0 150.0+	16 1	106 57	170 134	250 250
PROPORTION/'Z'		17.0 150.0+	0.064/1.555 0.004/2.652	0.424/0.202 0.228/0.739	0.68/-0.468 0.536/-0.101	

$d'_e = 0.5$	$\beta'_e = 0.91$

Table 1.7

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: 90 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	2	17.0 150.0+	3 0	28 15	40 35	50 50
4	3	17.0 150.0+	1 2	16 10	25 28	50 50
6	5	17.0 150.0+	0 0	26 10	42 22	50 50
8	3	17.0 150.0+	2 1	23 6	37 21	50 50
10	4	17.0 150.0+	1 0	19 8	35 20	50 50
TOTALS		17.0 150.0+	7 2	112 49	179 126	250 250
PROPORTION/'Z'		17.0 150.0+	0.028/1.881 0.008/2.326	0.448/0.126 0.196/0.842	0.716/-0.583 0.504/0.00	

$d'_e = 0.55$	$\beta'_e = 1.5$

Table 1.8

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: 100 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category 4	3	2	1
2	4	17.0 150.0+	0 0	18 8	35 27	50 50
4	1	17.0 150.0+	3 1	25 8	39 24	50 50
5	5	17.0 150.0+	2 1	30 14	40 37	50 50
7	3	17.0 150.0+	3 0	24 12	38 34	50 50
10	1	17.0 150.0+	6 1	34 11	45 30	50 50
TOTALS		17.0 150.0+	14 3	131 53	197 152	250 250
PROPORTION/'Z'		17.0 150.0+	0.056/1.55 0.012/2.326	0.524/-0.05 0.212/0.807	0.788/-0.807 0.608/-0.279	

$d'_e = 0.7$	$\beta'_e = 1.23$

Table 1.9

SUMMARY OF RESULTS

SUBJECT: "B. S."

CONDITION: 110 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	1	17.0 150.0+	1 0	26 10	43 37	50 50
3	3	17.0 150.0+	2 1	18 9	31 19	50 50
6	4	17.0 150.0+	3 1	23 12	42 32	50 40
8	5	17.0 150.0+	1 0	18 10	30 27	50 50
9	5	17.0 150.0+	4 0	24 11	38 24	50 50
TOTALS		17.0 150.0+	11 2	109 52	184 139	250 250
PROPORTION/'Z'		17.0 150.0+	0.044/1.751 0.008/2.326	0.436/0.151 0.208/0.807	0.736/-0.643 0.556/-0.151	

$d'_e = 0.6$	$\beta'_e = 1.36$

APPENDIX B

Tables 2.0 to 2.9

Summary of response by Rating Scale to "flickering" and "fused" light by subject "W. T." for each of ten auditory conditions

Table 2.0

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: HEADPHONES AND EARPLUGS

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	1	14.5 150.0+	3 2	29 19	47 50	50 50
3	2	14.5 150.0+	0 0	17 7	41 32	50 50
5	5	14.5 150.0+	0 1	25 18	46 44	50 50
7	3	14.5 150.0+	4 3	27 27	47 46	50 50
9	4	14.5 150.0+	8 3	32 26	49 45	50 50
TOTALS		14.5 150.0+	15 9	130 107	230 217	250 250
PROPORTION/'Z'		14.5 150.0+	0.06/1.555 0.936/1.751	0.52/-0.050 0.428/0.176	0.92/-1.4 0.868/-1.1	

$d'_e = 0.25$	$\beta'_e = 0.96$

Table 2.1

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: HEADPHONES

Session	Block	cps Flicker Fused	Cumulative Responses by Category 4	3	2	1
1	1	14.5 150.0+	6 0	28 9	46 47	50 50
3	4	14.5 150.0+	3 1	28 11	44 40	50 50
6	5	14.5 150.0+	6 3	30 17	45 44	50 50
7	2	14.5 150.0+	0 0	7 2	30 20	50 50
9	3	14.5 150.0+	15 6	32 31	45 48	50 50
TOTALS		14.5 150.0+	30 10	125 70	210 199	250 250
PROPORTION/'Z'		14.5 150.0+	0.12/1.175 0.04/1.751	0.50/0.00 0.28/0.583	0.84/-0.995 0.796/-0.842	

$d'_e = 0.425$	$\beta'_e = 1.12$

Table 2.2

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: 40 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	5	14.5 150.0	2 3	24 14	47 44	50 50
4	1	14.5 150.0+	12 0	36 99	46 34	50 50
5	3	14.5 150.0+	4 1	27 21	47 45	50 50
8	2	14.5 150.0+	10 1	35 16	46 40	50 50
10	4	14.5 150.0+	10 1	32 15	49 42	50 50
TOTALS		14.5 150.0+	38 6	154 75	235 205	250 250
PROPORTION/'Z'		14.5 150.0+	0.152/1.037 0.024/2.054	0.616/-0.306 0.3/0.525	0.94/-1.555 0.82/-0.915	

$d'_e = 0.85$	$\beta'_e = 0.96$

Table 2.3

SUMMARY OF RESULTS

SUBJECT: "W.TT."

CONDITION: 50 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category 4	3	2	1
1	3	14.5 150.0+	3 1	23 18	45 43	50 50
3	1	14.5 150.0+	10 3	29 11	44 35	50 50
6	4	14.5 150.0+	7 3	30 23	46 46	50 50
8	5	14.5 150.0+	7 2	32 28	46 47	50 50
9	2	14.5 150.0+	15 6	38 26	48 43	50 50
TOTALS		14.5 150.0+	42 15	152 106	229 214	250 250
PROPORTION/'Z'		14.5 150.0+	0.168/0.954 0.06/1.555	0.608/-0.279 0.424/0.202	0.916/-1.405 0.856/-1.080	

$d'_e = 0.5$	$\beta'_e = 1.03$

Table 2.4

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: 60 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	3	14.5 150.0+	9 2	25 19	43 43	50 50
4	4	14.5 150.0+	8 0	23 14	43 42	50 50
5	2	14.5 150.0+	10 1	28 17	48 40	50 50
7	5	14.5 150.0+	10 4	37 23	46 46	50 50
10	1	14.5 150.0+	10 1	34 18	44 40	50 50
TOTALS		14.5 150.0+	47 8	147 91	224 211	250 250
PROPORTION/'Z'		14.5 150.0+	0.188/0.878 0.032/1.881	0.588/-0.229 0.364/0.359	0.896/-1.282 0.844/-0.995	

$d'_e = 0.5$ $\beta'_e = 0.99$

$d'_e = 0.5$	$\beta'_e = 0.99$

Table 2.5

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: 70 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	5	14.5 150.0+	9 0	28 12	46 43	50 50
3	3	14.5 150.0+	7 1	30 13	43 38	50 50
6	1	14.5 150.0+	7 0	35 9	46 28	50 50
7	4	14.5 150.0+	12 0	32 20	45 45	50 50
10	2	14.5 150.0+	9 3	36 14	48 45	50 50
TOTALS		14.5 150.0+	44 4	161 68	228 199	250 250
PROPORTION/'Z'		14.5 150.0+	0.140/1.080 0.016/2.054	0.644/-0.359 0.272/0.613	0.912/-1.341 0.796/-0.842	

$d'_e = 0.85$	$\beta'_e = 0.96$

Table 2.6

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: 80 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	4	14.5 150.0+	3 1	21 10	37 36	50 50
4	2	14.5 150.0+	8 0	26 15	47 42	50 50
5	1	14.5 150.0+	7 2	26 7	47 30	50 50
8	3	14.5 150.0+	9 1	32 21	45 36	50 50
9	5	14.5 150.0+	5 7	26 30	46 44	50 50
TOTALS		14.5 150.0+	32 11	131 83	222 188	250 250
PROPORTION/'Z'		14.5 150.0+	0.128/1.126 0.044/1.751	0.524/-0.05 0.332/0.44	0.888/-1.227 0.752/-0.675	

$d'_e = 0.5$	$\beta'_e = 0.99$

Table 2.7

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: 90 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	4	14.5 150.0+	8 2	30 13	48 46	50 50
4	3	14.5 150.0+	8 0	26 16	46 43	50 50
6	3	14.5 150.0+	4 2	22 16	43 36	50 50
8	1	14.5 150.0+	10 3	26 17	44 32	50 50
10	5	14.5 150.0+	6 8	29 28	46 44	50 50
TOTALS		14.5 150.0+	36 15	133 90	227 201	250 250
PROPORTION/'Z'		14.5 150.0+	0.144/1.08 0.06/1.555	0.532/-0.075 0.362/ 0.359	0.908/-1.341 0.804/-0.842	

$d'_e = 0.5$	$\beta'_e = 1.17$

Table 2.8

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: 100 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	2	14.5 150.0+	2 0	24 9	42 39	50 50
3	5	14.5 150.0+	4 5	28 15	43 45	50 50
5	4	14.5 150.0+	5 1	38 19	47 42	50 50
7	1	14.5 150.0+	10 1	28 11	39 28	50 50
10	3	14.5 150.0+	8 1	36 17	46 44	50 50
TOTALS		14.5 150.0+	29 8	154 71	217 198	250 250
PROPORTION/'Z'		14.5 150.0+	0.116/1.175 0.032/1.881	0.616/-0.306 0.284/0.583	0.868/-1.126 0.792/-0.807	

$d'_e = 0.65$	$\beta'_e = 1.07$

Table 2.9

SUMMARY OF RESULTS

SUBJECT: "W. T."

CONDITION: 110 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	2	14.5 150.0+	7 0	33 10	47 45	50 50
4	5	14.5 150.0+	5 0	29 11	45 41	50 50
6	3	14.5 150.0+	8 0	29 14	44 35	50 50
8	4	14.5 150.0+	11 1	35 18	44 44	50 50
9	1	14.5 150.0+	14 1	38 20	48 40	50 50
TOTALS		14.5 150.0+	45 2	164 73	228 205	250 250
PROPORTION/'Z'		14.5 150.0+	0.18/2.054 0.008/2.326	0.656/-0.413 0.292/0.553	0.912/-2.326 0.82/-0.915	

$d'_e = 0.8$	$\beta'_e = 1.44$

APPENDIX C

Tables 3.0 to 3.9

Summary of response by Rating Scale to "flickering" and "fused" light by subject "D. C." for each of ten auditory conditions

Table 3.0

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: HEADPHONES AND EARPLUGS

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	1	16.0 150.0+	15 0	27 14	43 29	50 50
3	4	16.0 150.0+	12 4	30 15	43 33	50 50
6	5	16.0 150.0+	12 6	30 24	42 40	50 50
8	2	16.0 150.0+	14 6	24 25	41 38	50 50
10	3	16.0 150.0+	11 5	27 19	43 38	50 50
TOTALS		16.0 150.0+	64 21	138 97	212 178	250 250
PROPORTION/'Z'		16.0 150.0+	0.256/0.643 0.084/1.405	0.552/-0.126 0.388/0.279	0.848/-1.037 0.712/-0.553	

$d'_e = 0.5$	$\beta'_e = 0.93$

Table 3.1

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITIONS HEADPHONES

Session	Block	cps Flicker Fused	Cumulative Responses by Category 4	3	2	1
1	5	16.0 150.0+	1 1	11 6	43 36	50 50
3	2	16.0 150.0+	12 8	28 18	46 38	50 50
5	3	16.0 150.0+	15 5	28 20	45 31	50 50
8	1	16.0 150.0+	15 4	30 19	42 34	50 50
10	4	16.0 150.0+	12 6	28 22	42 40	50 50
TOTALS		16.0 150.0+	55 24	125 85	218 179	250 250
PROPORTION/'Z'		16.0 150.0+	0.22/0.772 0.096/1.282	0.50/0.0 0.34/0.413	0.872/-1.126 0.716/0.583	

$d'_e = 0.4$	$\beta'_e = 1.04$

Table 3.2

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: 40 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	5	16.0 150.0+	14 4	34 17	43 37	50 50
4	3	16.0 150.0+	8 3	22 16	37 37	50 50
5	4	16.0 150.0+	11 7	25 19	40 34	50 50
7	1	16.0 150.0+	18 6	35 18	43 38	50 50
9	2	16.0 150.0+	21 8	39 21	48 38	50 50
TOTALS		16.0 150.0+	72 28	155 91	211 194	250 250
PROPORTION/'Z'		16.0 150.0+	0.288/0.553 0.112/1.227	0.62/-0.306 0.364/0.359	0.844/-0.995 0.776/-0.772	

$d'_e = 0.6$	$\beta'_e = 0.82$

Table 3.3

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: 50 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	3	16.0 150.0+	3 0	8 5	36 34	50 50
3	5	16.0 150.0+	7 6	25 18	46 37	50 50
6	1	16.0 150.0+	15 3	31 20	43 40	50 50
8	4	16.0 150.0+	8 8	27 22	42 36	50 50
10	2	16.0 150.0+	11 7	31 24	43 40	50 50
TOTALS		16.0 150.0+	44 24	122 89	210 187	250 250
PROPORTION/'Z'		16.0 150.0+	0.176/0.915 0.096/1.282	0.488/0.025 0.356/0.359	0.84/-0.995 0.748/-0.675	

$d'_e = 0.4$	$\beta'_e = 1.07$

Table 3.4

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: 60 dB (SPL) WHITE NOISE

Session	Block	cps Flicker cps Fused	Cumulative Responses by Category 4	3	2	1
2	3	16,0 150.0+	8 4	24 16	40 37	50 50
4	2	16.0 150.0+	8 5	25 22	45 38	50 50
5	1	16.0 150.0+	12 5	26 20	39 36	50 50
7	4	16.0 150.0+	11 9	32 21	41 38	50 50
9	5	16.0 150.0+	10 5	28 22	42 37	50 50
TOTALS		16.0 150.0+	49 28	135 101	217 186	250 250
PROPORTION/'Z'		16.0 150.0+	0.196/0.842 0.112/1.227	0.54/-0.101 0.404/0.253	0.868/-1.126 0.744/-0.643	

$d'_e = 0.4$	$\beta'_e = 1.13$

Table 3.5

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: 70 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	1	16,0 150.0+	2 0	14 4	37 39	50 50
3	3	16.0 150.0+	15 7	31 15	46 36	50 50
5	2	16.0 150.0+	14 5	29 15	42 30	50 50
8	5	16.0 150.0+	14 6	35 16	46 31	50 50
9	4	16.0 150.0+	15 4	37 17	45 36	50 50
TOTALS		16.0 150.0+	60 22	146 67	216 172	250 250
PROPORTION/'Z'		16.0 150.0+	0.24/0.706 0.088/1.341	0.584/-0.202 0.268/0.613	0.864/-1.080 0.688/-0.496	

$d'_e = 0.6$	$\beta'_e = 1.18$

Table 3.6

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: 80 dB (SPL) WHITE NOISE

Session	Block	cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	4	16.0 150.0+	12 3	29 14	38 29	50 50
4	5	16.0 150.0+	14 4	29 23	38 34	50 50
6	2	16.0 150.0+	13 7	26 22	42 40	50 50
7	3	16.0 150.0+	12 6	25 23	39 38	50 50
9	1	16.0 150.0+	15 4	30 21	44 36	50 50
TOTALS		16.0 150.0+	66 24	139 103	201 177	250 250
PROPORTION/'Z'		16.0 150.0+	0,264/0.643 0.096/1.282	0.556/-0.151 0.412/0.228	0.804/-0.842 0.708/-0.553	

$d'_{ee} = 0.5$	$\beta'_{ee} = 0.71$

Table 3.7

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: 90 dB (SPL) WHITE NOISE

Session	Block	cps cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	4	16.0 150.0+	22 0	8 4	31 34	50 50
4	1	16.0 150.0+	11 3	30 13	44 34	50 50
6	3	16.0 150.0+	11 5	30 25	43 40	50 50
7	2	16.0 150.0+	10 14	31 25	42 44	50 50
10	5	16.0 150.0+	12 6	35 22	45 35	50 50
TOTALS		16.0 150.0+	46 28	1341 89	205 187	250 250
PROPORTION/'Z'		16.0 150.0+	0.184/0.915 0.112/1.341	0.536/-0.101 0.356/0.359	0.82/-0.915 0.748/-0.675	

$d'_e = 0.35$	$\beta'_e = 0.94$

Table 3.8

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: 100 dB (SPL) WHITE NOISE

Session	Block	cps cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
2	2	16.0 150.0+	6 4	23 15	39 34	50 50
3	1	16.0 150.0+	16 4	33 10	44 30	50 50
6	4	16.0 150.0+	14 1	31 14	42 36	50 50
7	5	16.0 150.0+	14 5	35 16	44 35	50 50
9	3	16.0 150.0+	13 3	31 17	42 36	50 50
TOTALS		16.0 150.0+	63 17	1531 72	211 171	250 250
PROPORTION/'Z'		16.0 150.0+	0.252/0.675 0.068/1.476	0.612/-0.279 0.288/0.553	0.844/-0.995 0.684/-0.468	

$d'_e = 0.7$	$\beta'_e = 0.9$

Table 3.9

SUMMARY OF RESULTS

SUBJECT: "D. C."

CONDITION: 110 dB (SPL) WHITE NOISE

Session	Block	cps cps Flicker Fused	Cumulative Responses by Category			
			4	3	2	1
1	2	16.0 150.0+	1 2	8 4	32 23	50 50
4	4	16.0 150.0+	9 4	28 14	41 35	50 50
5	5	16.0 150.0+	16 2	28 12	42 29	50 50
8	3	16.0 150.0+	15 5	30 21	41 35	50 50
10	1	16.0 150.0+	15 6	31 19	47 32	50 50
TOTALS		16.0 150.0+	56 19	125 70	203 154	250 250
PROPORTION/'Z'		16.0 150.0+	0.224/0.772 0.076/1.405	0.5/0.0 0.28/0.583	0.812/-0.878 0.616/-0.306	

$d'_e = 0.6$	$\beta'_e = 1.18$

APPENDIX D

Figures 7.0 to 7.9

ROC and double probability ROC curves illustrating the performance of subject "B. S." on the visual task for each of ten auditory conditions

SUBJECT : B.S.
CONDITION : Headphones and Earplugs
SLOPE = 0.9

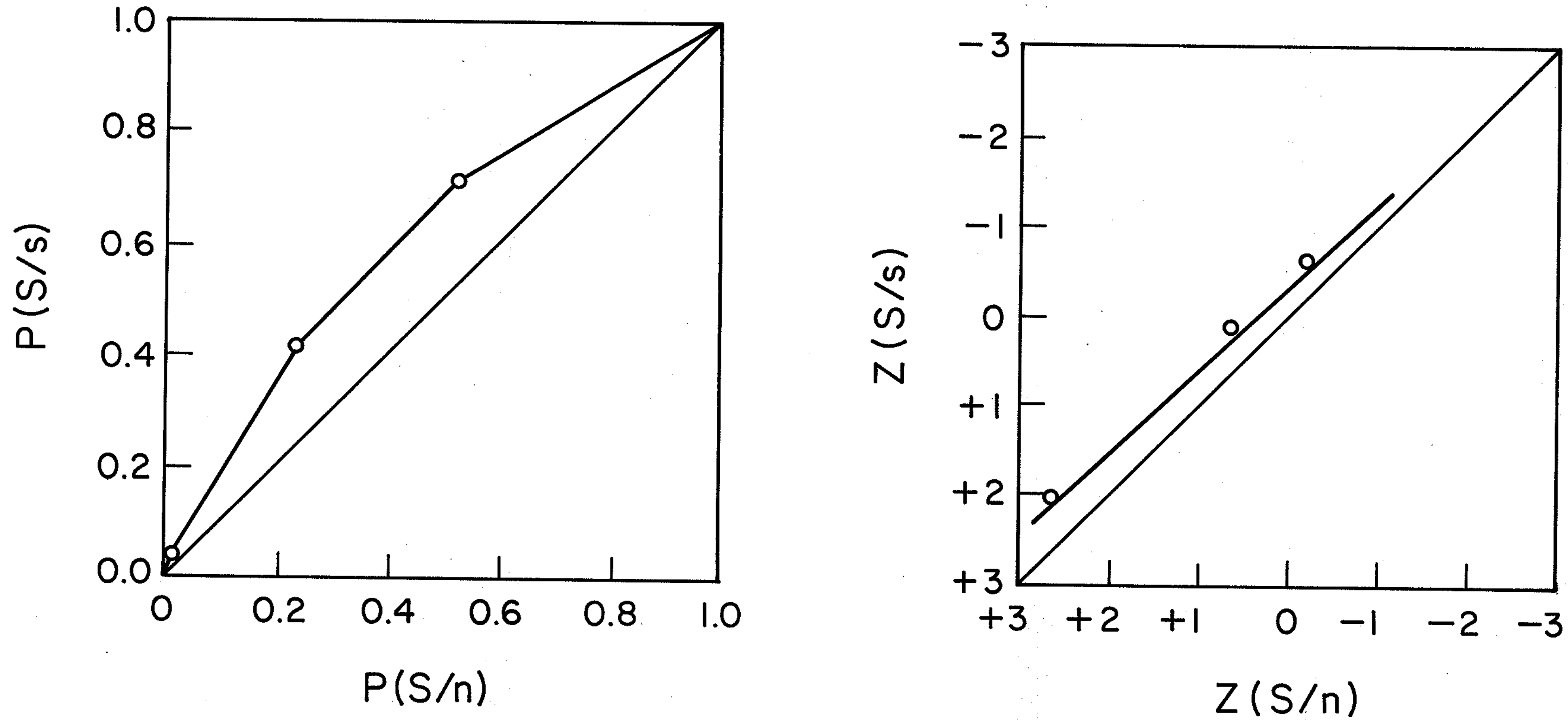


Figure 7.0

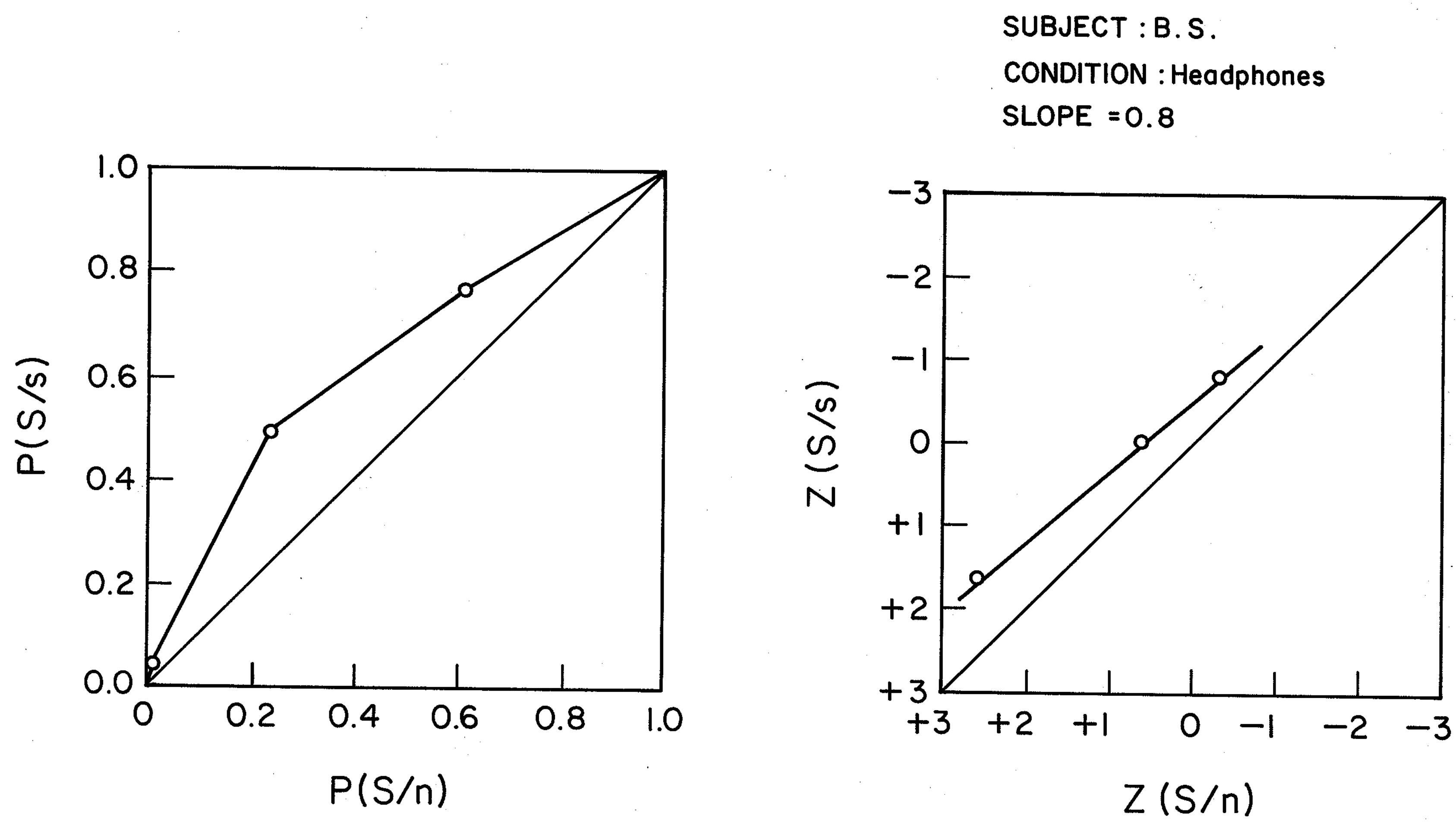

SUBJECT : B. S.
CONDITION : Headphones
SLOPE = 0.8
P(S/s)
P(S/n)
0.0
0.2
0.4
0.6
0.8
1.0
0
Z (S/s)
Z (S/n)
+3
+2
+1
0
−1
−2
−3

Figure 7.1

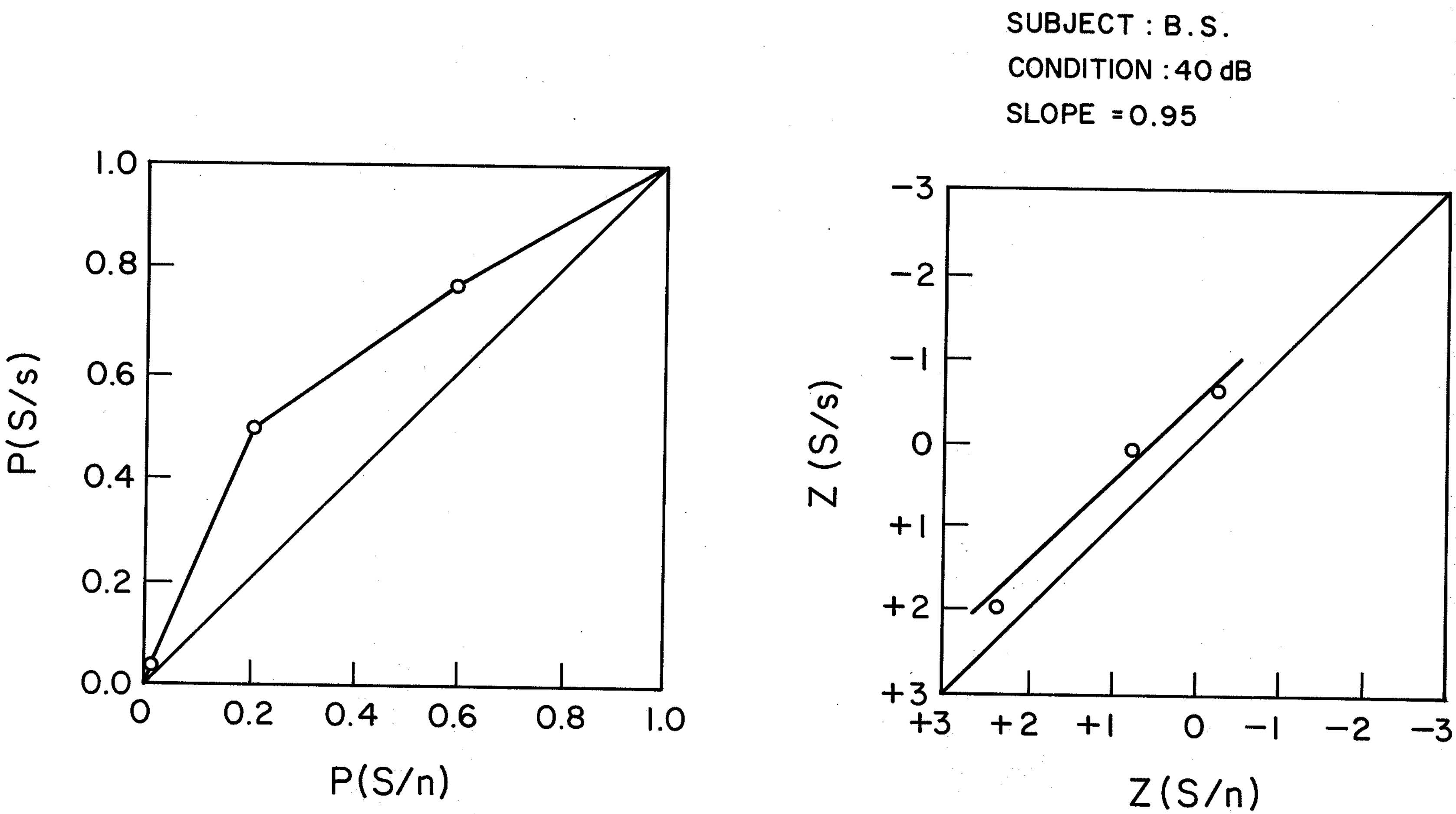

SUBJECT : B.S.
CONDITION : 40 dB
SLOPE = 0.95
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z (S/s)
Z(S/n)

Figure 7.2

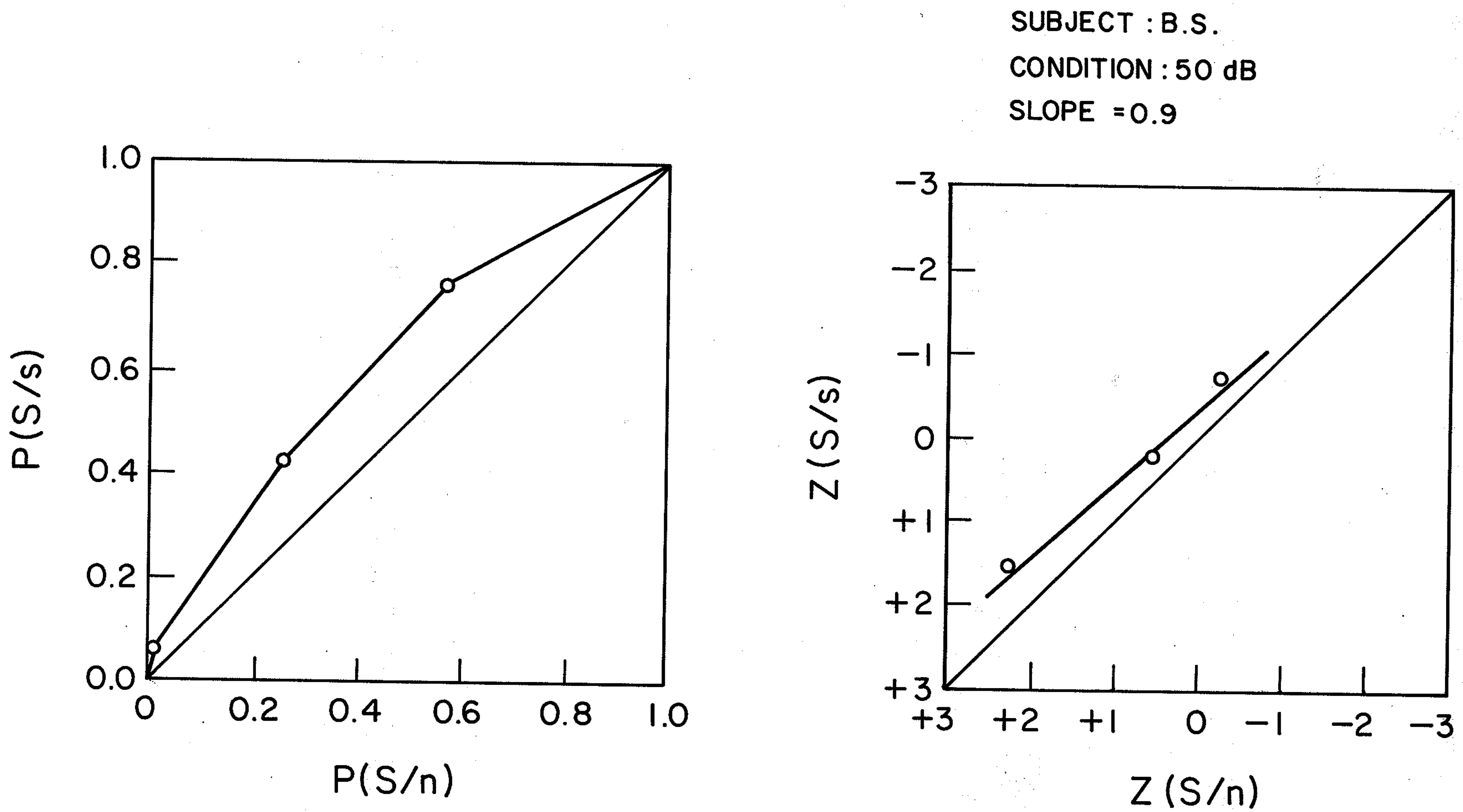

SUBJECT : B.S.
CONDITION : 50 dB
SLOPE = 0.9
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z(S/s)
Z(S/n)

Figure 7.3

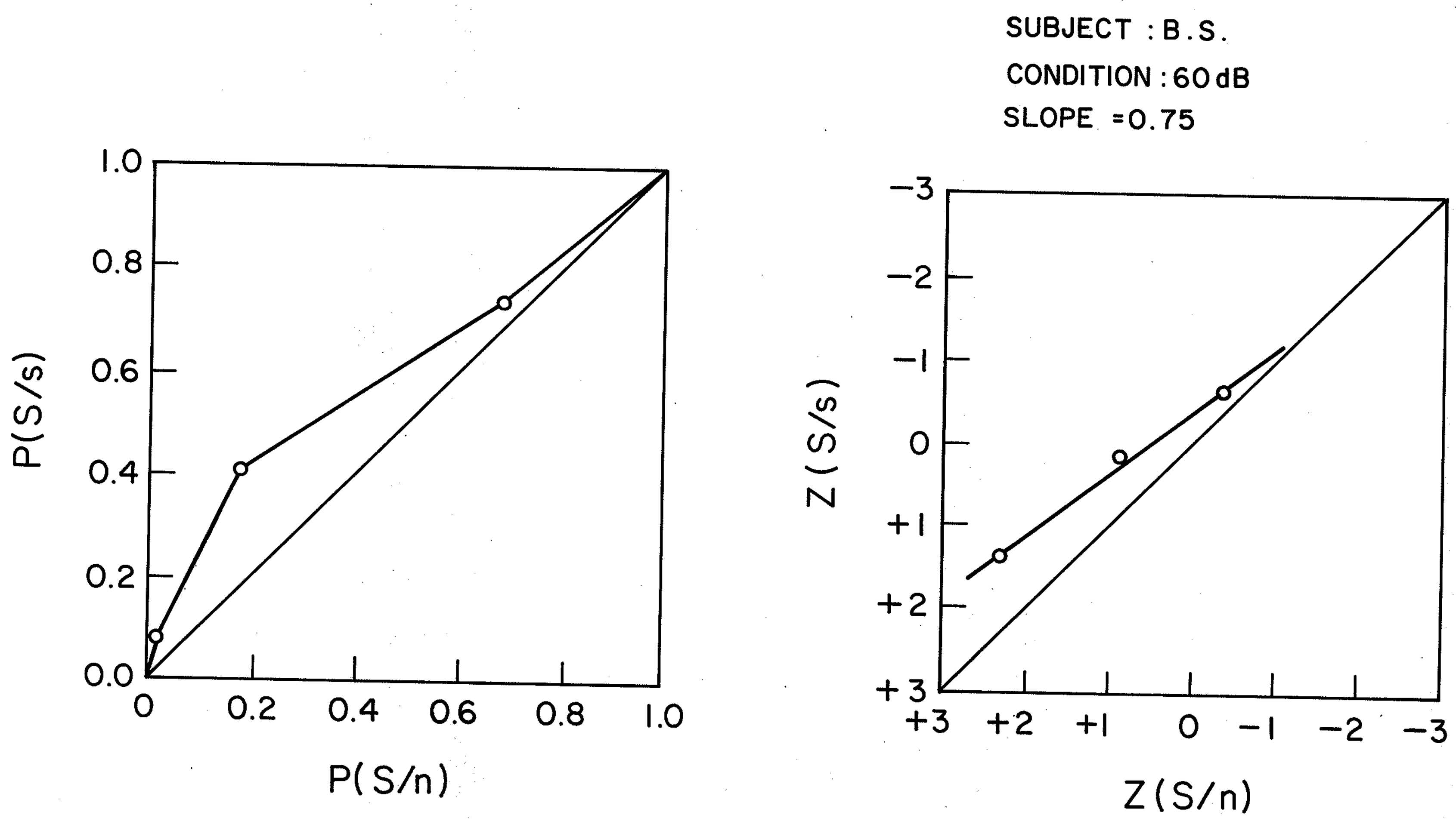

1.0
0.8
0.6
0.4
0.2
0.0
P(S/s)
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
SUBJECT : B.S.
CONDITION : 60 dB
SLOPE = 0.75
−3
−2
−1
0
+1
+2
+3
Z(S/s)
+3
+2
+1
0
−1
−2
−3
Z(S/n)

Figure 7.4

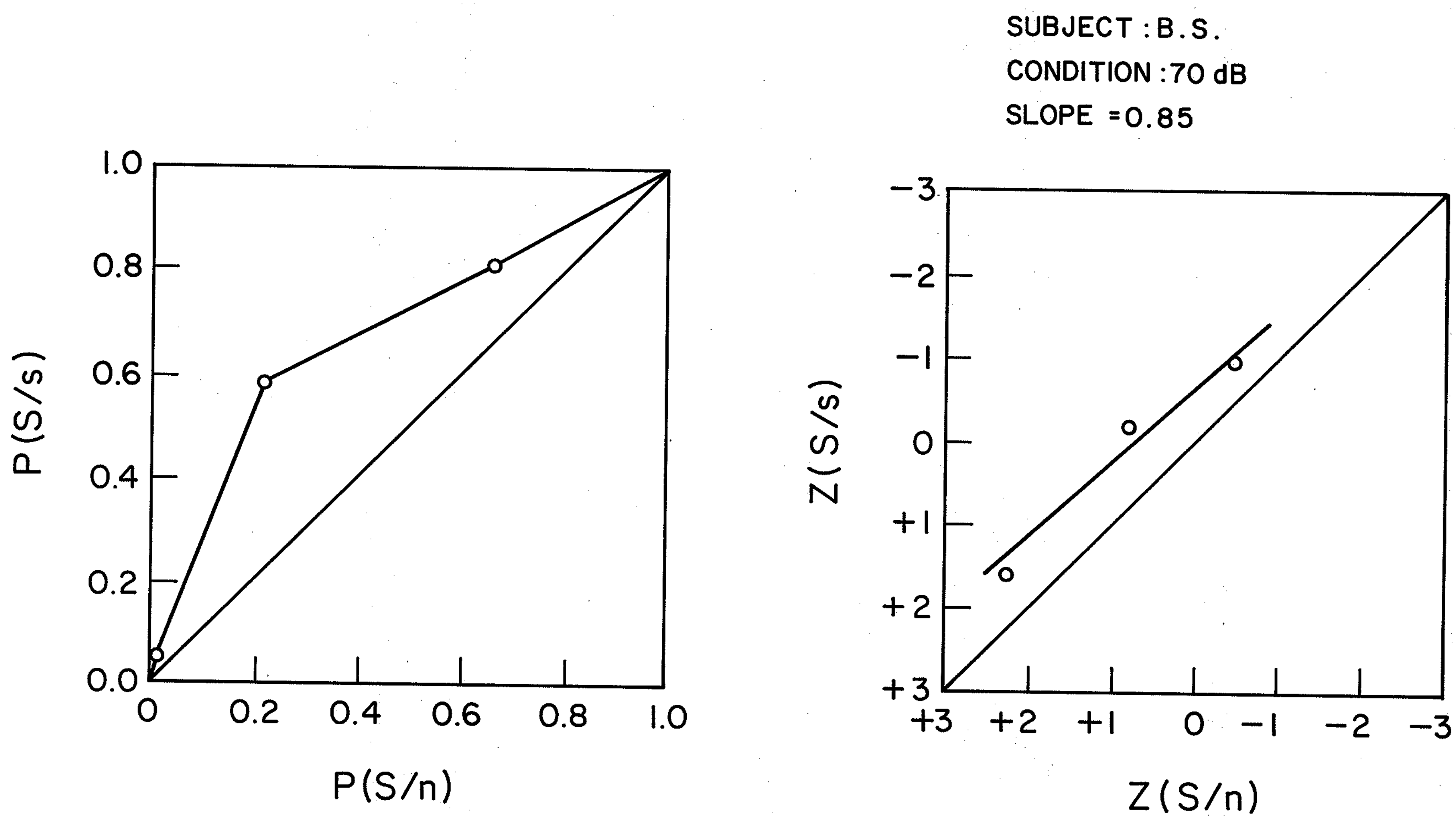
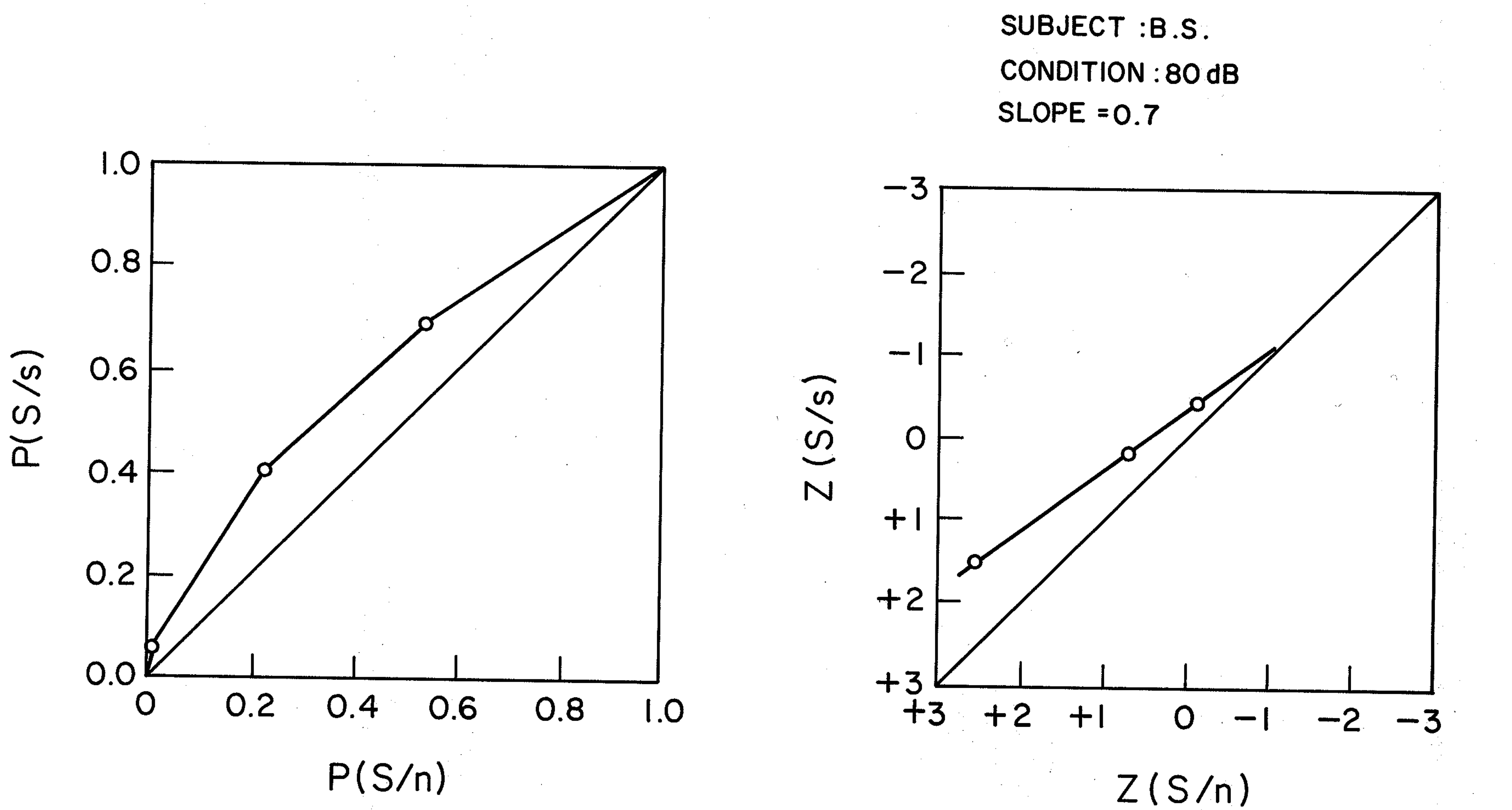

SUBJECT : B.S.
CONDITION : 70 dB
SLOPE = 0.85
P(S/s)
P(S/n)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
Z(S/s)
Z(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3

Figure 7.5



SUBJECT :B.S.
CONDITION : 80 dB
SLOPE = 0.7
P(S/s)
P(S/n)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
Z(S/s)
Z(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3

Figure 7.6

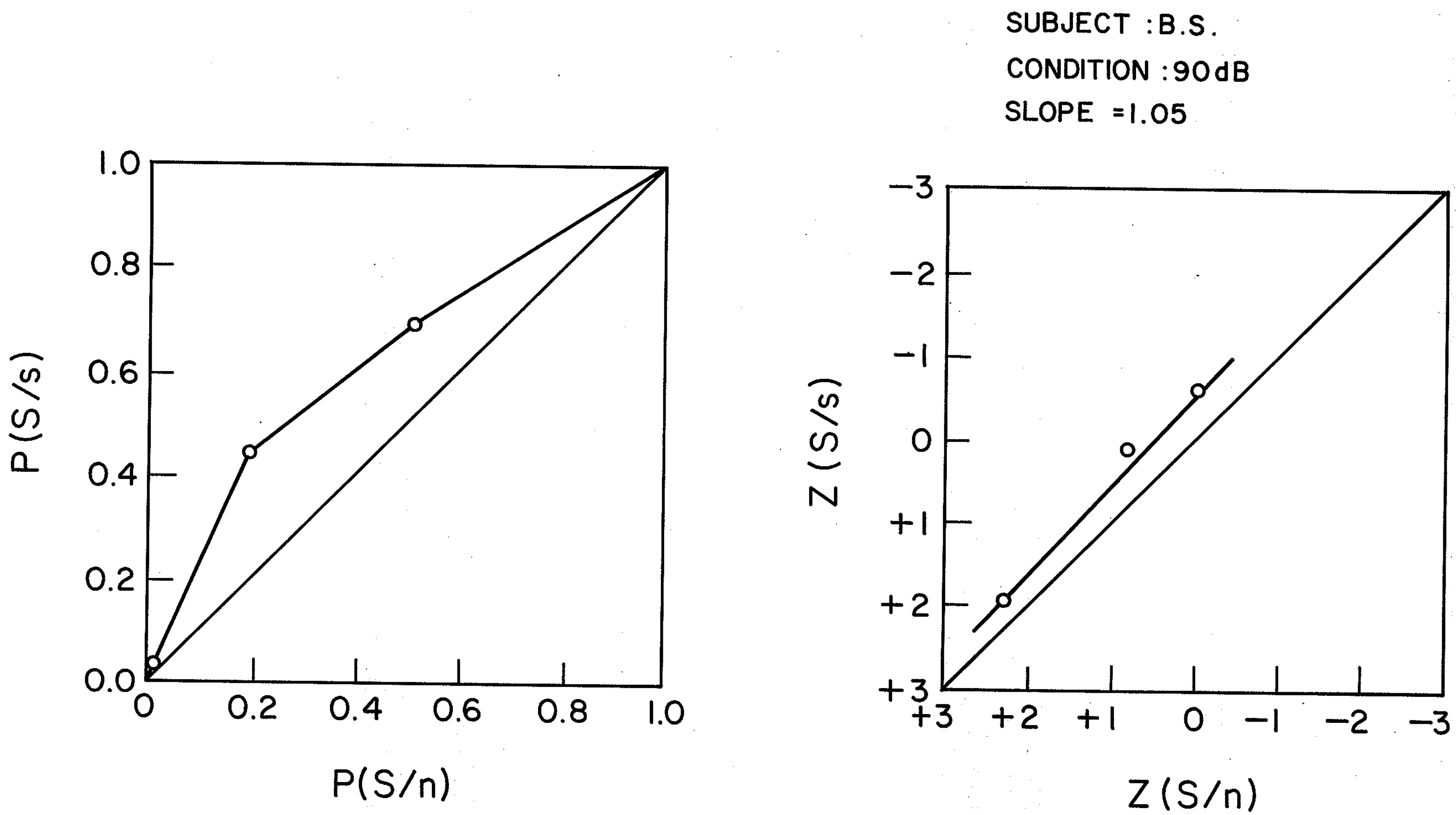

SUBJECT : B.S.
CONDITION : 90dB
SLOPE = 1.05
P(S/s)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
Z(S/s)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z(S/n)

Figure 7.7

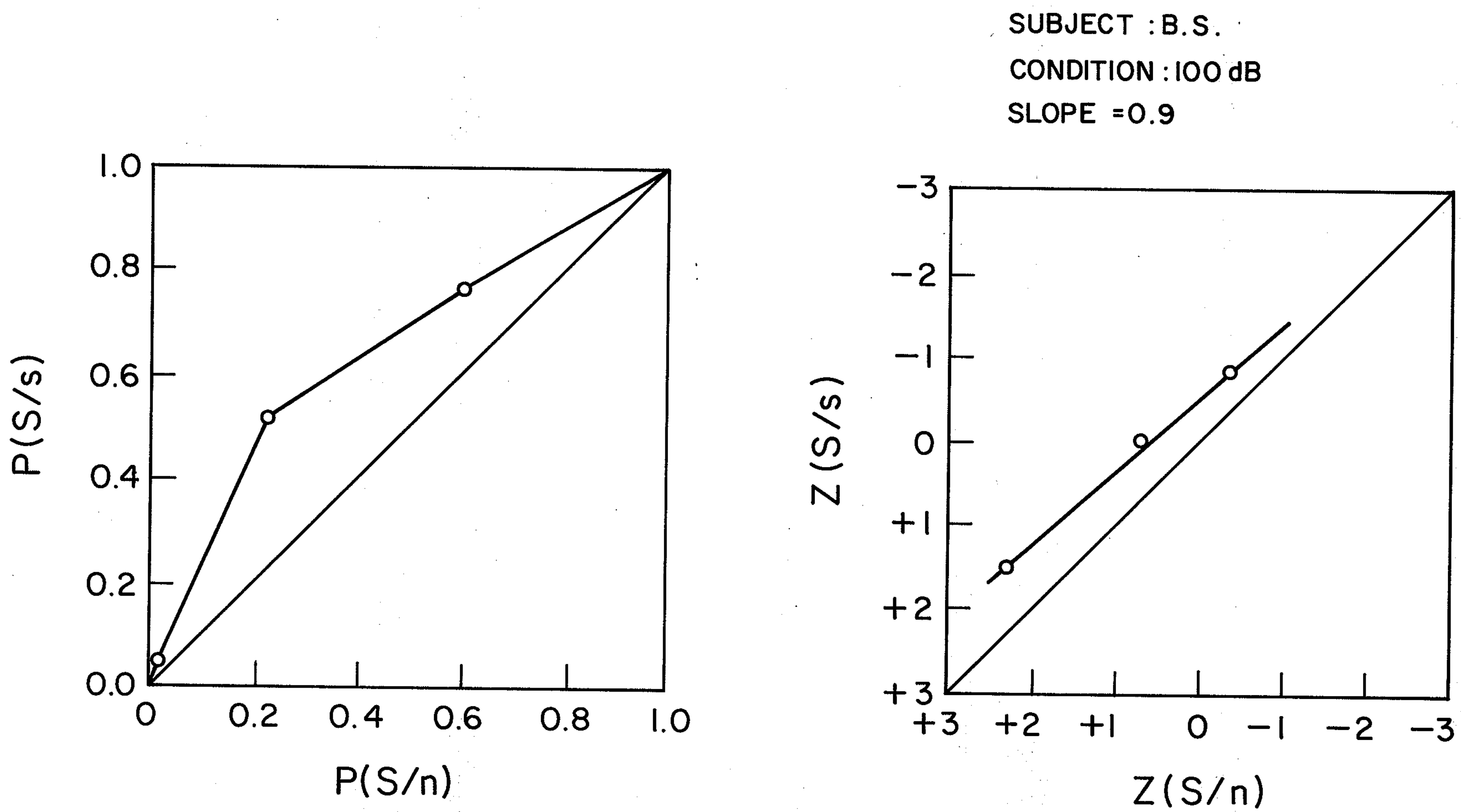

SUBJECT : B.S.
CONDITION : 100 dB
SLOPE = 0.9
P(S/s)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
Z(S/s)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z(S/n)

Figure 7.8

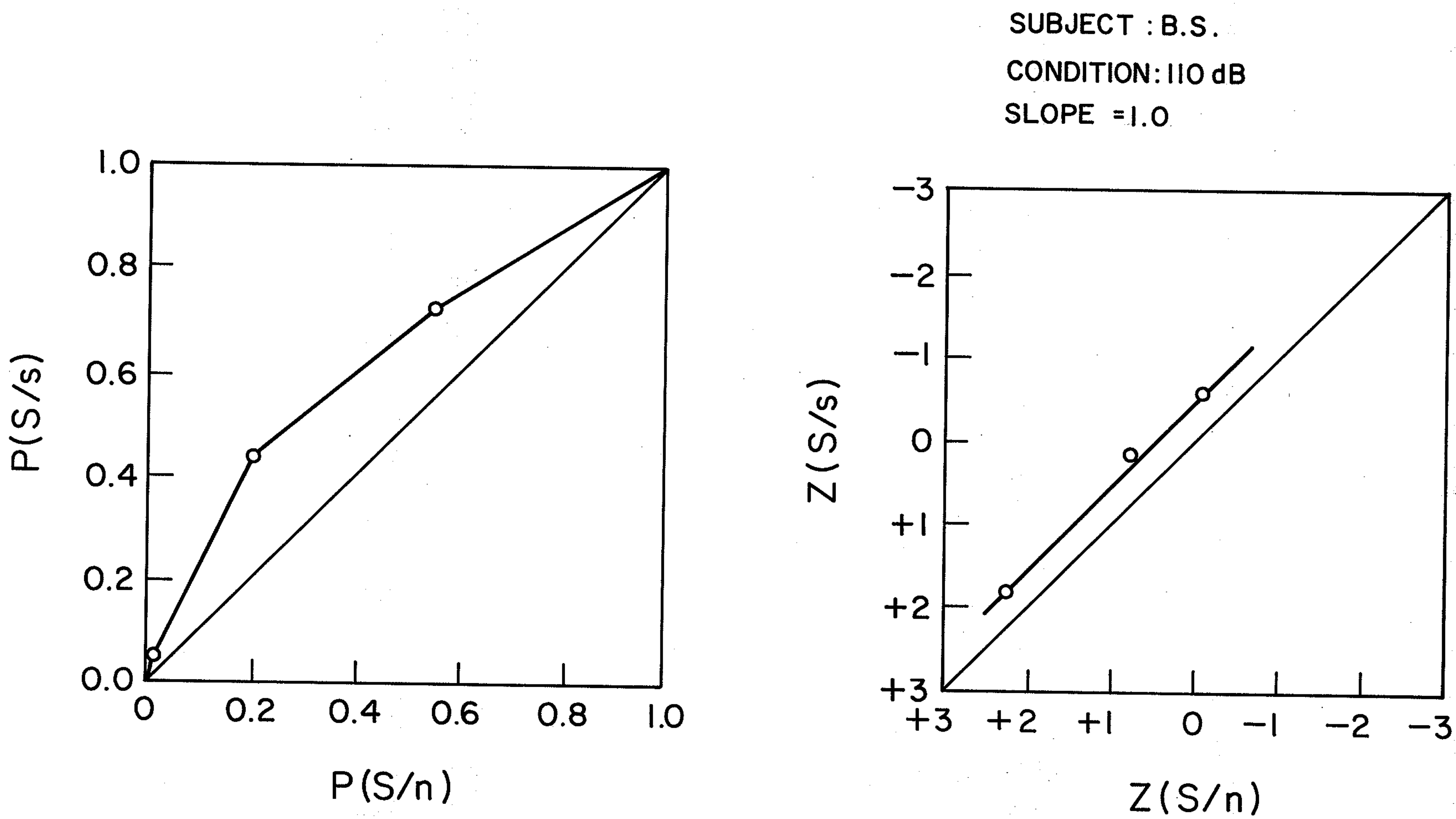

SUBJECT : B.S.
CONDITION: 110 dB
SLOPE = 1.0
P(S/s)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
Z(S/s)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z(S/n)

Figure 7.9

APPENDIX E

Figures 8.0 to 8.9

ROC and double probability ROC curves illustrating the performance of subject "W. T." on the visual task for each of ten auditory conditions

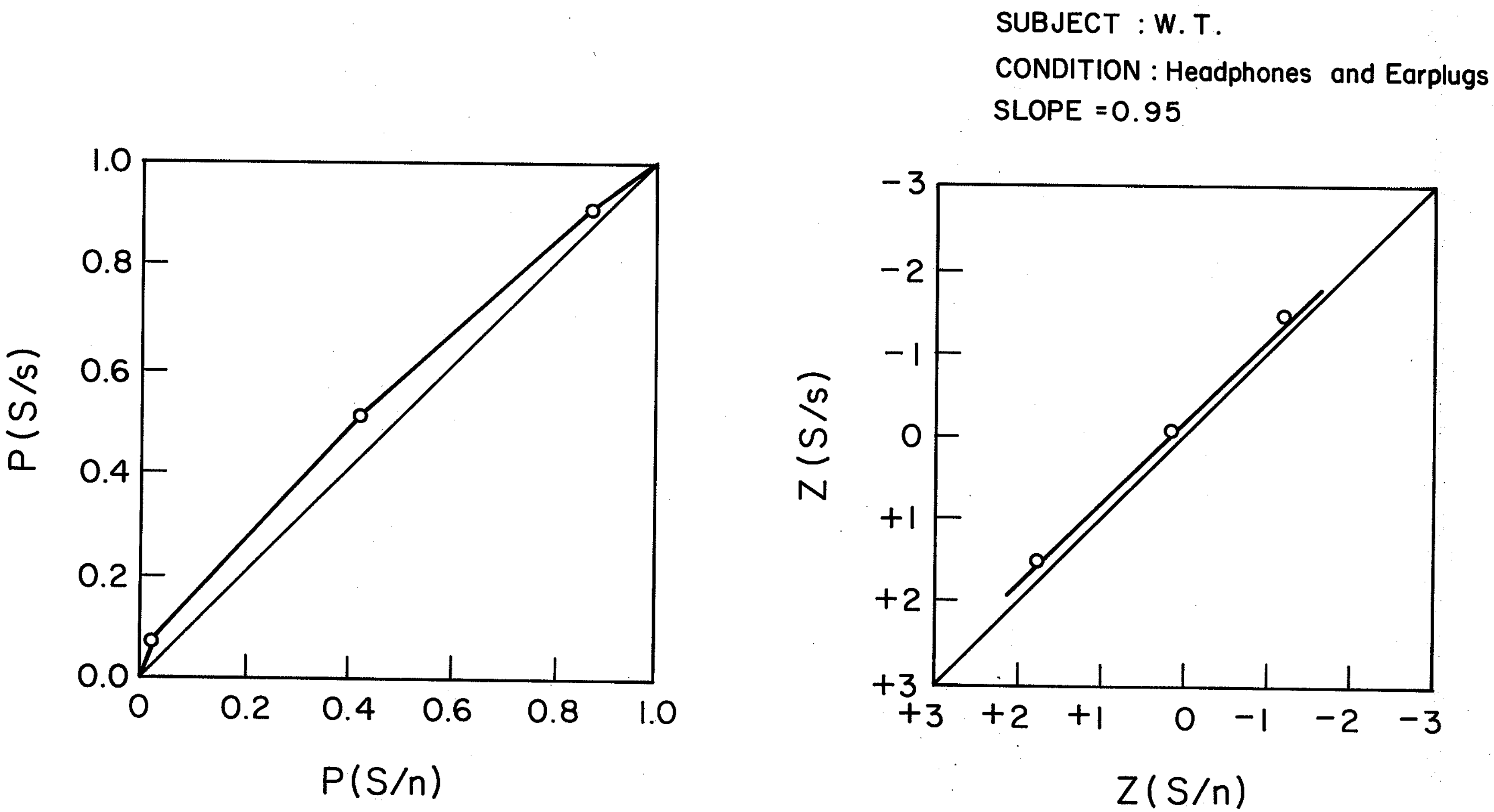

SUBJECT : W. T.
CONDITION : Headphones and Earplugs
SLOPE =0.95
P(S/s)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
Z(S/s)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z(S/n)

Figure 8.0

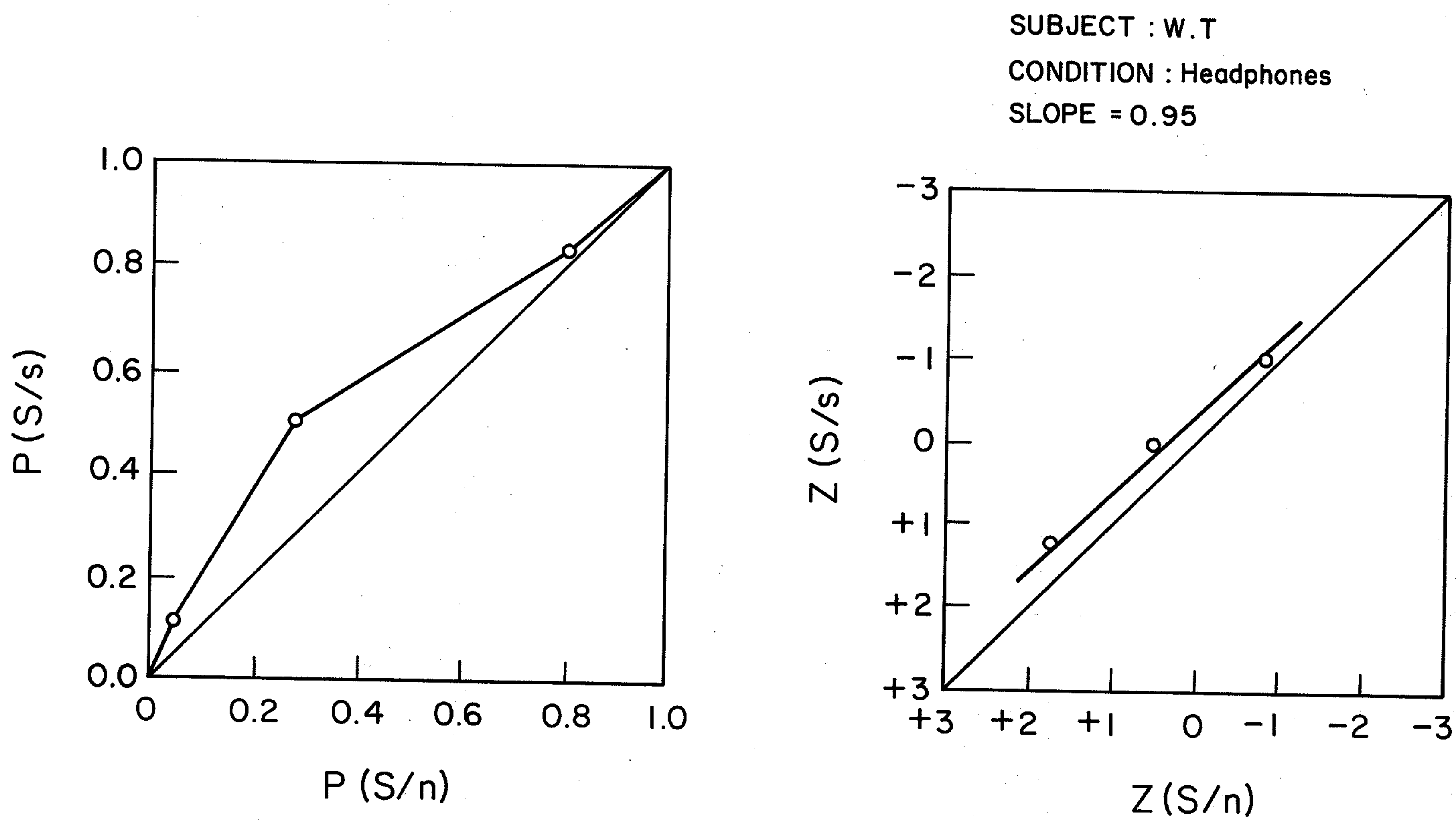

SUBJECT : W.T
CONDITION : Headphones
SLOPE = 0.95
P (S/s)
P (S/n)
Z (S/s)
Z (S/n)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
-3
-2
-1
0
+1
+2
+3
+3
+2
+1
0
-1
-2
-3

Figure 8.1

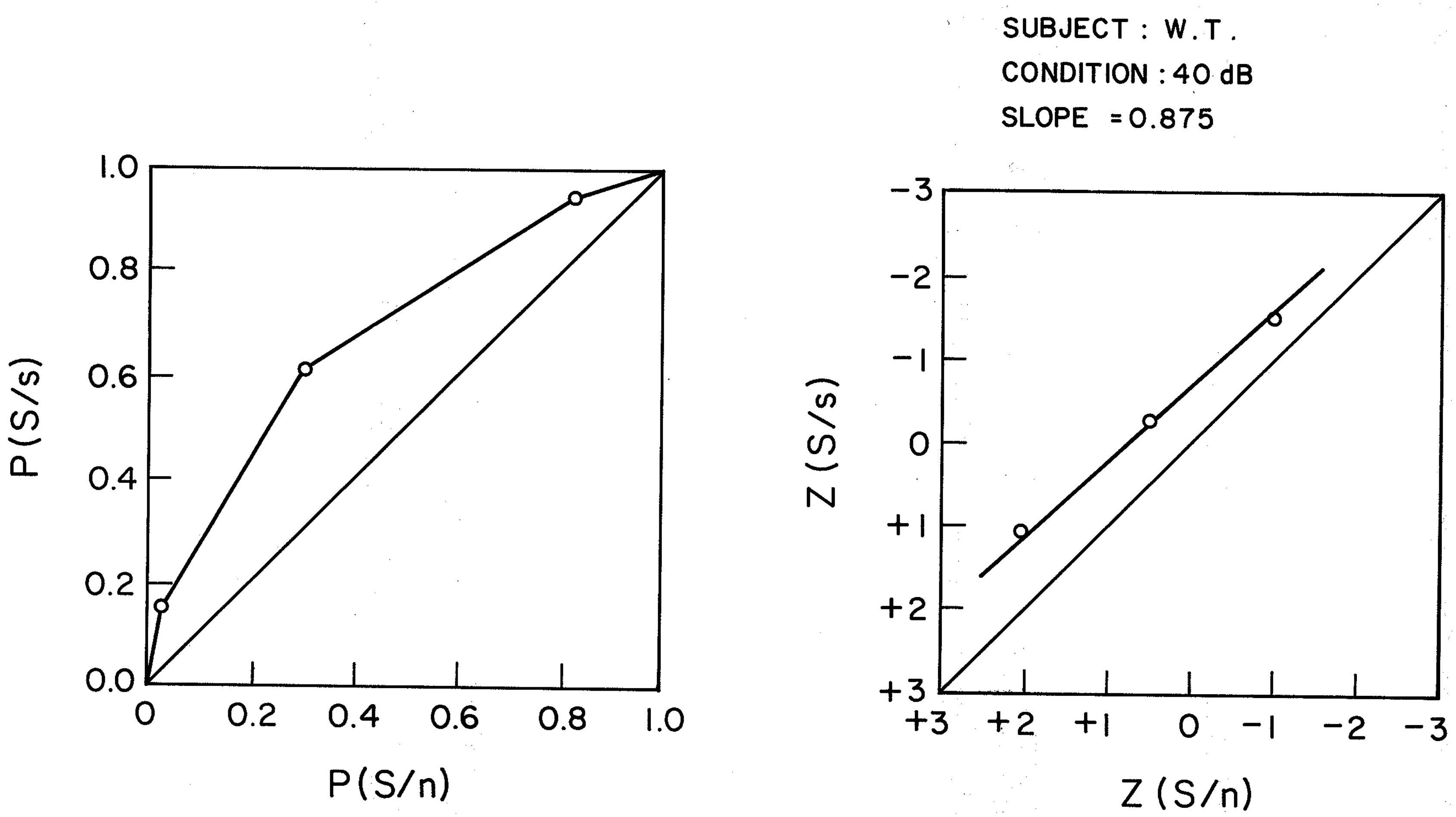

SUBJECT : W.T.
CONDITION : 40 dB
SLOPE = 0.875
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z(S/s)
Z(S/n)

Figure 8.2

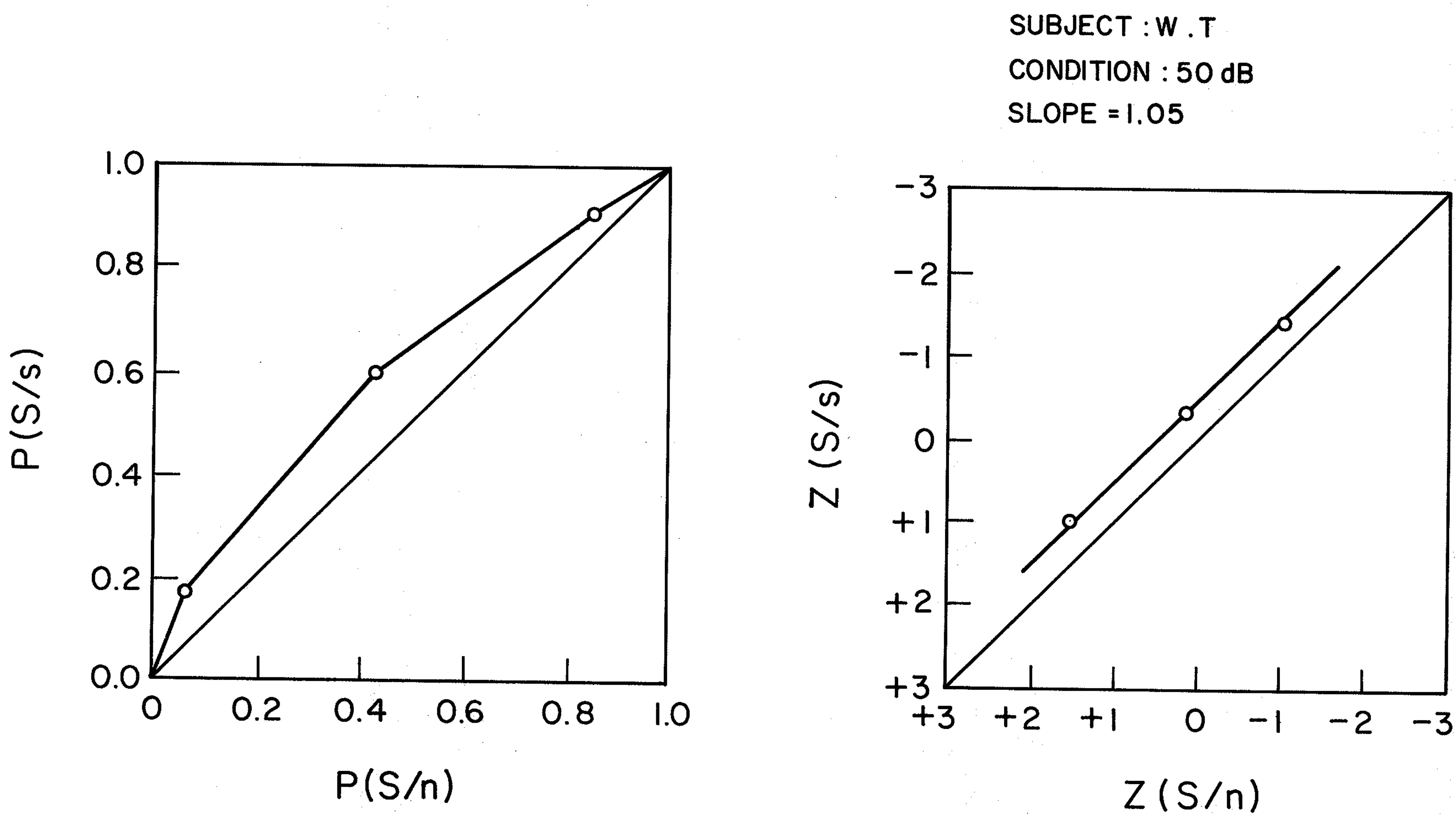

SUBJECT : W . T
CONDITION : 50 dB
SLOPE = 1.05
P(S/s)
P(S/n)
0.0
0.2
0.4
0.6
0.8
1.0
0
Z (S/s)
Z (S/n)
−3
−2
−1
0
+1
+2
+3

Figure 8.3

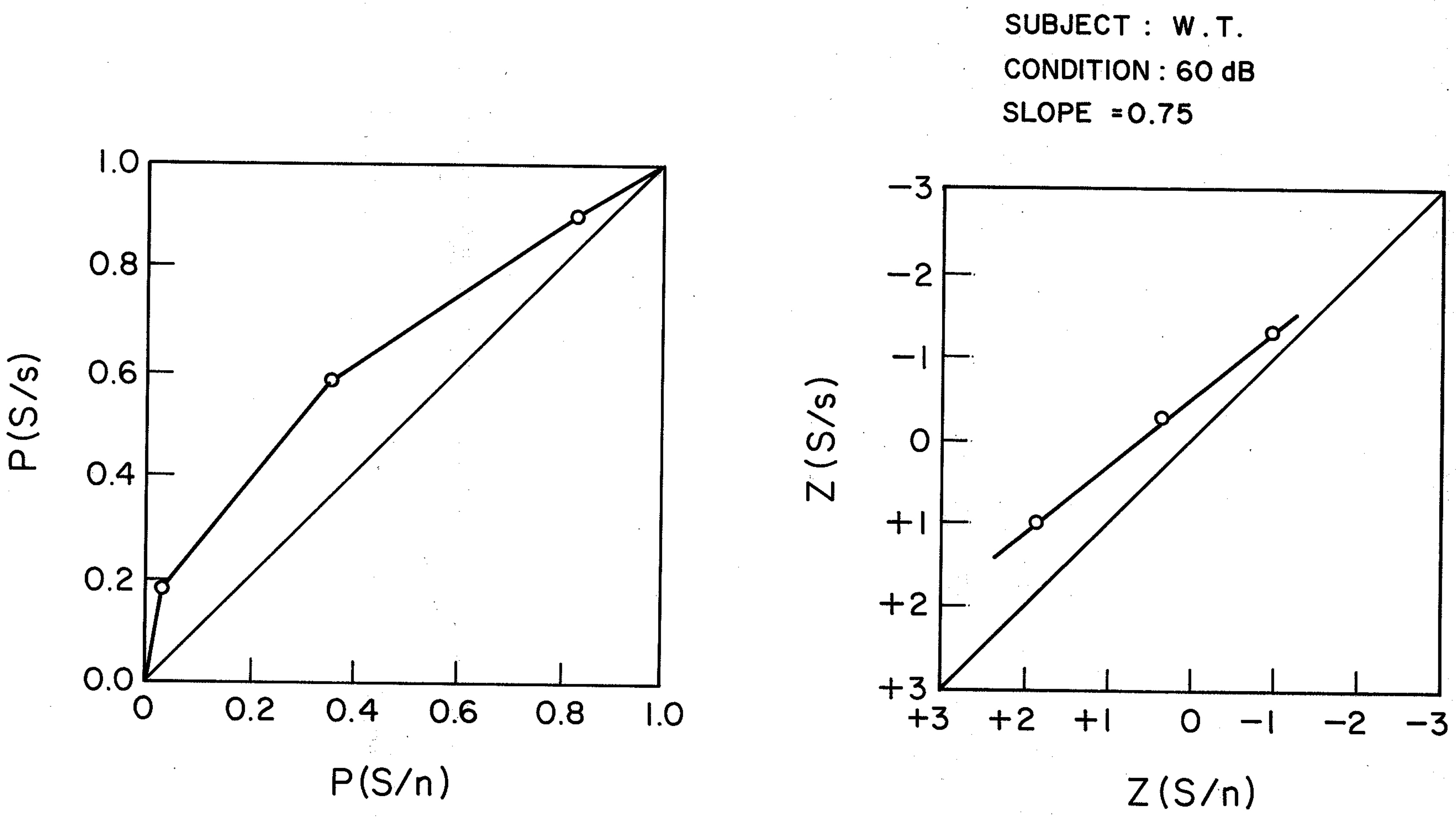

SUBJECT : W.T.
CONDITION : 60 dB
SLOPE =0.75
P(S/s)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
Z(S/s)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z(S/n)

Figure 8.4

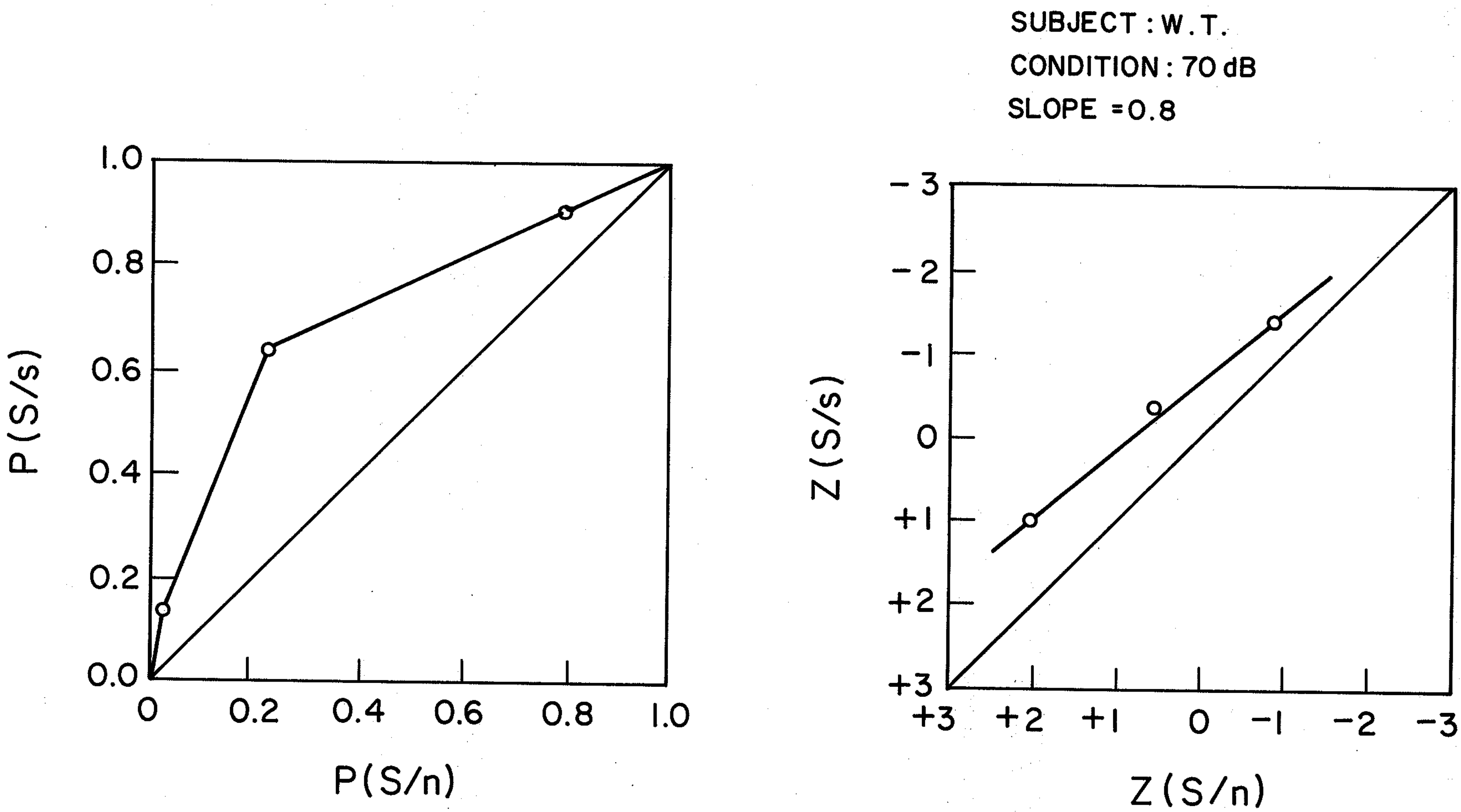

SUBJECT : W.T.
CONDITION : 70 dB
SLOPE = 0.8
P(S/s)
P(S/n)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
Z(S/s)
Z(S/n)
-3
-2
-1
0
+1
+2
+3
+3
+2
+1
0
-1
-2
-3

Figure 8.5

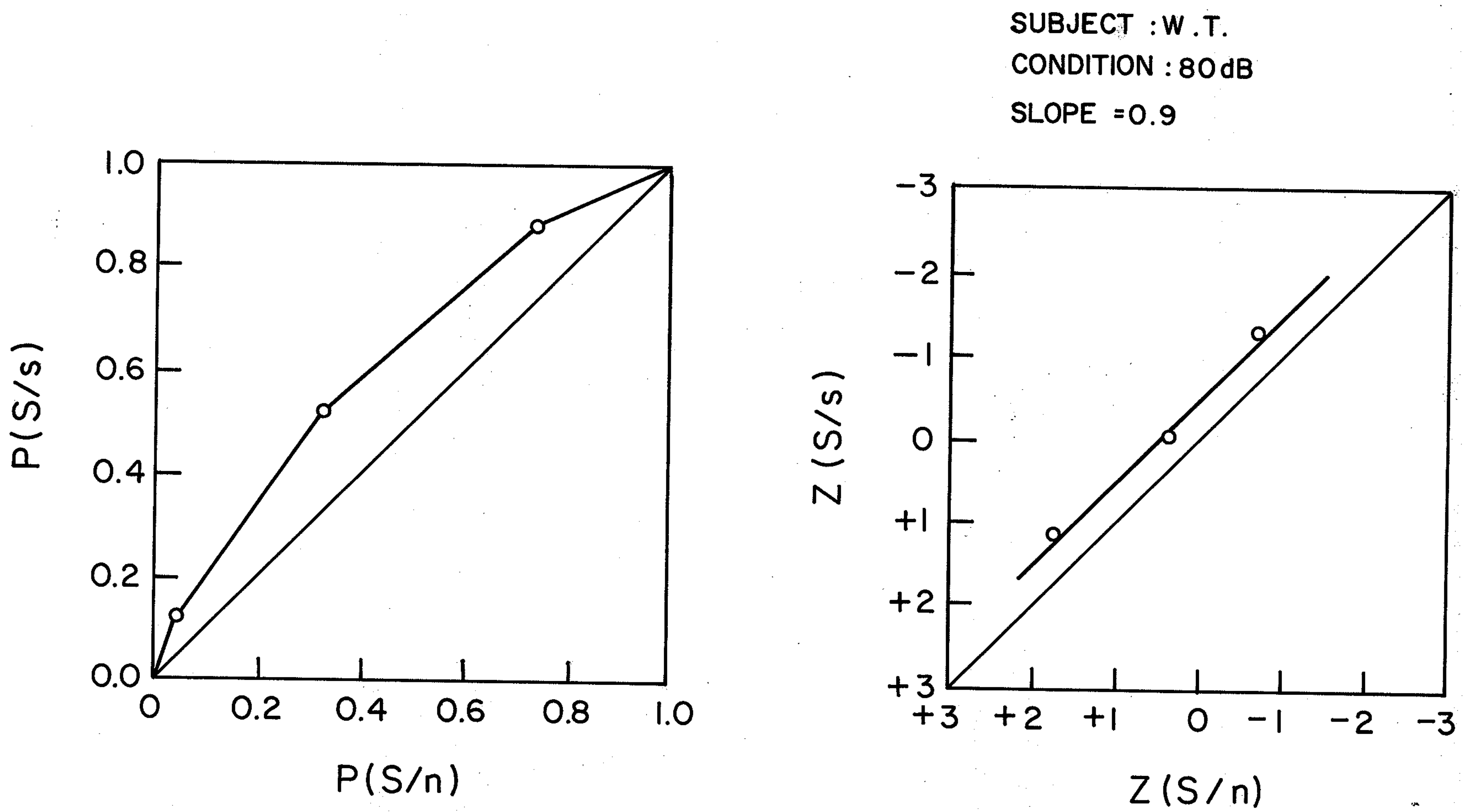

SUBJECT : W.T.
CONDITION : 80dB
SLOPE = 0.9
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
-3
-2
-1
0
+1
+2
+3
+3
+2
+1
0
-1
-2
-3
Z (S/s)
Z (S/n)

Figure 8.6

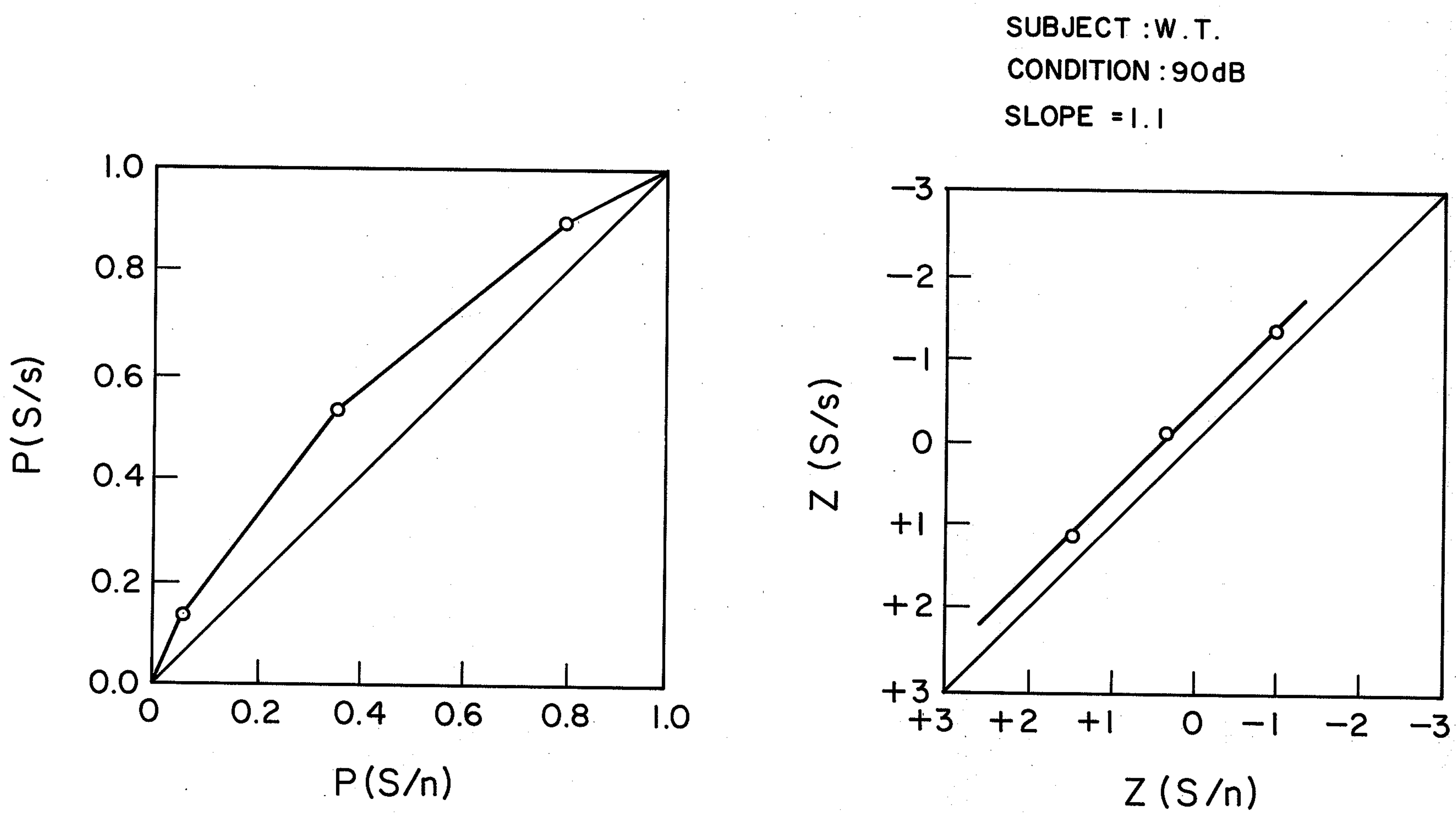

SUBJECT : W.T.
CONDITION : 90dB
SLOPE = 1.1
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
−3
−2
−1
0
+1
+2
+3
Z (S/s)
Z (S/n)

Figure 8.7

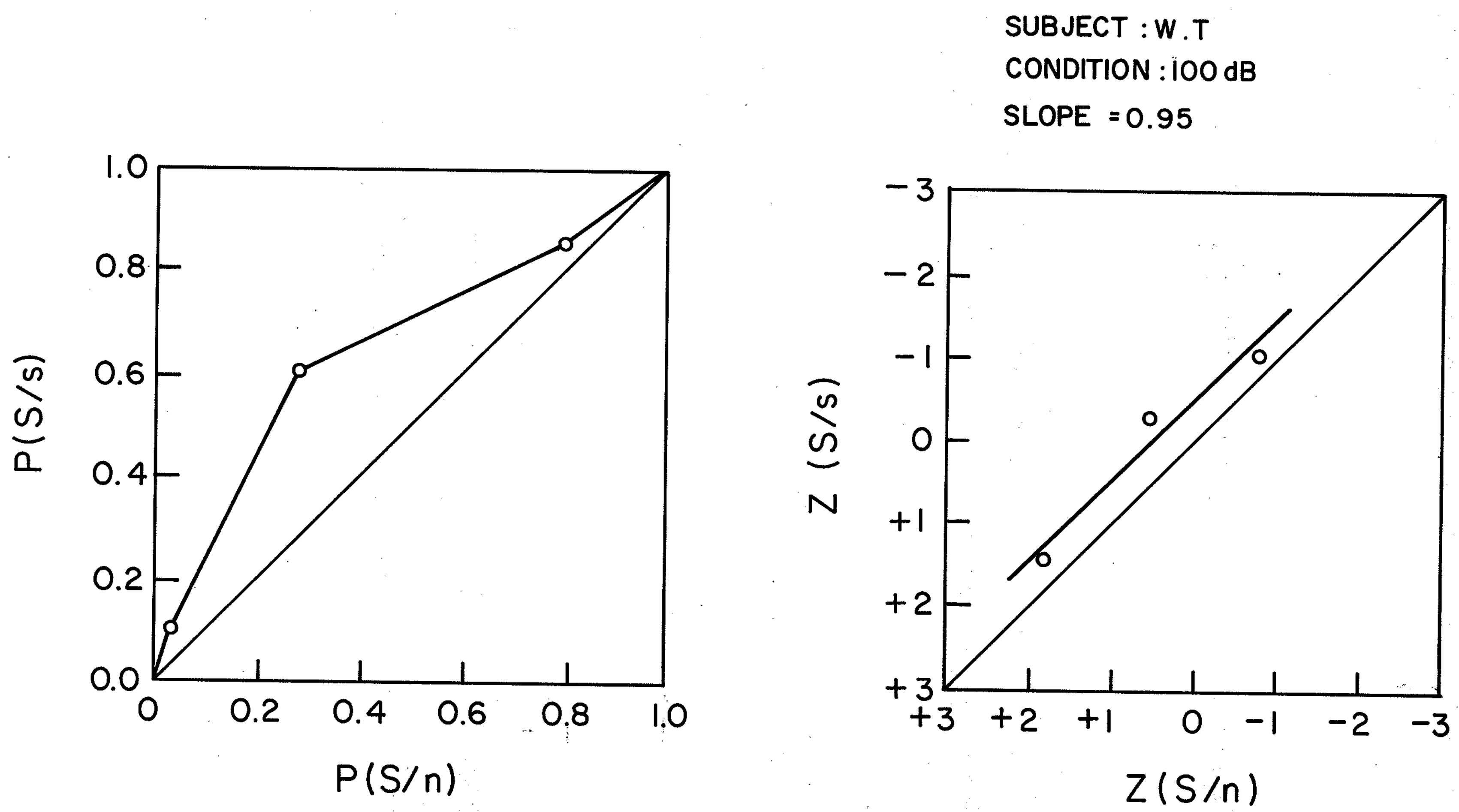

SUBJECT : W.T
CONDITION : 100 dB
SLOPE = 0.95
P(S/s)
P(S/n)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
Z (S/s)
Z(S/n)
-3
-2
-1
0
+1
+2
+3
+3
+2
+1
0
-1
-2
-3

Figure 8.8

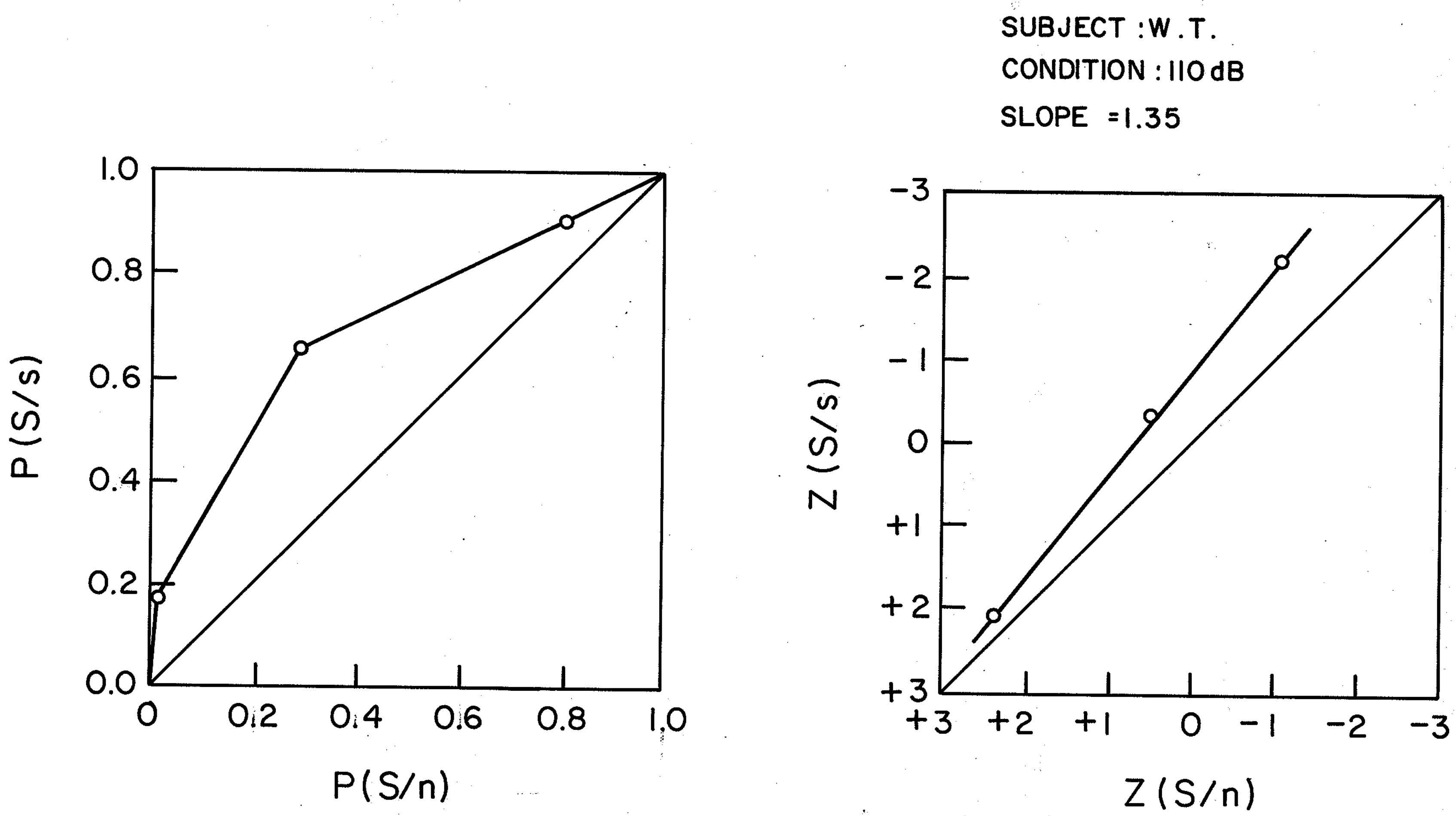

SUBJECT : W.T.
CONDITION : 110 dB
SLOPE = 1.35
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
-3
-2
-1
0
+1
+2
+3
+3
+2
+1
0
-1
-2
-3
Z(S/s)
Z(S/n)

Figure 8.9

APPENDIX F

Figures 9.0 to 9.9

ROC and double probability ROC curves illustrating the performance of subject "D. D." on the visual task for each of ten auditory conditions

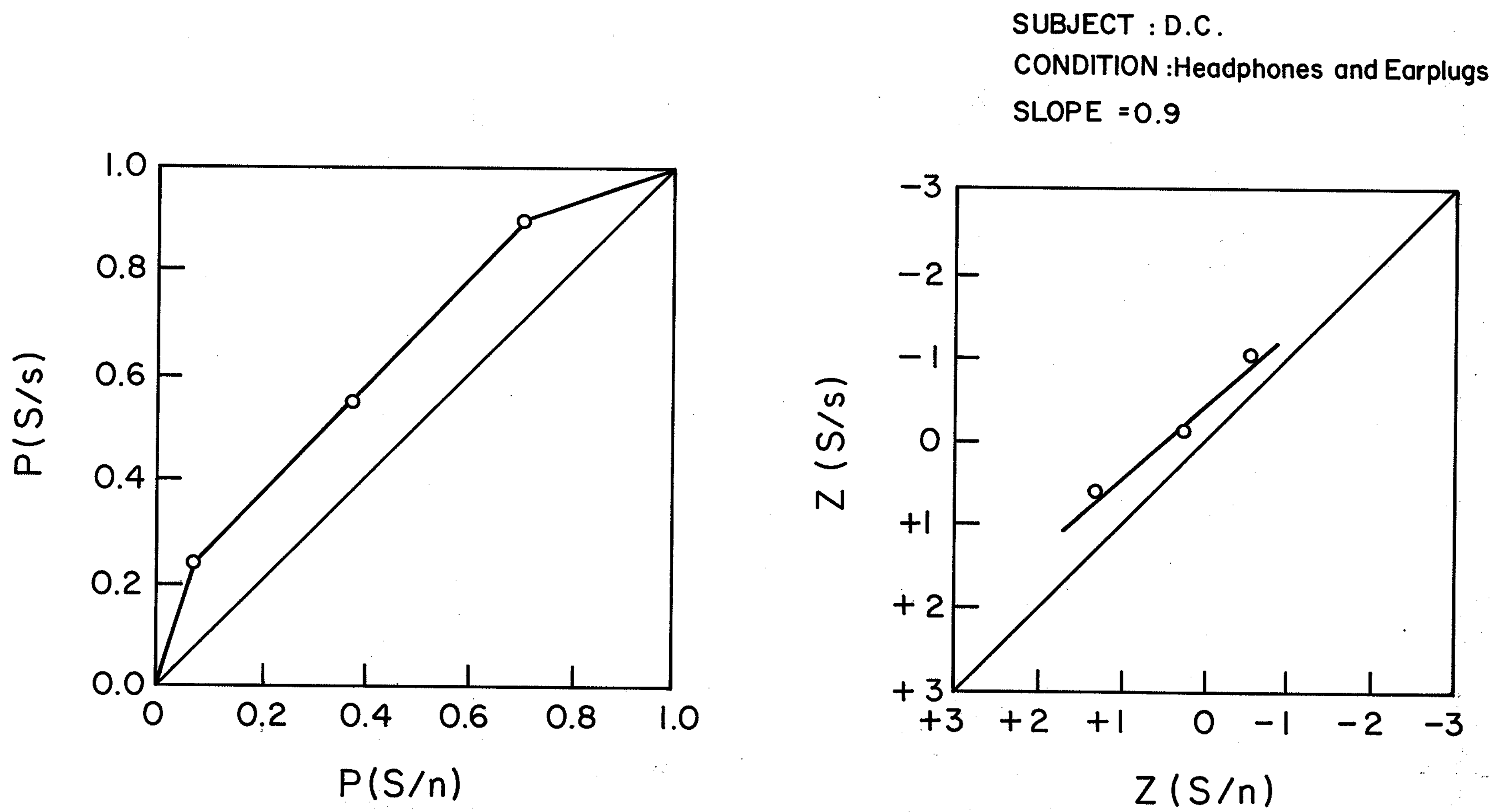
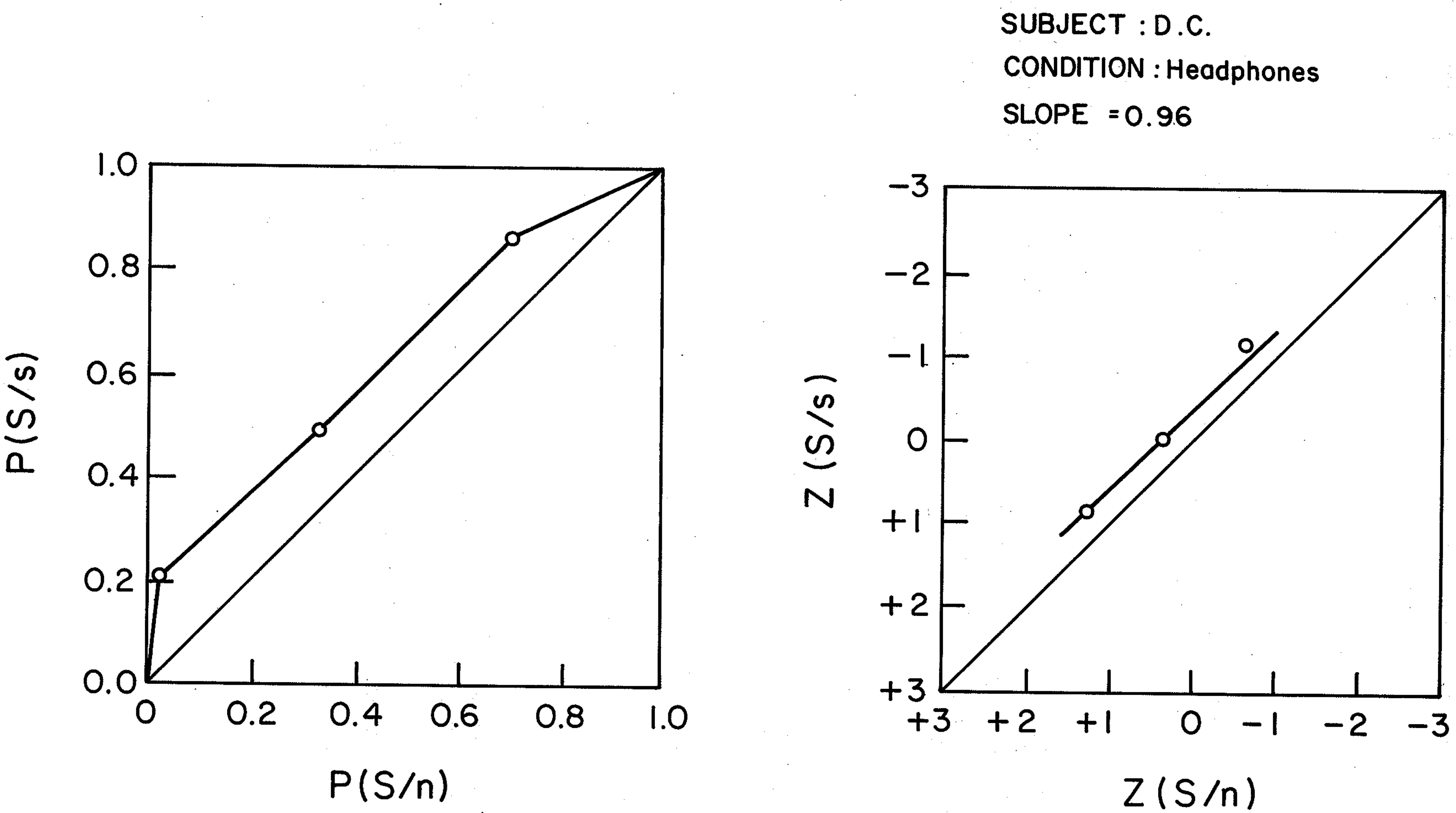

SUBJECT : D.C.
CONDITION :Headphones and Earplugs
SLOPE =0.9
1.0
0.8
0.6
0.4
0.2
0.0
P(S/s)
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
−3
−2
−1
0
+1
+2
+3
Z (S/s)
+3
+2
+1
0
−1
−2
−3
Z (S/n)

Figure 9.0



SUBJECT : D.C.
CONDITION : Headphones
SLOPE = 0.96
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z (S/s)
Z (S/n)

Figure 9.1

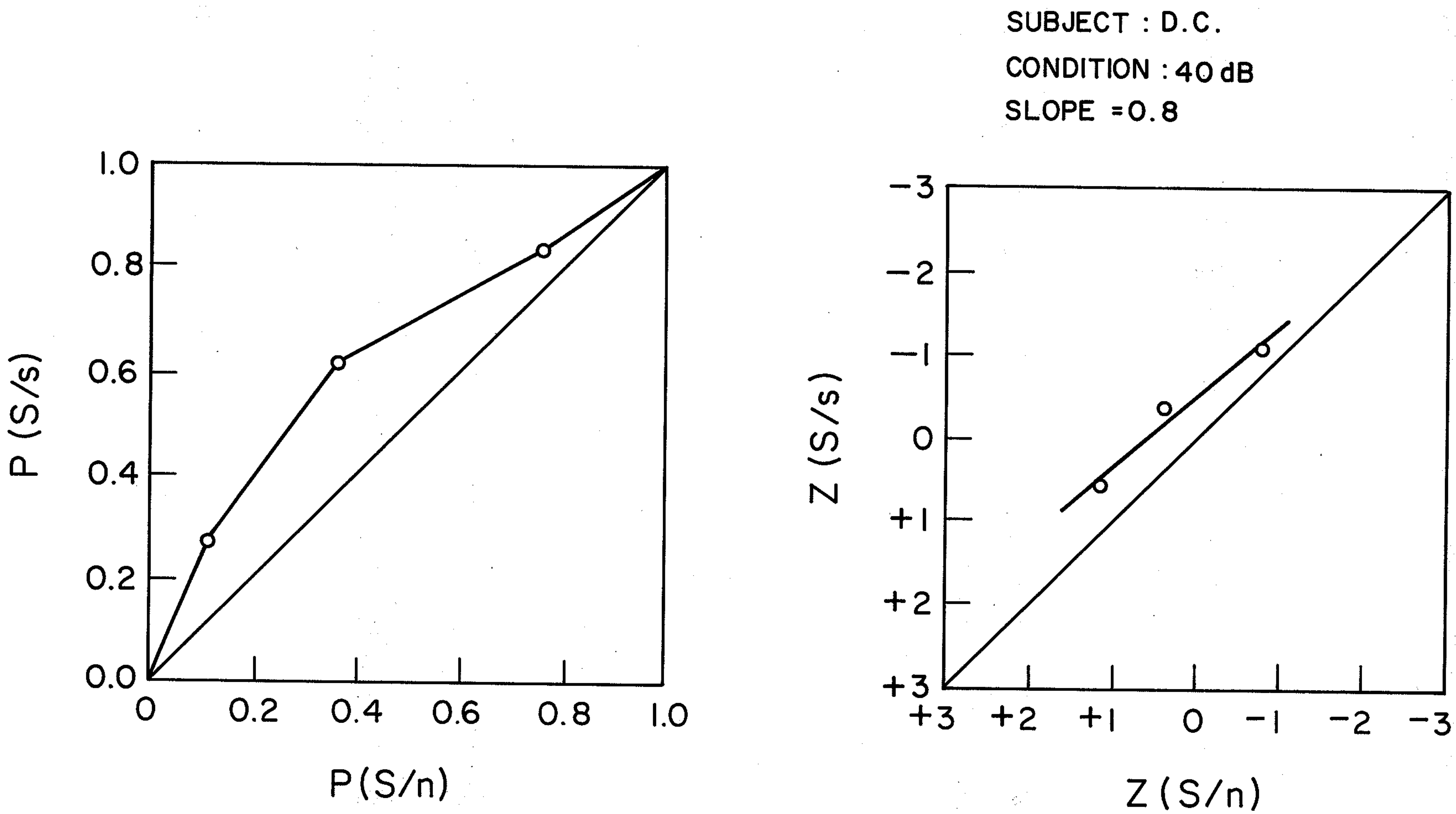

SUBJECT : D.C.
CONDITION : 40 dB
SLOPE = 0.8
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P (S/s)
P(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z (S/s)
Z (S/n)

Figure 9.2

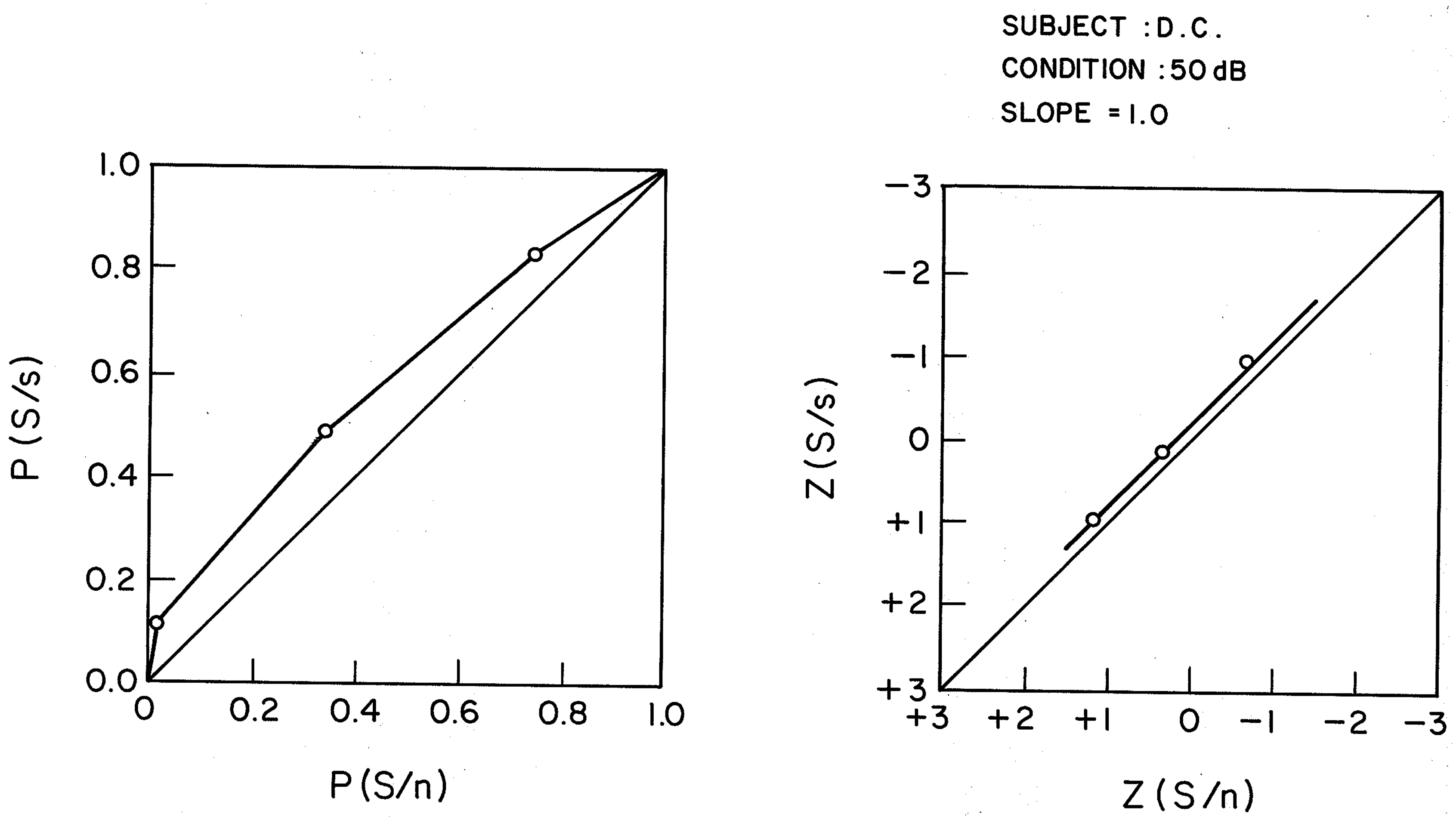

SUBJECT : D.C.
CONDITION : 50 dB
SLOPE = 1.0
P (S/s)
P (S/n)
0.0
0.2
0.4
0.6
0.8
1.0
0
Z (S/s)
Z (S/n)
−3
−2
−1
0
+1
+2
+3

Figure 9.3

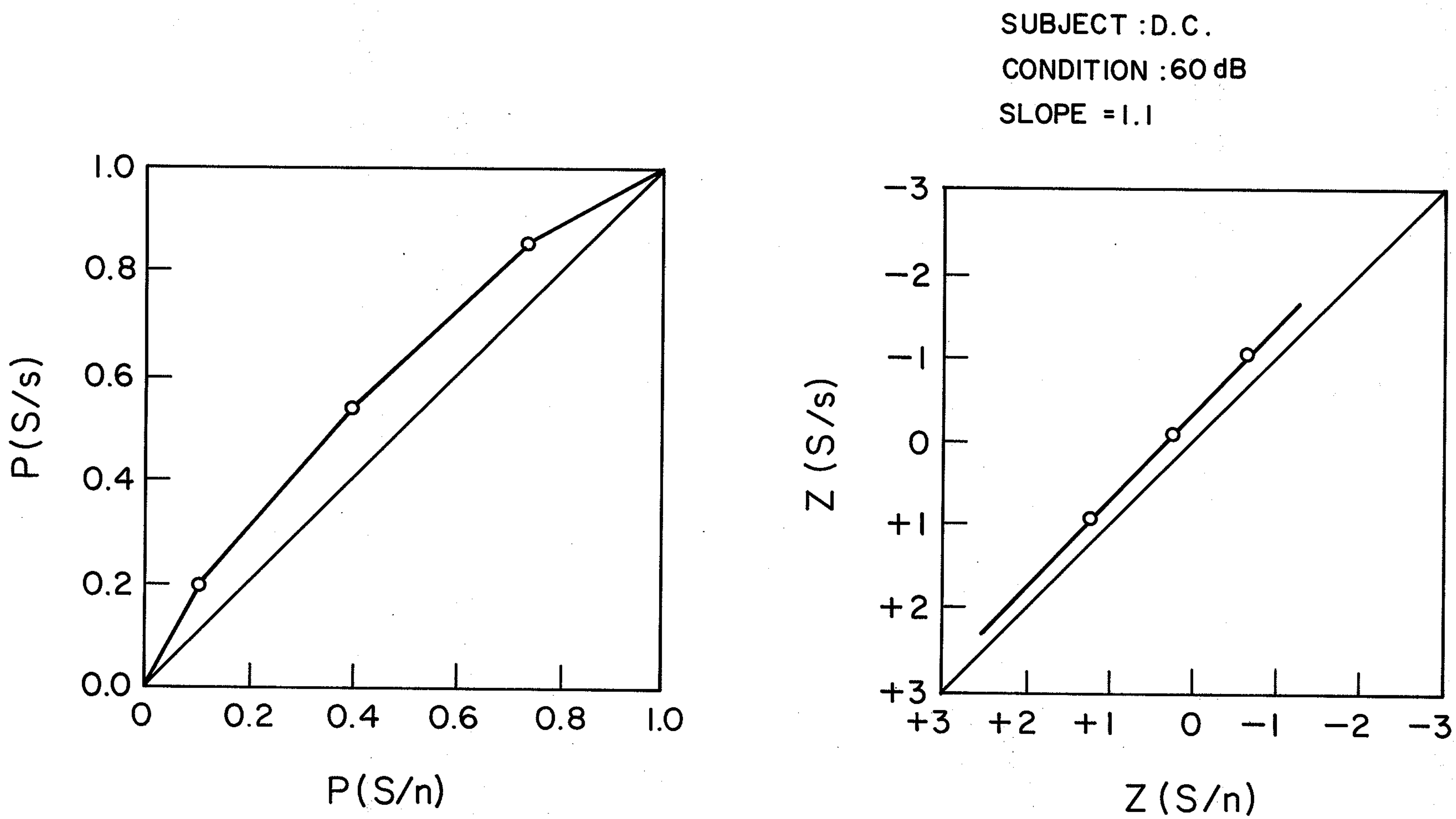

SUBJECT : D.C.
CONDITION : 60 dB
SLOPE = 1.1
P(S/s)
P(S/n)
Z (S/s)
Z (S/n)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3

Figure 9.4

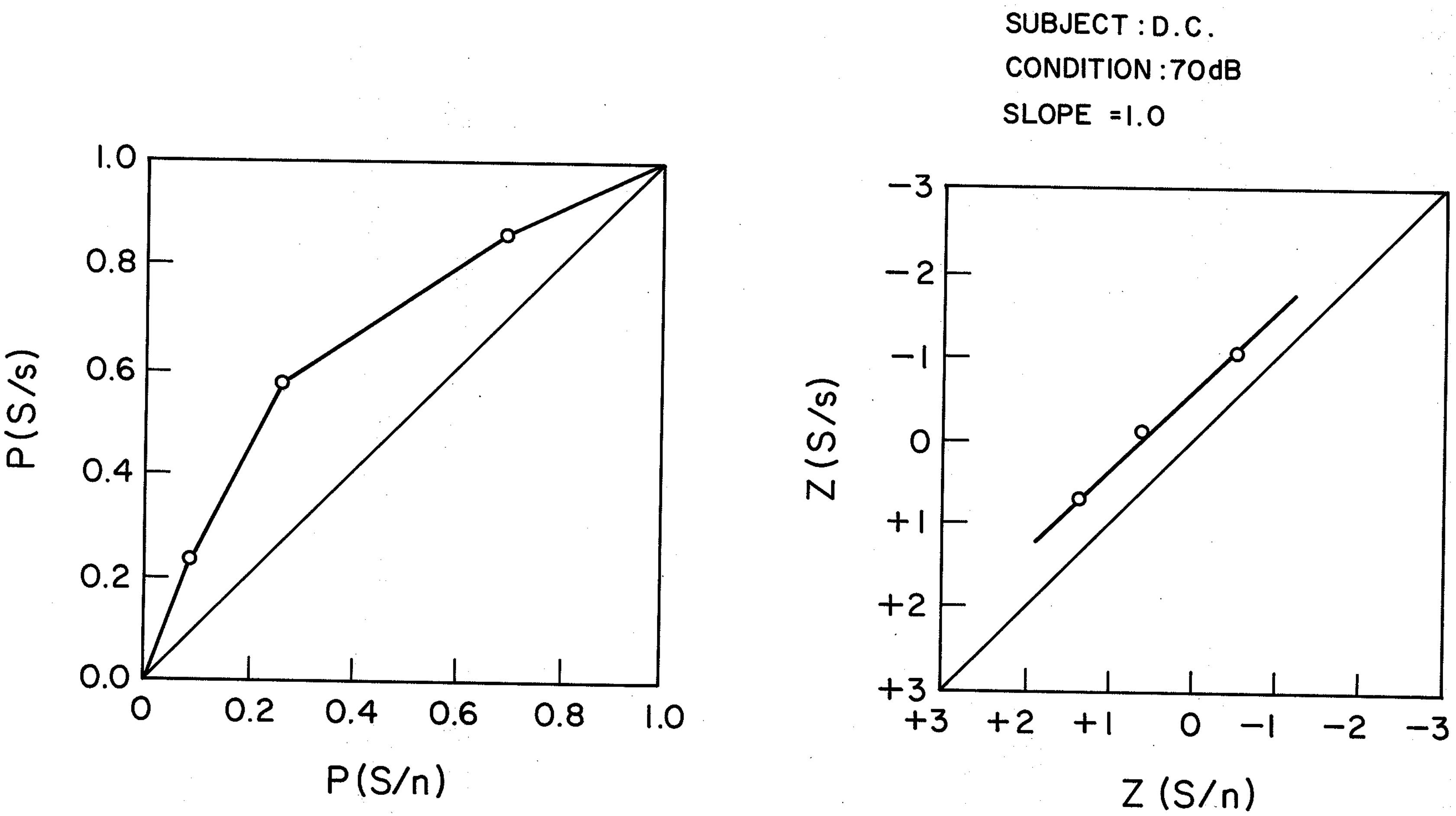

SUBJECT : D.C.
CONDITION : 70dB
SLOPE = 1.0
P(S/s)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
Z(S/s)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z (S/n)

Figure 9.5

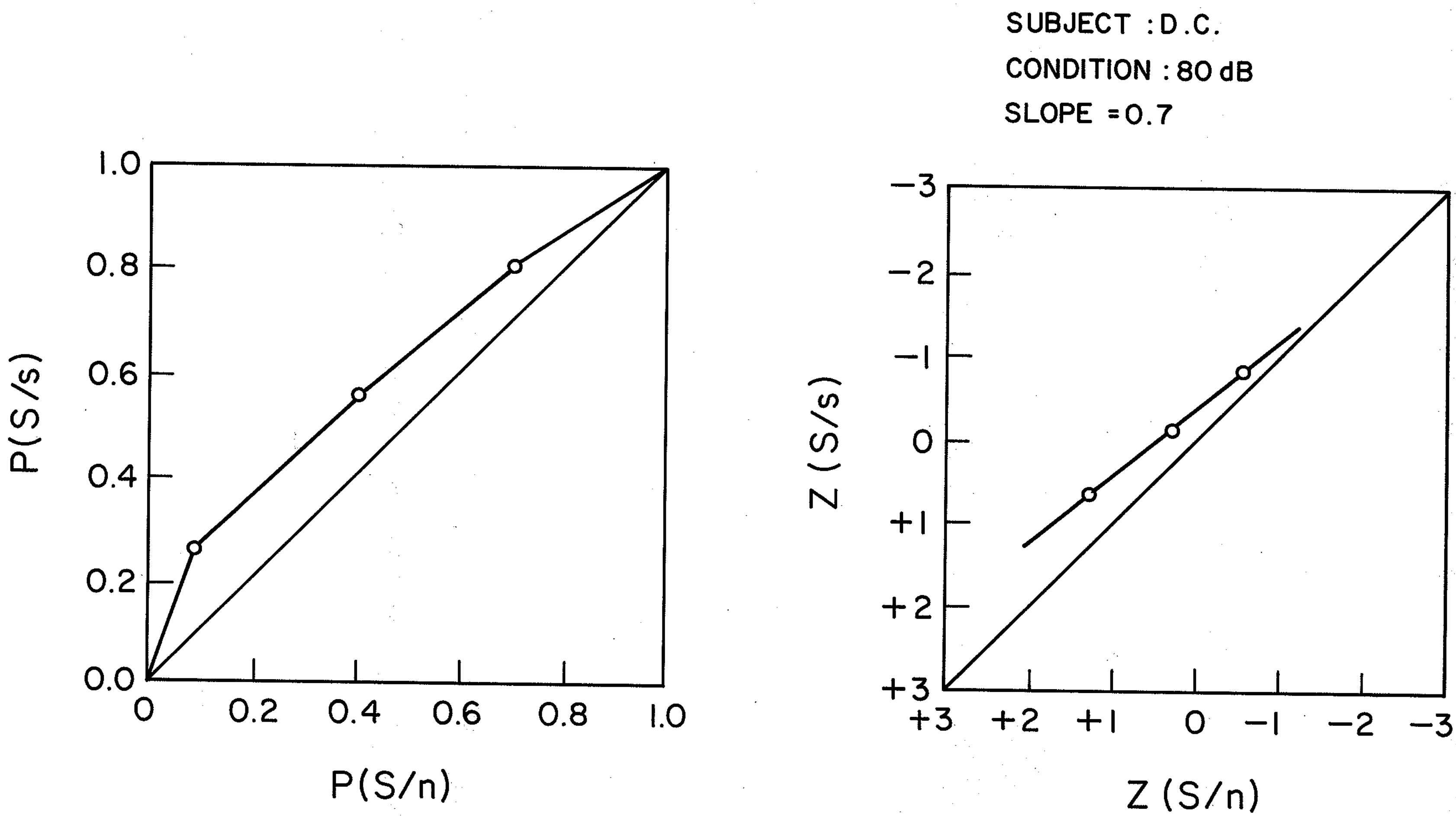

SUBJECT : D.C.
CONDITION : 80 dB
SLOPE = 0.7
P(S/s)
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/n)
Z (S/s)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z (S/n)

Figure 9.6

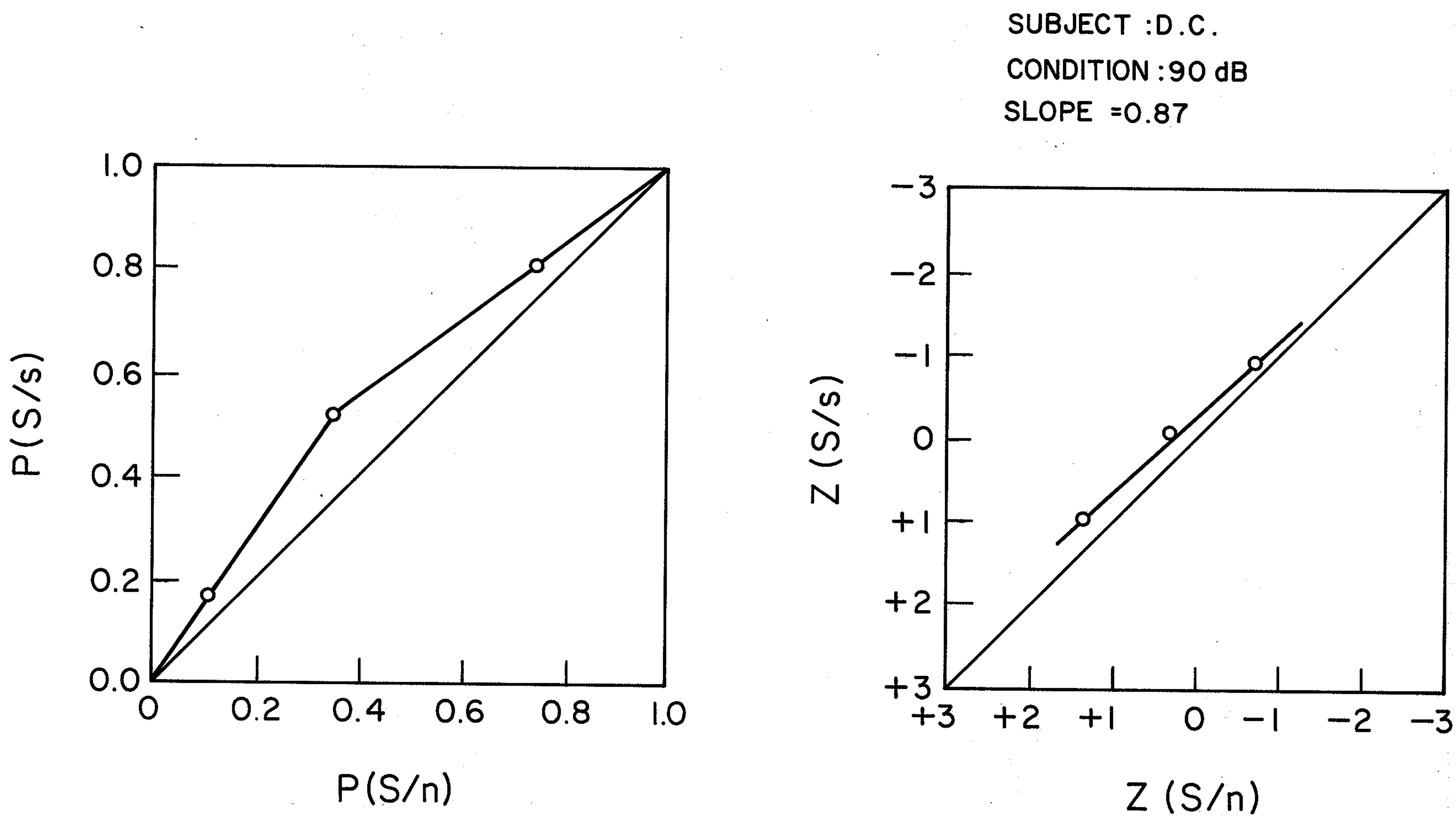

SUBJECT :D.C.
CONDITION :90 dB
SLOPE =0.87
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z (S/s)
Z (S/n)

Figure 9.7

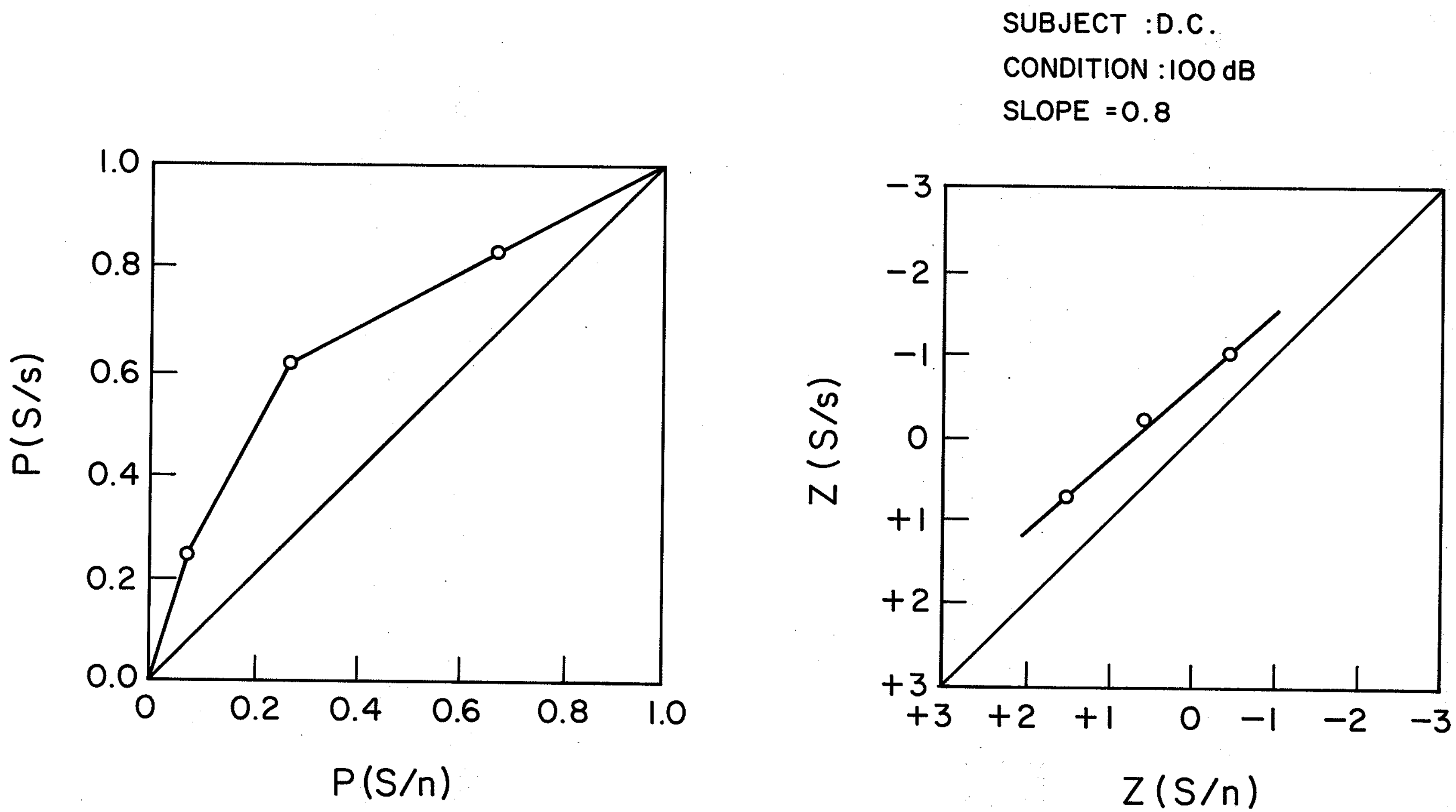

SUBJECT :D.C.
CONDITION :100 dB
SLOPE =0.8
P(S/s)
P(S/n)
0.0
0.2
0.4
0.6
0.8
1.0
0
0.2
0.4
0.6
0.8
1.0
Z(S/s)
Z(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3

Figure 9.8

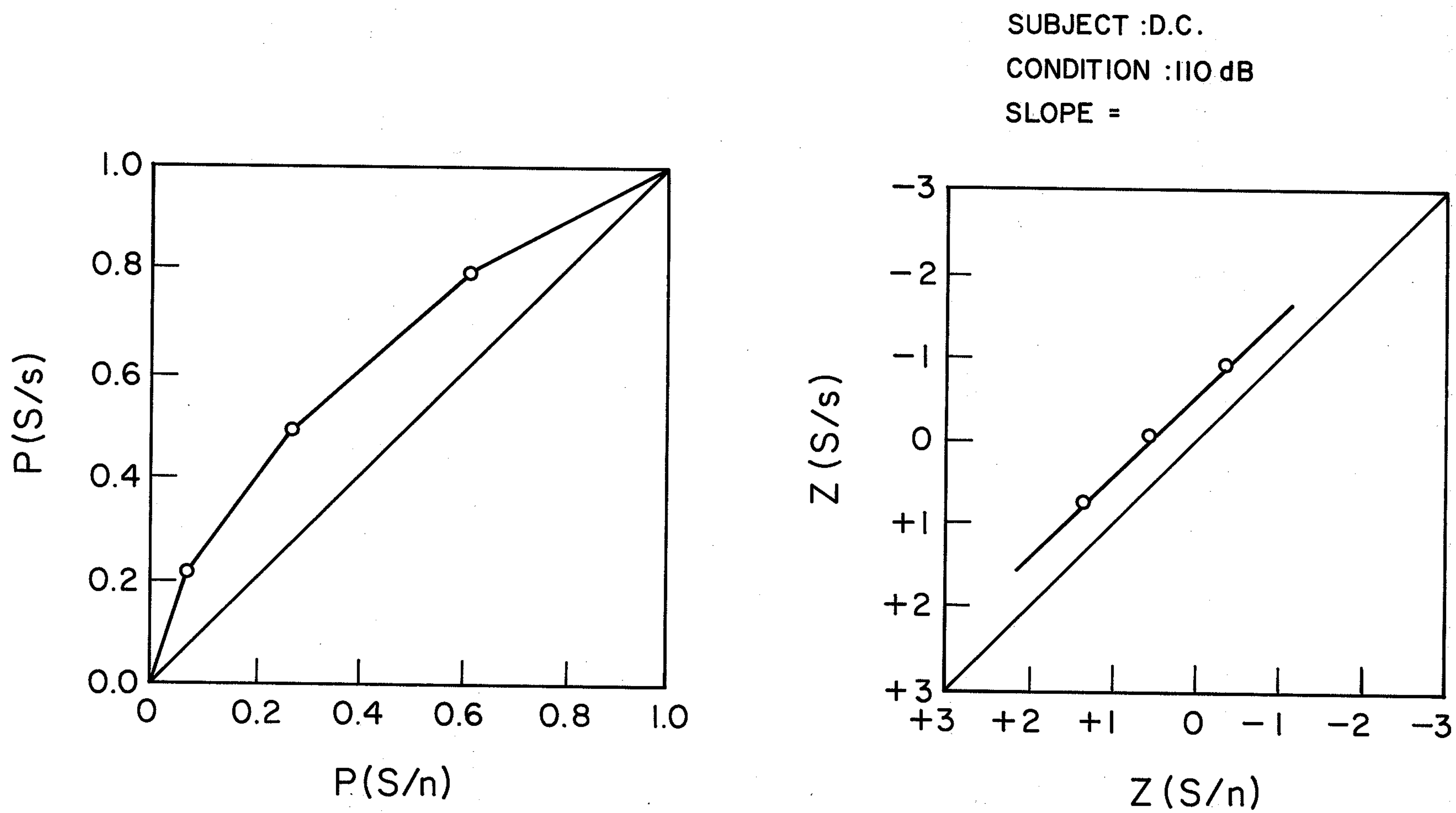

SUBJECT :D.C.
CONDITION :110 dB
SLOPE =
1.0
0.8
0.6
0.4
0.2
0.0
0
0.2
0.4
0.6
0.8
1.0
P(S/s)
P(S/n)
−3
−2
−1
0
+1
+2
+3
+3
+2
+1
0
−1
−2
−3
Z (S/s)
Z (S/n)

Figure 9.9