BOZARTH, Max D., 1927-

THE CRITICAL INTERVAL FOR JUDGMENT OF THE TEMPORAL ORDER OF AUDITORY AND TACTUAL SIGNAL EVENTS.

The University of Oklahoma, Ph.D., 1969
Psychology, experimental

University Microfilms, Inc., Ann Arbor, Michigan

THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

THE CRITICAL INTERVAL FOR JUDGMENT OF THE TEMPORAL ORDER OF AUDITORY AND TACTUAL SIGNAL EVENTS

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

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Oklahoma City, Oklahoma

1969

THE CRITICAL INTERVAL FOR JUDGMENT OF THE TEMPORAL ORDER OF AUDITORY AND TACTUAL SIGNAL EVENTS

APPROVED BY

DISSERTATION COMMITTEE

ACKNOWLEDGMENT

The author wishes to express his appreciation to the director of this study, Dr. Eugene O. Mencke, for his guidance and encouragement throughout the conduct of this dissertation.

Appreciation is expressed to Dr. Robert C. Duncan of the Department of Biostatistics and Epidemiology, University of Oklahoma Medical Center, for his services as statistical consultant.

Thanks are due to Dr. Howard B. Ruhm and Dr. S. Joseph Barry for their advice and assistance in the construction of the experimental apparatus.

The writer also wishes to express his gratitude to his wife, Marilyn, for her encouragement and understanding throughout this period of graduate study.

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CHAPTER I

INTRODUCTION

A full understanding of human auditory behavior requires that the system's response to changes in acoustic signal patterns be completely described and the resolving power of the ear specified. Stimulus pattern changes obviously occur over time. Time is the gridwork for stimulus patterns in auditory perception. That is, the referents for auditory perception are events whose cues for recognition depend on what it is that changes, by how much, and how fast in time. Not only is time a dimension of auditory perception, but, it also serves a background role for the ordering of events in the structure of language.

Time dependent phenomena are associated also with perception in other sense modalities such as vision and taction. There have been a number of psychological treatises on time (7, 10, 11, 14, 20, 35) all of which have contributed to an understanding of the temporal framework of human experience. More fundamental, however, is an understanding of the parameters of time which operate in the transmission of sensory data through the various modality pathways within the central nervous system. It is suggested that such information may prove helpful in further describing just how the various sensory systems mediate time data.

There are several aspects of temporal judgment to be considered. For one thing, the quality of a single event may be influenced by time, such as the difference in two sounds of varying rise-time. Then, too, there are judgments of simultaneity and successiveness which are associated with the phenomena of temporal fusion. These have proven useful for comparing the behavior of the auditory and visual system. Finally, there are judgments of serial order which require that a listener judge which of two successive signals occurred first.

The researcher investigating the processing of temporal events within the auditory system is faced with the problem of binaural fusion. Each ear is bilaterally represented at every level of the afferent pathway from the cochlear nucleus to the auditory cortex. If two auditory signals are identical in their parameters, the normal hearing subject will perceive the two signals as a single image localized at the midline. Consequently, other than studies of localization or time-intensity trading relationships, the study of time perception through the auditory sense modality has traditionally been divided among comparison of filled and unfilled intervals (2, 3, 7, 15, 34) ; the reproduction of intervals (7, 34) or the difference limen for duration (3, 6, 16, 28, 29, 32) .

The problem of binaural fusion in the study of time may be circumvented by pairing an auditory stimulus with a different sense modality stimulus and ask for judgments of temporal order. This method provides a means whereby the subject can label each event discreetly and report its order of occurrence.

This approach has not been extensively used in auditory research, although it certainly is not new. Exner (9) studied temporal order by heteromodal stimulation in 1875. At that time, he reported temporal intervals necessary for judgments of simultaneity and successiveness by unimodal and heteromodal stimulation. Exner's intervals were much larger than those reported in later studies. This difference was probably due to the limitations of Exner's instrumentation and procedures. He concluded from his studies that the critical interval for judgments of successiveness and for judgments of temporal order was the same. This same author stated that in heteromodal stimulation the interval depended on which modality was stimulated first.

More recently, Hirsh (17) studied successiveness and temporal order in the auditory system and found the temporal separation necessary for judgment of order to be ten-fold that necessary for the threshold of successiveness. Hirsh and Sherrick (19) investigated temporal order in the auditory, visual, and tactual modalities under conditions of both unimodal and heteromodal stimulation. Their results with unimodal stimulation agreed with the previous findings of Hirsh (17).

One of the purposes of Hirsh and Sherrick's (19) study was to further explore Exner's finding that the critical temporal interval for judgment of order in heteromodal stimulation was different than for unimodal stimulation. Piéron (24) and Fraisse (10) had also stated that judgments of simultaneity are easiest to obtain when stimuli are presented to the same sense modality. Hirsh and Sherrick's (19) data do not support the conclusions of any of these authors. They found that the critical interval for judgment of order was independent of the sense modality employed. They did not, however, study the effect of which modality was stimulated first.

Some disagreement is apparent among investigations studying the temporal resolving power within a sense modality as well as between paired sense modalities. Furthermore, when the auditory modality has been paired with other sense modalities it has not been determined if differences exist between the two ears or whether there are differences that may be attributed to ipsilateral or contralateral pairing of the ear with the member of the other modality being stimulated.

In 1963, Efron (8) presented some interesting findings in his work with the visual and tactual senses. He hypothesized that discrimination of temporal order takes place in the dominant hemisphere for speech. In man this is the left temporal lobe (23). By ipsilateral and contralateral pairing of the visual and tactual senses, Efron (8) has defined an "interhemispheric transmission time" for visual and tactual stimuli. It has not been determined if this same phenomenon is present in the auditory sense.

The present study was designed to define the temporal separation between a click to the ear and a shock to the finger necessary for normal subjects to judge their order of occurrence. Four conditions were studied in which both ipsilateral and contralateral pairing of the auditory and tactual senses was utilized. Two modes of presentation (click-interval-shock and shock-interval-click) were used in order to test Exner's finding that the critical interval for judgment of temporal order varied according to which modality was stimulated first.

In all, three questions were asked in this investigation: (1) What is the temporal interval separating a click to the ear and a shock to the finger necessary to judge their order of occurrence? (2) Is this interval different for ipsilateral and contralateral pairing of the two modalities? (3) Is there a difference according to which modality is stimulated first?

A review of the literature pertinent to this investigation is presented in the following chapter.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The present experiment was an investigation of heteromodal temporal order in which the effect of contralateral and ipsilateral pairing of the two modalities on the critical interval was studied. This chapter is devoted to a review of the pertinent literature concerning the theories of time perception, judgments of temporal experience through the various sense modalities, and their importance to understanding the human sensory mechanism.

Theories of Time Perception

Gilliland, Hofeld, and Eckstrand (14) have reviewed the earlier theories of time perception. Older theories were propogated around a special "time sense" which included an internal clock mechanism. Other theories that have been suggested have to do with: (1) the fading neural trace, (2) changes in the brain field, and (3) rhythm and body movement.

Central Nervous System Mechanisms

Many attempts have been made to explain the brain mechanism used to judge time. Fraisse (10) presents a review of these theories. One of the common explanations is the theory of the fading neural trace. James (20) stated that "each stimulus leaves some latent activity behind it which only gradually passes away". While the listener is responding to a present stimulus he still hears the echo of an earlier stimulus. Some conditions cause the neural trace to persist while under other conditions the trace fades rapidly. This causes a difference in time judgment. Frankenhaeuser (11) states that if two sounds are presented successively, the impression made by the second sound will be compared with the sinking or fading trace of the first stimulus. This results in the judgment that the second sound is longer. There are times when the second of two sounds is judged to be shorter than the first. Frankenhaeuser believes this kind of error is found when the interval between the two sounds is short. The brief interstimulus interval results in a temporary decrease of excitability in the sensory pathway.

Postman (27) believes that the physiological process of successive comparison is dependent on an electrical gradient in the brain field. According to his theory, the stimulation of a peripheral organ disturbs the equilibrium in the brain field and leaves a trace. A second stimulus can then be compared to the trace of the first.

More recently, Creelman (6) has offered an explanation of the neurological processes involved in time judgments. He suggested that perhaps "a counting mechanism, a simple accumulator, could store neural pulses in reverberatory circuits or, for that matter, store an electrical charge due to a chemical process".

The Internal Time Clock

In virtually all the literature concerning the perception of time there is mention of the internal time clock. Fraisse (10) reports on Mach's theory that time is a general sense which is distinct from the five special senses. Mach thought that the ear was the organ for the time sense. However, the estimation of time or the discrimination of temporal events is not limited to the auditory sense. These judgments are just as possible through the visual or tactual modalities. Gilliland (13) and Doerhing (7) both state that a review of the literature of time perception gives no indication of an internal clock mechanism or a special time sense.

Physiological Processes as a Basis of Time Estimation

Attempts have been made to correlate time estimation to body movements and physiological body processes. Wundt (36) felt that introspective sensations could come from the ears and from feelings of tension and relaxation. These would provide temporal signs through which time could be ordered. Gilliland (13) attempted to correlate time estimation with pulse rate, breathing rate, heart work, lung work and blood pressure changes. There were no significant correlations to any of these body functions. Gardner (12) found no relationship between basal metabolic rate and time estimations. From these studies, it appears that there is no support for a theory of time perception based on physiological functions.

Simultaneity, Successiveness and Order

If a human observer is required to make judgments concerning temporal events, the nature of his judgments must be classified. That is, he must judge two events to be simultaneous, successive, or to be ordered. Various experimenters have studied the perception of time and some confusion seems to exist in the classifications and conclusions reached by some authors. For example, Exner (9) states that there is no difference between successiveness and order while Hirsh (17) found a ten-fold difference in the interval necessary for these two judgments.

Fraisse (10) points out that it is common sense to say that two events are simultaneous when they occur at the same moment in time. However, the actual physical occurrence of two events may differ from the psychological perception of the temporal pattern. There are several reasons why this is true. Even if the peripheral receptors are stimulated at the same moment in time there may be a difference in the speed of transmission of a stimulus through the various sensory pathways to the cortical centers. Different neural systems have different latency periods. One modality may be a discrete system such as the visual modality, whereas another may be a diffuse system such as the auditory sense. It follows, therefore, that the judgment of simultaneity depends on the moment in time when the two events occur within the center or centers where temporal discrimination takes place rather than the true physical temporal relationship (10). Piéron (24) distinguishes between simultaneity and successiveness in the following manner:

> We receive an impression of simultaneity for two events perceived when these two events belong to the same mental present and are not able to be placed in order of time. The events may be very brief or may be lasting ones. Temporal acuity corresponds to the discriminative power in the time dimensions, just as spatial acuities represent discriminative powers in the dimensions of space. A certain minimum separation between two events is necessary in order that their succession may be perceived and their order of appearance determined. The reciprocal of this separation can be taken as a measure of temporal acuity.

Piéron (24) implies that successiveness and order are the same thing. Exner (9) would agree. However, evidence from the studies of Hirsh (17) shows the judgment of order to require a temporal separation between two events ten-fold that necessary to judge successiveness or the occurrence of two discrete events. Hirsh's subjects were able to identify two discrete clicks when they were separated by 2 msec, but a separation of 20 msec was required in order to judge which came first.

Bürck, Kotowski, and Lichte (5) showed the threshold of successiveness of pure tones to be on the order of 10 msec. They stated that:

> ...If the first tone sounds long enough for its pitch to become established in the ear of the listener before

> the second tone begins, the tones will appear successive. If the time between the tones is insufficient to establish the pitch of the first before the second tone arrives, the onset will appear simultaneous".

Stevens and Davis (31) point out that transient signals will require less separation for successiveness than pure tones of gradual onset.

Miller and Taylor (22) presented their subjects with a white noise and asked them to determine if the signal was continuous or interrupted. They found that subjects were able to discern interruptions in a white noise at a frequency of 1000 per second. In other words, they would perceive successive noise bursts with an interval of 1 msec of separation. This leads one to the conclusion that judgments of simultaneity and successiveness are dependent on the kind of stimulus used as well as the experimental method.

In order to investigate the ability of subjects to distinguish successive from simultaneous events, the researcher needs only to present a pair or a series of events and ask the subjects to report if there was one or two discrete events or one continuous event. To investigate temporal order, one must allow the observer a way of labeling each event separately and differently so that he can use these labels to report which occurred first.

The judgment of order is of particular relevance to the present study, therefore, the literature in this area will be presented in subsequent sections of this chapter.

The capacity for temporal discrimination is best summed up by presenting the three cases which can exist. This division of stimulus modes was purported by Piéron (25) .

1. "The two stimuli are identical and act on the organism at the same point. . . . "
2. "The two stimuli are identical but act on the

organism at two different points, or are similar but not identical. . . . "

3. "The two stimuli are very different (different sense modalities) ".

In the first case, the two stimuli cannot be identified as separate events but are perceived as one. Judgment of order cannot be obtained under this condition. This truly is a condition of simultaneity. In the second instance, the subject could determine the presence of one or two signals in which case a threshold of successiveness could be established. Finally, the third instance, which allows each signal to be labeled separately provides a means of obtaining judgments of order of occurrence.

Perceived Temporal Order with Unimodal Stimulation

The early work of Exner (9) represents some of the most extensive works regarding temporal discrimination. Although the instrumentation that Exner used was crude by modern standards, some of his findings have been substantiated and are in good agreement with results obtained in more recent investigations. Exner (9) set out to delineate successiveness from simultaneity but reported that there was no difference in the temporal separation of two events to enable subjects to judge order of occurrence as opposed to successiveness. He used brief flashes of light and set out to determine when they appeared to be non-simultaneous. His result varied according to the point of stimulation, but, he considered 44 msec to represent the temporal resolving power of the eye. In some cases, his subjects were able to detect apparent movement and would have judged the flashes of light to be non-simultaneous, but Exner (9) interpreted this as an artifact and tended to disregard this finding.

In his study of the auditory modality, Exner (9) used successive spokes of a Savart wheel to present clicks to the ear. He stimulated two ears in one condition and only one ear in the other condition. He found that a 2 msec separation between clicks presented to the same ear would give rise to a judgment of successiveness. This is exactly the same value reported by Hirsh (17) . When the two clicks were delivered separately, one to each ear, the minimum temporal separation for successiveness was as large as 64 msec. Perhaps the large interval observed in this condition was a result of differences in instrumentation and the experimental task.

Hirsh (17) is the only investigator who has completed exhaustive studies concerning temporal order in the auditory system. He presented a series of five studies in which he investigated the effects of pairing continuous sounds having a frequency difference, continuous sounds with a quality difference, and a transient signal (click) with a pure tone of various rise-time and duration.

In the first experiment, five pairs of tones were used. The frequency pairs used were 250-300, 250-1200, 250-4800, 1000-1200, and 1000-4800 Hz. The minimum frequency separations between the two tones was 50 Hz while the maximum frequency difference was 4550 Hz. The tones had a duration of 0.5 sec and recurred once every 1.8 sec. Both tones had a rise-time of 20 msec. The temporal interval separating the onset of the two tones was varied between -60 and +60 msec in 20 msec steps. Both tones were terminated simultaneously. Judgments were based on a two-alternative forced-choice technique in which the subjects task was to write down "lower" or "higher" depending on which frequency they thought came first. The two stimuli were presented monaurally.

In experiment II, Hirsh (17) used two continuous sounds of different quality. One was a pure tone while the other was a wide-band noise. Three tonal frequencies were employed: 250, 1000, and 4000 Hz. The tones were set at a loudness level of 80 phons and the noise voltage level was adjusted so that the noise would be equally loud. The voltage values were obtained from the results of a study by Pollack (26) . The procedure and the subjects task were the same as in the first experiment.

The first two experiments allowed the study of differences in judgments of order due to alterations in frequency or spectrum. The third experiment was a study of differences due to duration. In this experiment, Hirsh (17) paired a click with a noise. Three different rise-times for the noise were used: 15, 7, and 2 msec. For one-half of the experiment the noise was passed through a high-frequency octave-band filter (2400-4800 Hz) while in the other half the noise was passed through a low-frequency octave-band filter (300-600 Hz) . The level of the noise was 70-dB sound pressure level while that of the click was set so that the first half-wave of the click was equal in peak amplitude to a pure tone whose RMS sound pressure level was 96 dB. The intervals were adjusted in 20 msec steps and the listeners' task was the same as in the first two experiments.

Experiment number four paired a click and a 1000-Hz pure tone. Three parameters of the tone were varied: rise-time, duration, and intensity. The rise-times were 7 and 15 msec, the durations were 20, 50, and 100 msec, and the levels were 50 and 90 dB. The level of the click was constant at a peak equivalent of 80 dB RMS sound pressure level. Again, the procedure and subject task was the same as in the previous experiments.

Hirsh's final experiment paired two clicks. Pulses from a pair of pulse generators were passed through filters to yield a difference in pitch. One pulse was fed through a 1000 Hz low-pass filter and the other through a 4000 Hz band-pass filter. The two clicks were set at a peak equivalent of 80-dB RMS sound pressure level. Temporal intervals between the two clicks were 50, 30, and 10 msec. The listeners judged whether the "higher" or "lower" tone occurred first. Table 1 shows a summary of the combinations of sounds used in the five experiments.

TABLE 1

COMBINATIONS OF SOUNDS USED IN HIRSH'S EXPERIMENTS

Experiment	Sounds	Band Width	Duration	Different with respect to:
I	Tones, Noise Bands	Both Narrow	Both Long	Frequency
II	Tones vs. Noise	One Narrow One Wide	Both Long	Quality
III	Click vs. Noise	Both Wide	One Short One Long	Duration
IV	Click vs. Tone	One Wide and Short - One Narrow and Long		Duration Quality
V	Hi Click vs. Lo Click	Both Narrow	Both Short	Frequency

The results of Hirsh's experiments showed that whereas a temporal interval of about 2 msec between two brief sounds will enable the listener to distinguish two sounds instead of one, an interval approximately ten times as large is required for the listener to judge which one occurred first.

The minimum time required for a correct judgment of temporal order was found to be independent of differences in frequency or quality between the two sounds. Combinations of clicks with noise or clicks with tones having a fast rise-time yielded somewhat smaller intervals, but the differences among conditions were small and considered to be unimportant relative to the general agreement among all experimental conditions. Hirsh concluded that:

> ..."Because the judgment of temporal order requires temporal separations as much as 20 msec, more of the perceptual systems is involved than merely the ear itself. Therefore, the judgment of temporal order will not be closely related to the factors that have shown to be important for the peripheral auditory system".

Hirsh's original work was extended by Hirsh and Sherrick (19) in 1961. They defined the temporal separation necessary for judgment of order in the visual, auditory, and tactual systems.

For the visual experiment, flashes of light of 5 msec duration were spaced 18 cm apart in either a vertical or a horizontal arrangement. The light flashes were generated by pulses from two pulse generators driven by a single wave-form generator so that the interval between the flashes could be controlled by the delay adjustment of the pulse generators. The intervals ranged from -60 to +60 msec and were adjusted in 20 msec steps. There were twenty presentations at each interval and four trained subjects judged which came first.

Three conditions were employed in the auditory experiment. Pulses were passed through resonant circuits so that one signal sounded like a high-pitched "bing" and the other like a low-pitched "bong". The three different conditions of stimulation were (a) Monotic Hi-Lo, (b) Dichotic Hi-Lo, and (c) Dichotic Hi-Hi. Five adults, different from those of the visual experiment, served as subjects. The subjects reported high first or low first except in the third condition in which they reported right first or left first. The intervals ranged from -30 to +30 msecs and were adjusted in 10 msec steps.

The same apparatus and procedure as that of the previous experiments were used in the experiment involving the tactual sense, except that the pulse generators supplied a pulse to a power amplifier whose output was fed to two tactual vibrators. The vibrators were attached to the index fingers of the right and left hand. The subject reported which hand was stimulated first. Temporal intervals were varied in 10 msec steps from a 30 msec lead on the left side to a 30 msec lead on the right.

Figure 1 summarizes the results of Hirsh and Sherrick's (19) data for the three sense modalities. For the auditory modality, the dichotic presentation utilizing identical sounds is plotted because this condition is most analogous to the condition used in the visual and tactual experiments.

The data from Hirsh and Sherrick's (19) studies show that the amount of time that must separate two events in order for an observer to determine their correct order (75 per cent of the time) is approximately 20 msec. This interval was not found to be different among the three sense modalities studied: visual, auditory, and tactual.

The results obtained in the investigations of Hirsh (17) and Hirsh and Sherrick (19) are almost identical. The values reported by Exner (9) are a great deal larger than those of the two later studies. These differences are attributed to more precise instrumentation in the later studies and to differences in procedure. Exner (9) required a judgment of correct order 10 successive times to establish the interval for perceived order. Such a stringent requirement would be about the 98 per cent point on the psychophysical functions shown by Hirsh and Sherrick (19) .

Temporal Order With Heteromodal Stimulation

In studies reported in 1875, Exner (9) conducted one investigation where he paired modalities. Using the auditory and visual modalities, he found intervals comparable to those for the visual sense and similar to those obtained when the two ears were stimulated (40-60 msec) . Exner (9) reported that the temporal separation between two signals

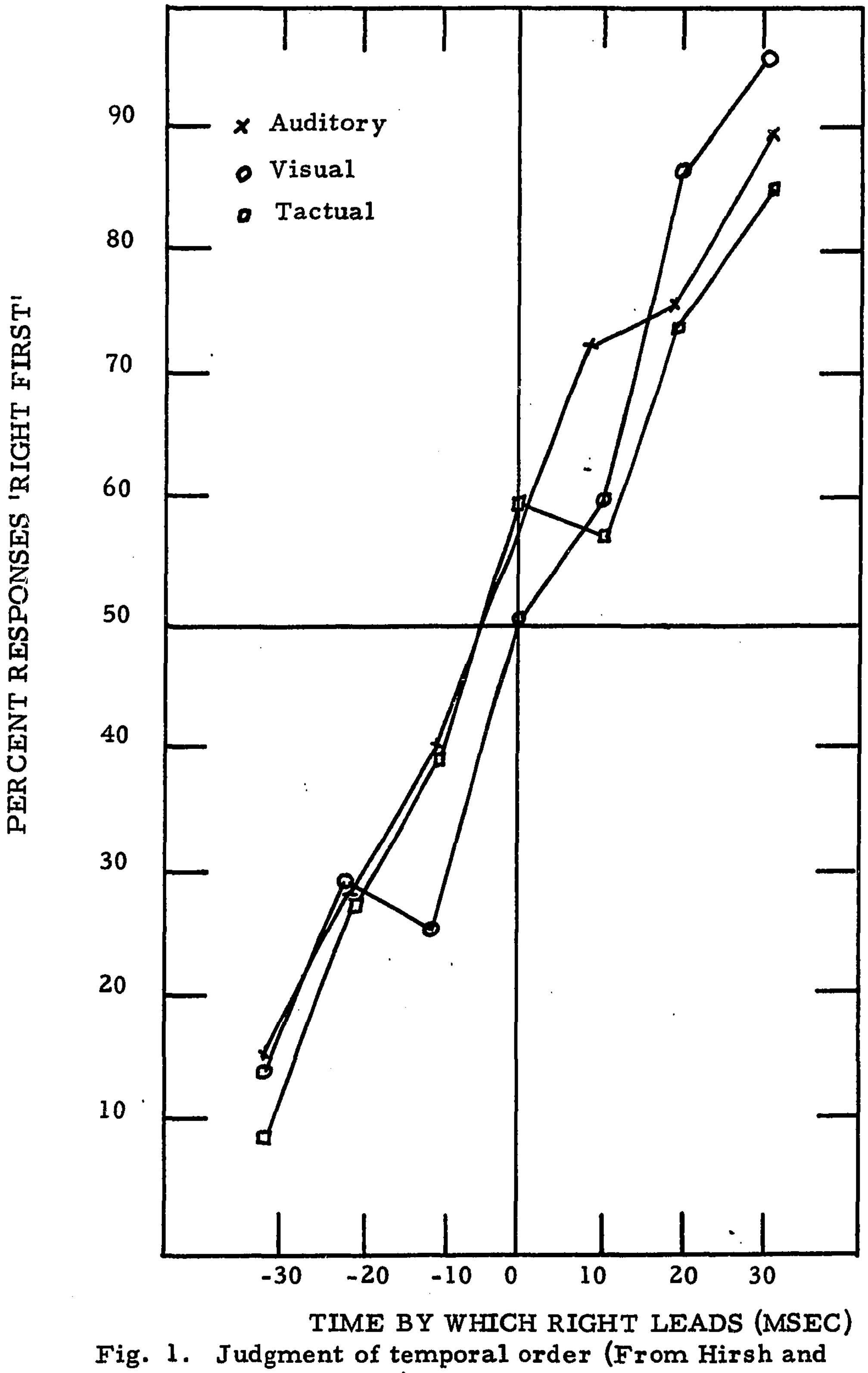

Fig. 1. Judgment of temporal order (From Hirsh and Sherrick 1961)

necessary to make a judgment of correct order was not constant when the stimuli were presented to separate modalities. The interval was dependent on which modality was stimulated first. When the auditory sense was stimulated first the interval was 16 msec, a value comparable to that found in later studies. When the order was reversed, visual sense stimulated first, the interval was 60 msec. This discrepency prompted the research of Bald, et al. (1) who studied errors associated with judgment of temporal order of auditory and visual stimuli. They concluded that the difference was due to the attention attracted by the stimulus. According to these authors, light attracts more attention than sound. Therefore, it may be that the subjects in Exner's (9) study experienced some difficulty in shifting their attention from the visual to the auditory stimulus.

This same phenomenon is not evident, however, in the studies of Hirsh and Sherrick (19). After these authors had conducted their experiments with unimodal stimulation, they did a study in which the auditory sense and the visual sense were paired, the tactual sense was paired with the auditory, and the visual modality was paired with the tactual modality. The procedures and instrumentation for this experiment were the same as reported in the previous section. Again, the temporal separation necessary for the correct judgment of order (75 per cent of the time) was on the order of 20 msec. Hirsh and Sherrick (19) hypothesized that since the interval remained relatively constant for all modalities independently, as well as with paired modalities, that the center within the central nervous system where temporal judgment takes place must be shared by all modalities.

The series of experiments by Efron (8) is of particular interest to the present investigation. This author conducted a series of experiments in which he paired the visual and tactual modalities to establish what he termed the "inter hemispheric transmission time" for visual and tactual stimuli. Efron (8) states that his data strongly suggest that:

> ...The temporal discrimination of simultaneity and order are performed in the hemisphere which is dominant for speech, sensory data by the non-dominant hemisphere must be transferred across some pathway (Corpus Collosum) to the dominant side, and the delays in this transmission, while detectable by the classical methods of psychophysics, are (like all other transmission delays) not of sufficient magnitude to require any correction.

To test this hypothesis, Efron (8) used shocks delivered to the right and left index finger and light flashes delivered to the left and right nasal retina. In the first experiment, the stimulus was delivered to one side 100 msec before the other. The interval was reduced in 5 msec steps until the subject responded with a judgment of simultaneity. Then the procedure was reversed. If the stimulus had initially been delivered to the left side first, the procedure was repeated with the stimulus presented to the right side first. The order of presentation was randomized across subjects to avoid any possible order effects. All subjects were practiced and rewarded if their performance stayed within a certain range of variability. Subjects for this experiment were divided into two groups. The subjects in one group were all right handed while the subjects in the second group were all left handed.

The results of this experiment showed that the right handed subjects judged the stimuli to be simultaneous when the left stimulus preceded the right by 3.81 msec for the light stimulus and 3.32 msec for the shock. Efron (8) felt that these results confirmed his prediction that the stimulus which was delivered to the left side would be received first in the right or nondominant hemisphere whereupon it would be transferred by way of interhemispheric connections to the dominant hemisphere. The 3 to 4 msec lead required of the left stimulus would according to Efron (8) represent the transmission time through the interhemispheric pathway.

The left-handed subjects judged the stimuli to be simultaneous when the presentations to the two sides were essentially simultaneous. This was explained by the fact that few left-handed persons are true sinistrals and any effect to be noticed in these subjects was cancelled out. In other words, some of the group would have speech dominence in the right hemisphere and others in the left hemisphere. When treated as a group, any deviations would be cancelled as in random selection.

In a subsequent experiment, Efron (8) delivered light flashes to another group of right-handed and left-handed subjects. Their task was to judge which came first, the right flash or the left flash, or whether there was simultaneous presentation. The right-handed subjects judged the presentations to be simultaneous when the left flash preceded the right by 4 msec. Conversely, the left-handed subjects judged simultaneity when the right flash preceded the left by 3 msec. Even though the task was different in these two experiments, the results of both experiments support the hypothesis.

Since the hypothesis had been supported by the data obtained using both visual and shock stimuli, Efron (8) felt that on the basis of this theory he could make predictions as to the results of cross-modality judgments. He designed a series of experiments using one subject who had been consistent in his judgments in previous experiments. This subject was right-handed. The experimental arrangement was to have the subject judge simultaneity of light and shock under various experimental conditions. Two control experiments (A and B) consisted of presenting shocks to the right and left index fingers (Experiment A) and light flashes to the right and left visual fields (Experiment B) . These results showed deviations of 2.50 and 9.75 msecs for shocks and lights respectively. Light was then delivered to the right visual field and shock to the right index finger

(Experiment C) . In this situation, the subject perceived the stimuli as simultaneous when the light preceded the shock by 11.25 msec. With this information, predictions could be made for Experiments D, E, and F. Efron (8) reasoned that:

> ..."If two stimuli are delivered to the nondominent hemisphere and are transferred to the dominent one the light will be delayed by 9.75 msec and the shock by 2.50 msec. The difference in the delays across the brain will be 7.25 msec, the light being delayed by this amount more than the shock. But we know that the light was delayed by 11.25 msec in its transmission even under the conditions of delivering both stimuli to the left hemisphere. By delivering both stimuli to the right hemisphere, an additional "relative" delay of 7.25 msec will be introduced in the light pathways bringing the total delay (light before shock) to a predicted value of 18.50 msec.

The results of the experimental conditions showed an observed delay of 17.25 msec which was well within the expected error. In Experiment E, a shock was delivered to the left finger and a light flash to the right visual field. It was already known that the subject required 11.25 msec difference between light and shock to judge them simultaneous. Since the shock was delivered to the right hemisphere with the delay in transfer of 2.50 msec, one would predict a delay of 13.75 msec for the simultaneous judgment (2.50 msec of the 13.75 msec was attributed to time required for stimulus transfer from right to left hemisphere) . The observed delay was 13.25 msec.

In the last of this series of experiments, a shock was delivered to the right index finger and a light flash to left visual field. Here the light would be delayed 9.75 msec due to transmission from the right to the left hemisphere. The 9.75 msec added to the 11.25 msec required to judge the stimuli as simultaneous when both were presented to the left hemisphere would result in a prediction of 21.00 msec delay for the simultaneous judgment. The observed result was 18.00

TABLE 2

CROSS-MODALITY JUDGMENT OF SIMULTANEITY BY EFRON

	Exp. A	Exp. B	Exp. C	Exp. D	Exp. E	Exp. F
	LS-RS	LVF-RVF	RVF-RS	LVF-LS	LS-RVF	RS-LVF
Mean	+2.50	+9.75	11.25	17.25	13.25	18.00
Standard Deviation	$\pm$2.36	$\pm$4.49	$\pm$3.95 (light first)	$\pm$3.22 (light first)	$\pm$4.16 (light first)	$\pm$3.69 (light first)
Predicted Means				18.50 (light first)	13.75 (light first)	21.00 (light first)

LS=Left Index Finger Shock; RS=Right Index Finger Shock; RVF=Right Visual Field Flash; LVF=Left Visual Field Flash.

msec. The results of this series of experiments are summarized in Table 2.

Efron (8) concluded that since there were no significant differences between the predicted result and the observed result for the conditions tested that his hypothesis was supported. Furthermore, he could state that the interhemispheric transmission time for a tactual stimulus was 2.50 msec and for the visual stimulus 9.75 msec.

It was Efron's work that led this author to ask the second question in the present study. "Will the minimum temporal interval separating a click to the ear and a shock to the finger necessary to allow an observer to judge their order of occurrence be different for contralateral pairing of the modalities than when the two modalities are paired ipsilaterally?" If these conditions were to yield different results than new information concerning auditory function would be obtained.

Summary

It is apparent that the literature dealing with judgments of temporal order is meager. There is a wide divergence of results among the few studies that have been reported using unimodal as well as heteromodal stimulation. This variation is probably due to differences in experimental apparatus and procedural variables. Only one of the studies employing heteromodal stimulation was concerned with an investigation of the effects of ipsilateral and contralateral pairing of the two modalities. This study utilized the visual and tactual senses (8).

The literature reveals that this effect has not been studied when the auditory sense is paired with another modality. Furthermore, when the auditory sense has been paired with the tactual modality ipsilaterally the only transducer for the tactual stimulus has been a vibrator. In this study, electrodes were secured to the subjects' fingers. It is not known if delivering the tactual stimulus with electrodes placed on the fingers would result in a different judgment of order between the auditory and tactual stimuli

The present study was designed to specify the temporal separation between a click to the ear and a shock to the finger necessary for normal subjects to judge their order of occurrence. Four conditions in which the two modalities were paired ipsilaterally and contralaterally were tested. The experiment was programmed electronically and a two-alternative, forced-choice procedure was used throughout. Three features inherent in the procedure, sequential analysis (33), practiced subjects, and immediate knowledge of results were used to minimize variances within and among subjects as well as to drive each subject to maximum performance. A description of the experimental conditions, as well as the apparatus and procedure are outlined in the following chapter.

CHAPTER III

PROCEDURE AND INSTRUMENTATION

INTRODUCTION

This experiment was designed to determine the critical temporal interval by which a click to the ear and a shock to the finger must be separated to allow normal subjects to correctly judge their order of occurrence. This critical interval was established under four experimental conditions.

The instrumentation utilized in this study consisted of two signal channels and a timing apparatus. The acoustic click was produced by means of a pulse generated from a Tektronix type 161 pulse generator which rang a TDH-39 earphone. Another pulse generated by a Tektronix type 161 pulse generator was fed through a transformer, a variable resistor, and on to the electrodes to produce the shock signal. The electrodes were placed on the palmar surface of the subject's third finger of one or the other hand. The signal sequence and the timing of the inter-stimulus interval was controlled by a Grason-Stadler 1200 modular series. A warning signal preceded the stimulus pattern. It consisted of a noise-burst of 50 msec duration which was fed to a companion of the test earphone.

The critical interval for determining correct temporal order was established under four conditions in which the auditory and tactual stimuli were paired both ipsilaterally and contralaterally. The subjects were extensively practiced in the experimental task before the data was collected. A table of sequential analysis (Appendix B) dictated pass/fail criteria.

A detailed description of the subjects, experimental apparatus, and procedure is presented in the following sections.

Subjects

Four normal-hearing right-handed females served as subjects for this experiment. Their ages ranged from 20 to 30 years. None of the subjects had any known history of ear pathology or neurological problems. Each subject's hearing sensitivity was assessed audiometrically before acceptance as an experimental subject. Hearing thresholds of 15-dB hearing level (ISO-1964) or better at octave frequencies from 125 through 8000 Hz defined normal hearing. In addition, the fingers of the subjects were examined for scars, excessive calluses, or any condition which might have interfered with the presentation of the shock stimuli.

Each subject was expected to report to each experimental session in a rested condition. This was necessary in order to insure mental and physical alertness for maximum performance in the experimental task. If for any reason the subject reported that he was not physically or mentally alert, the experimental session for that subject was postponed and an appointment made for another session. The order of presentation of the experimental conditions was balanced across subjects.

Apparatus

All practice and experimental tests were conducted in a sound-treated two-room suite located in the Speech and Hearing Center, University of Oklahoma Medical Center. The physical arrangement of the test suite allowed visual communication between the investigator and the subject.

Screening Apparatus

A commercially available pure tone audiometer (Beltone 15-CX) feeding either of two earphones (TDH-39-10Z) was used in the preliminary audiometric procedures administered to all subjects. The earphones were set in MX-41/AR cushions and mounted in a standard headband.

The acoustic output of the air-conduction system of this audiometer was calibrated by means of an audiometric calibration unit (Western Electric Condenser Microphone Complim[illegible]100/DE, used in conjunction with a Ballantine Vacu[illegible]model 300).

Experimen[illegible]

A simplified block diagra[illegible]g apparatus is shown in Figure 2 and the d[illegible]ins are shown in Figure 3.

The acoustic signal (a 0.[illegible] by a Tektronix type 161 pulse generat[illegible]pulse generator passed through an attenuator (He[illegible]del 350 AR) and produced an acoustic click in the test earphone.

The shock signal consisted of a pulse generated by a Tektronix type 161 pulse generator which was fed through an interstage transformer (Stancor, TA-32), a variable resistor, and on to the electrodes which were secured to the palmar surface of the subject's third finger. Stimulus sequence was controlled by appropriately programming the Grason Stadler 1200 modular series. The programming apparatus included four AND Gates (module 1213) which were activated by a Flip-Flop (module 1214) in conjunction with a 100-sec Timer (module 1216-A).

The acoustic signal was transduced and delivered to the subject's test ear by way of the test earphone (TDH-39-10Z). The shock was delivered to the palmar surface of the third finger of the subject's hand

Key to Flow Diagram

1285	Noise Generator
1211	Input Converter
1212	Or Gate
1214	Composite
1207	Power Supply
1222	Output Control
1223	Ten-Second Timer
1216-A	100-Second Timer
1215	Comulative Counter
1219	Sequence Counter
1209	Subject Control Panel
	Line Connections
	Signal Inverter

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The acoustic output of the air-conduction system of this audiometer was calibrated by means of an audiometric calibration unit (Western Electric Condenser Microphone Compliment, type 100/DE, used in conjunction with a Ballantine Vacuum-Tube Voltmeter, model 300) .

Experimental Test Apparatus

A simplified block diagram of the timing and recording apparatus is shown in Figure 2 and the diagrams for the two signal trains are shown in Figure 3.

The acoustic signal (a 0.1 msec pulse) was generated by a Tektronix type 161 pulse generator. The pulse from the pulse generator passed through an attenuator (Hewlett Packard, model 350 AR) and produced an acoustic click in the test earphone.

The shock signal consisted of a pulse generated by a Tektronix type 161 pulse generator which was fed through an interstage transformer (Stancor, TA-32) , a variable resistor, and on to the electrodes which were secured to the palmar surface of the subject's third finger. Stimulus sequence was controlled by appropriately programming the Grason Stadler 1200 modular series. The programming apparatus included four AND Gates (module 1213) which were activated by a Flip-Flop (module 1214) in conjunction with a 100-sec Timer (module 1216-A) .

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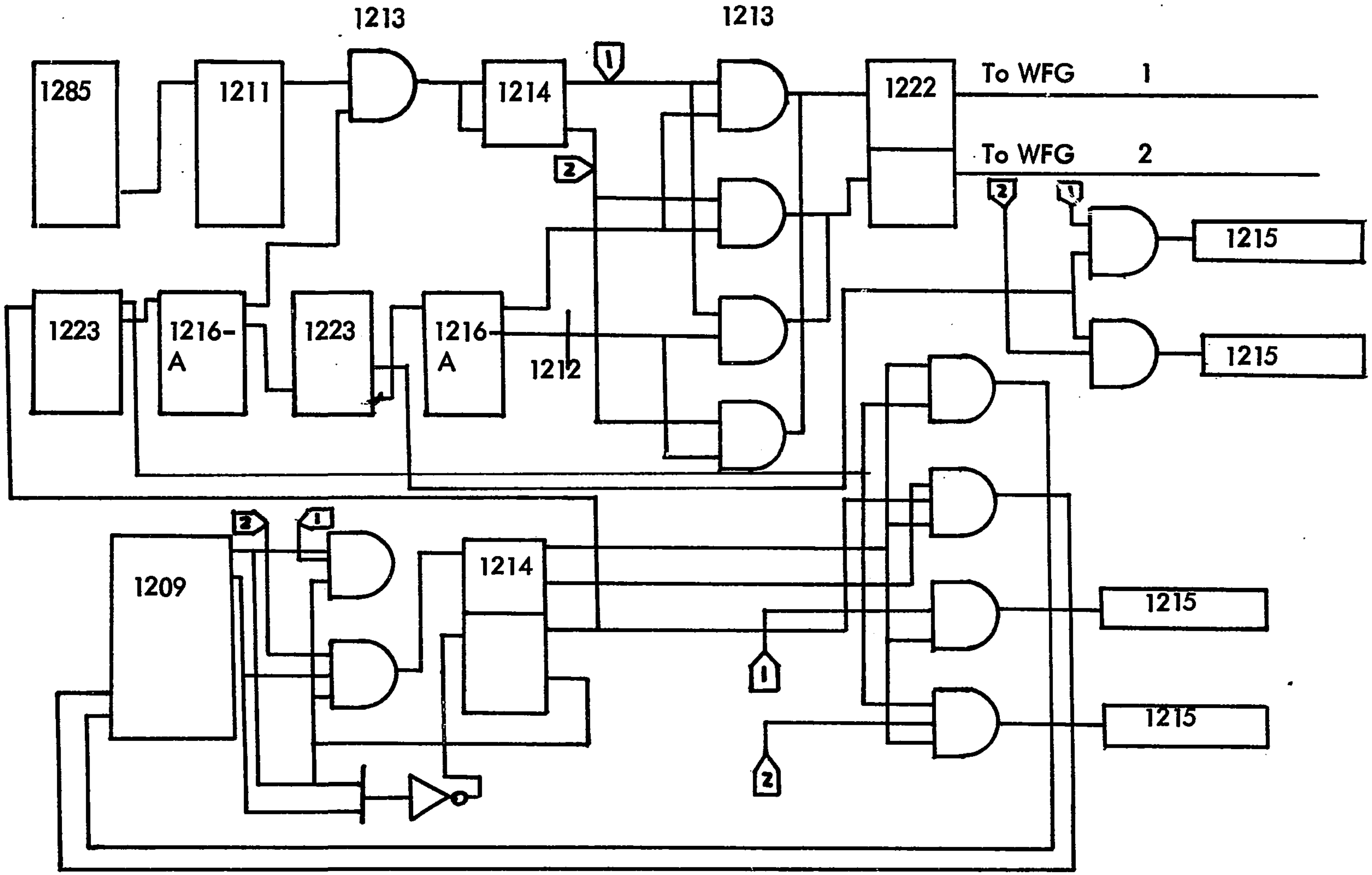

Fig. 2 - Flow Diagram of timing and recording Apparatus

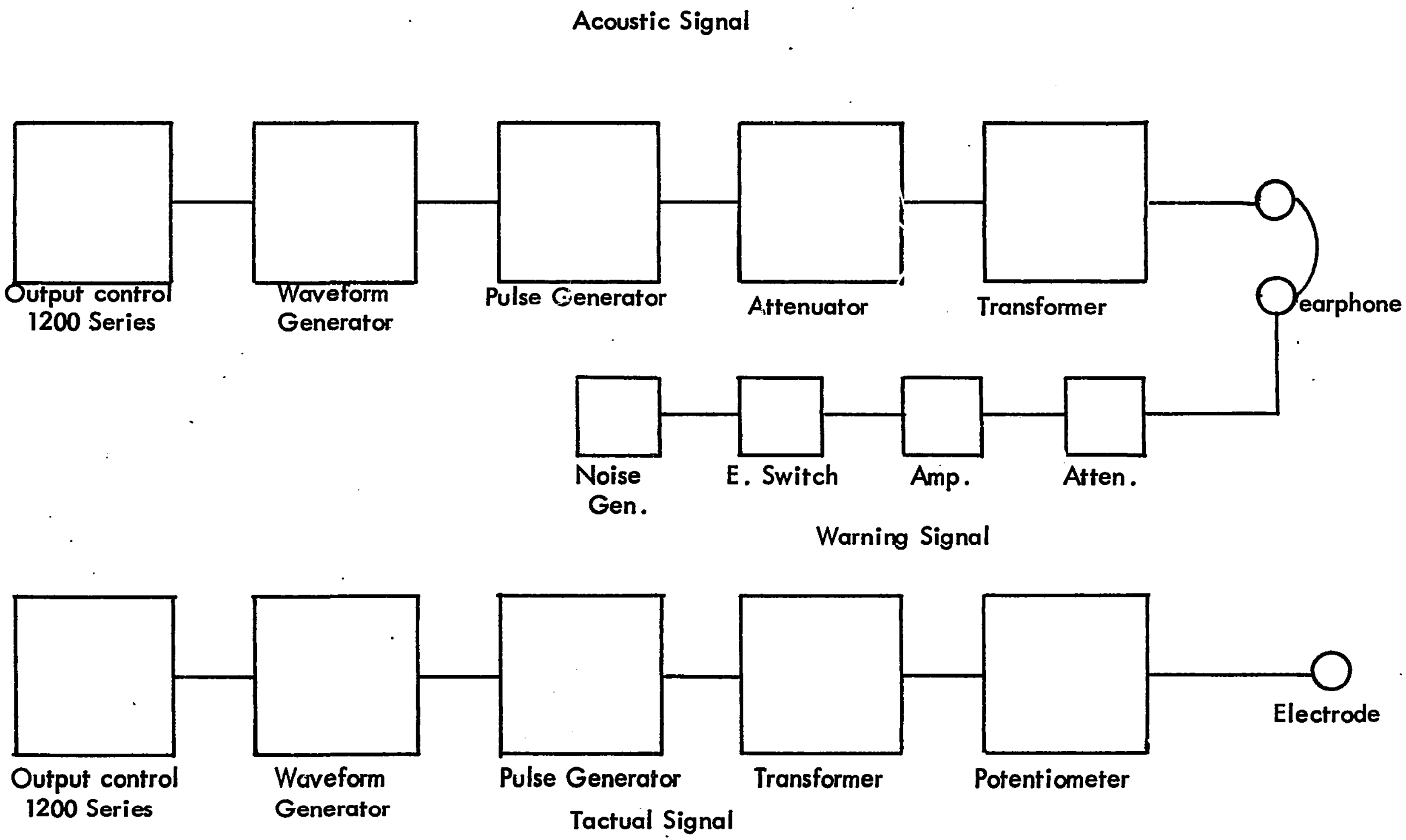

Fig. 3 - Flow Diagram of stimulus train for acoustic and tactual signals

through gold plated electrodes. A burst of random noise used as an alerting signal was fed to the non-test ear by way of a companion earphone. Both phones were set in MX-41/AR cushions and held by a standard headband.

The click or the shock was delivered either first or second at random. Random presentation of the test signals was achieved by the use of a Flip-Flop (module 1214) which activated one of four AND Gates (module 1213). If the Flip-Flop was in the set mode, an AND Gate was fired which caused the click to be presented first. If the Flip-Flop was in the Reset mode, an AND Gate was fired which caused the shock to be presented first. The Flip-Flop module was in either the Set or Reset mode with equal probability.

A program sequence (click-interval-shock or vice versa) automatically occurred when the apparatus was manually triggered. After the presentation of the first sequence, the subject's response switch reactivated the system each time a response was made. The subject's switch initiated a pulse out of the subject Control Panel (module 1209) which passed through an OR Gate (module 1212), a Signal Converter (module 1211), and a Flip-Flop (module 1214) to trigger the AND Gates which controlled the auditory and tactual signals. This circuit arrangement provided for the following sequence of events: a warning signal consisting of a burst of random noise of 50-msec duration followed by two seconds of silence, a click or shock, a variable interval, and finally a shock or click. Once the subject made his response, two seconds elapsed and the entire sequence was repeated.

The subject's response box was constructed from a standard aluminum cabinet (6" x 9" x 5") in which was mounted an eight-pole three-position lever-action spring-loaded switch (Switchcraft, model 60324L0). The subject was required to move the switch lever upward when he judged the clock to be first. When he judged the shock to be delivered first, he was required to move the switch lever downward. The switch positions, "click" and "shock", were appropriately labeled on the face of the response box.

Experimental Control

The voltage for the reference signal (the shock) was set by means of an oscilloscope (Tektronix model 561A). This voltage was also checked at the end of each experimental condition to make sure the voltage output remained stable during the experimental run.

The interval between the click and the shock was set with the aid of an electronic counter (Darcy/TSI, model 361-A-R). This instrument was also used to monitor the interval during any test set. The complete calibration procedure is described in Appendix C.

The entire experimental apparatus except the earphones, the shock electrodes, and the subject's response box were located in the control room of a two-room sound-treated suite. The subject was seated in the test room adjacent to the control room. A window between the two rooms provided for visual communication between the experimenter and the subject.

Procedure

This experiment was intended to determine the temporal separation between an acoustic click to the ear and a shock to the finger necessary to correctly judge their order of occurrence. This critical interval was determined for four experimental arrangements: (A) click, right ear-shock, right finger; (B) click, left ear-shock, right finger; (C) click, right ear-shock, left finger; (D) click, left ear-shock, left finger. The order of presentation of the experimental conditions was balanced across subjects. The intensity of the shock signal was set by doubling the voltage necessary to elicit threshold. A magnitude balance was then performed in which the level of the click was adjusted until the subject judged the click and the shock to be of equal magnitude.

The inter-signal interval separating the click and the shock was initially set at a duration which yielded one-hundred per cent correct performance. The subject was required to indicate which came first, the click or the shock. The inter-signal interval in subsequent test sets was decreased in discrete steps until the subject failed the task.

Employing a forced-choice technique, subjects were required to indicate in each case by appropriately positioning the two-position center-homing switch mounted on the subject-response box whether the click or the shock was presented first. The click or the shock was presented first or second randomly for each inter-signal interval tested. The time between each signal pair (click-interval-shock or vice versa) presented for subject judgment depended on how long the subject took to make his decision and register his response. Approximately 2 seconds after the subject had responded to the previous pair, a 50 msec burst of noise (60-dB SPL) alerted the subject to prepare to attend to the experimental signals which followed. The intensity level and duration of the click and shock remained the same throughout the experiment.

The subject received immediate knowledge of results concerning his judgments. Previous studies have shown that immediate knowledge of results elicits a significantly higher level of subject performance (21).

Two lamps, one red and one blue, were mounted on the subject response box. The circuit was constructed so that the blue lamp would light with each correct response while the red lamp would light with each incorrect response.

The psychophysical method employed in this study was a variation of the method of limits. For each test set, the number of correct responses necessary to pass the task at a five-per cent level of confidence or fail at a one-per cent level of confidence was dictated by a table of Sequential Analysis (33). The use of sequential analysis minimized the number of trials necessary to attain pass or fail criterion at a given level of confidence.

The subject was seated comfortably in the test suite and the appropriate instructions recorded in Appendix A were read. The specific instructions for each task were read to the subject immediately prior to his performing that task. Following the presentations of the instructions to the subject, the electrodes were taped to the subject's fingers and the earphones were positioned. The response box was placed on a table at the side of the subject opposite to that receiving the shock signal. Threshold for the shock stimulus was then determined using a modified method of limits. Threshold was defined as the minimal voltage that would evoke two responses to any three consecutive stimulus presentations.

After the threshold for the shock had been established, the voltage delivered to the subject was measured using an oscilloscope. A resistance substitution box set at fifty-thousand ohms was substituted for the subject during this measurement. The threshold voltage was then doubled for the experimental runs. The voltage delivered to the electrodes was kept constant and the subject made a subjective magnitude balance of the two stimuli. The attenuator controlling the intensity of the click was manipulated by the experimenter until the subject judged the shock and click to be of equal magnitude. The intensity of the click was adjusted first in an ascending and then in a descending manner. If the two procedures resulted in a different attenuator setting for a judgment of equality, an average of the two procedures was taken and the attenuator was set to the nearest decibel setting. This same procedure was repeated for all four experimental conditions: i.e., the click to the right ear was balanced against the shock to the right finger; the click to the left ear was balanced against the shock to the right finger; the click to the right ear was balanced against the shock to the left finger; the click to the left ear was balanced against the shock to the left finger. The attenuator values obtained in this manner were employed throughout the experimental runs.

Once threshold had been established and the magnitude balance between the shock and the click obtained, the attenuators were set at the appropriate level. Twenty sets of the stimulus pattern (10 in which the click was delivered first and 10 in which the shock was delivered first) were presented to allow the subject to become accustomed to the task. The subject was then alerted that the experimental run was to begin.

In order to avoid any contamination of the results due to practice effects, all subjects were extensively trained in practice sessions prior to the collection of the experimental data.

According to the balanced order of treatments shown in Table 3 the equipment was adjusted for the experimental conditions to be tested.

TABLE 3

BALANCED ORDER OF CONDITIONS FOR SUBJECTS

	Conditions			
Subjects	A	B	C	D
1	1	4	3	2
2	2	3	1	4
3	4	1	2	3
4	3	2	4	1

The variable inter-signal interval was initially set for a duration four msecs longer than the shortest interval the subject had passed in the training session. The interval was then decreased in 2 msec steps until the subject failed the task. The interval was then adjusted in 1 msec and 0.5 msec steps until the critical interval for the correct judgment of temporal order was measured to the nearest 0.5 msec.

Table 4 shows an example of the individual subject data form. It can be seen that the interval between the two events was initially set at 30 msec and decreased in 2 msec steps until the subject failed the task (20 msec) . The interval was then set at 21 msec and the subject passed. Finally, when the interval was set at 20.5 msec the subject failed the task. For this subject then the critical interval measured to the nearest 0.5 msec was 21.00 msec. This same procedure determined the critical interval for each experimental condition.

TABLE 4

EXAMPLE OF INDIVIDUAL SUBJECT DATA FORM

Interval	No. Correct	No. Incorrect	Pass	Fail
30 msec	10	0	X	
28 msec	12	4	X	
26 msec	14	5	X	
24 msec	14	5	X	
22 msec	24	11	X	
20 msec	16	15		X
21 msec	34	17	X	
20.5 msec	25	20		X

The shock or the click occurred first in random fashion. The subject judged which came first, the click or the shock, and recorded his response by moving the response-switch lever housed in the response box to the appropriately designated position. Immediate knowledge of results was provided by the system of lamps located on the face of the subject response box. If the response was correct, the blue lamp was illuminated. If the response was incorrect, the red lamp was illuminated. Approximately 2 seconds after the subject made his response, a warning signal (burst of random noise) was delivered to the non-test ear and the signal pair was again presented. When the subject had passed the tasks as dictated by a table of sequential analysis, the interval was reduced according to the aforementioned schedule. This same procedure was followed for all experimental conditions.

The design of this study incorporated several features for the purpose of minimizing experimental error, sampling error and intersubject variability. They were: (1) appropriate calibration checks at regular intervals on all signal parameters; (2) the subjective magnitude balances between the click and shock stimuli; (3) a homogenous group of young alert subjects who are highly trained in the experimental task; (4) frequent rest periods to minimize fatigue; (5) the testing method which included sequential analysis and immediate knowledge of results.

The raw data were submitted for statistical analysis. The experimental design was a two-factor factoral experiment with repeated measures on both factors. A factorial analysis was performed to test for main effects and simple effects. In addition to the over-all analysis of variance, the conditions sums of squares was partitioned to test for differences according to which ear received the auditory stimulus.

The statistical design was selected in collaboration with the department of Biostatistics and Epidemiology of the University of Oklahoma School of Medicine.

Summary

This study was designed to measure the critical temporal interval separating a click to the ear and a shock to the finger necessary to correctly judge their order of occurrence. Four normal-hearing right-handed persons between 20 and 30 years of age with no known history of ear pathology or neurological disorders served as subjects for this investigation. Four conditions were tested utilizing ipsilateral and contralateral pairing of the acoustic and tactual signals. The four conditions tested were: (A) click to the right ear-shock to the right finger; (B) click to the left ear-shock to the right finger; (C) click to the right ear-shock to the left finger; and (D) click to the left ear-shock to the left finger.

A modified psychophysical method of limits together with sequential analysis, highly practiced subjects and immediate knowledge of results was employed in gathering the data. This design was expected to be of motivational and training value in obtaining a more precise measure of the critical interval derived from judgments of the temporal order of sets of paired acoustic and tactual stimuli.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

This investigation was designed to determine the ability of normal subjects to discriminate the temporal order of a paired auditory and a tactual stimulus event. Four subjects were studied to define the temporal interval between a click to the ear and a shock to the finger necessary to identify correctly their order of presentation. This temporal interval was defined under four conditions: (A) click right ear - shock right finger, (B) click left ear - shock right finger, (C) click right ear - shock left finger, (D) click left ear - shock left finger.

One of the purposes of this study was to determine if the intersignal interval would change according to ipsilateral or contralateral pairing of the two stimuli. This finding has been reported in a previous investigation using visual and tactual stimulation (8) .

Two modes of stimulus presentation were utilized in order to determine any order effects due to stimulation of one modality prior to the other. In one mode the click was always presented first (mode 1) . Thus, the stimulus pattern in mode 1 was click - interval - shock. In the other mode the shock was always presented first (mode 2) , yielding a stimulus pattern of shock - interval - click.

A modified psychophysical method of limits was employed using a two - alternative forced - choice technique. The subject's task was to judge which came first, the click or the shock. The interval between the two signals was reduced in 2 msec steps until the subject could no longer pass the task. Pass or fail criterion was dictated by a table of sequential analysis (33) . The conditions tested were balanced so that each condition was tested first, second, third or fourth an equal number of times to mitigate any order effects.

The results obtained for each of the experimental conditions are reported and discussed in the following sections.

Results

The mean critical interval for all conditions tested in this investigation ranged from 18.88 to 23.25 msec. Individual subject data is presented in Table 5. The critical interval is defined as the smallest inter-signal interval that allowed subjects to identify correctly the temporal order of the two events; one auditory, the other tactual. Individual critical intervals obtained as raw data ranged from 14.5 to 26.5 msec. The critical interval for each condition was obtained under two modes of presentation. In the first mode, the click was presented first and the shock second. The order was reversed in the second mode; that is, the shock was presented first, followed by the click. The data for the two modes of presentation are labeled subscript 1 (click-shock) and subscript 2 (shock-click) . Thus, a total of eight conditions were tested.

When the click was presented to the right ear and the shock to the right finger (conditions A_1 and A_2) the critical interval for A_1 was 20.38 msec and for A_2, 18.88 msec. When the click was presented to the left ear and the shock to the right finger (conditions B_1 and B_2) the critical interval was 22.00 msec for B_1 and 21.25 for B_2. When the click was presented to the right ear and the shock to the left finger (conditions C_1 and C_2) the critical interval for C_1 was 23.25 msec and for C_2, 22.00 msec. When both the click and the shock were presented to the same side, click, left ear - shock, left finger (conditions

TABLE 5

INDIVIDUAL SUBJECT DATA DETERMINING THE CRITICAL INTERVAL FOR JUDGMENT OF THE TEMPORAL ORDER OF AN AUDITORY AND A TACTUAL STIMULUS EVENT

Subjects	Condition							
	A R. Ear - R. Finger		B L. Ear - R. Finger		C R. Ear - L. Finger		D L. Ear - L. Finger	
	A_1 C___S	A_2 S___C	B_1 C___S	B_2 S___C	C_1 C___S	C_2 S___C	D_1 C___S	D_2 S___C
1	21.0	16.5	23.5	18.5	26.0	24.5	21.5	17.5
2	18.0	20.0	17.0	19.5	19.5	26.5	20.5	17.5
3	19.5	20.5	24.0	24.5	22.0	14.5	20.5	22.5
4	23.0	18.5	23.5	22.5	25.5	22.5	23.5	22.5
MEAN	20.38	18.88	22.00	21.25	23.25	22.00	21.50	20.00
STANDARD DEVIATION	2.14	1.80	3.34	2.83	3.08	5.23	1.42	2.89

D_1 and D_2), the resultant critical interval was 21.50 msec for D_1 and 20.00 for D_2.

Table 6 shows the analysis of variance for these data. It is apparent from this analysis that it made no significant difference if the stimulus was delivered to the same side of the body or opposite sides as there were no significant differences among the conditions tested ($F=1.31$ $P > .05$). Further, the difference observed was not significant when the shock or click was presented first as the differences attributable to the mode of presentation resulted in an F of < 1 ($P > .05$).

Since there were no significant differences between the two modes of presentation, an analysis of variance was performed by combining the totals for each condition and partitioning the condition sum of squares into fingers within right ear, fingers within left ear and ears ignoring fingers. Each comparison is independent and is based on one degree of freedom. The data, therefore, are arranged in an orthogonal set. Table 7 shows the comparisons, divisions and sums of squares. An analysis of variance shown in Table 8 revealed that there were no significant differences in the critical interval when the auditory signal was delivered to either the right or left ear. Furthermore, there was no significant difference between pairing the right ear with the right finger and pairing the right ear with the left finger. This same finding obtained when the left ear received the auditory signal. The critical interval was not significantly different when the left ear was paired with the left finger than when the left ear was paired with the right finger.

Although there were no significant differences among the experimental conditions in this study, some trends appear in the data. Figure (4) shows the mean critical interval for each condition. Upon inspection of this graphic illustration of the data, three trends are apparent. First, the critical interval was always smaller for each

TABLE 6

SUMMARY OF THE ANALYSIS OF VARIANCE AND FACTORAL ANALYSIS OF THE EXPERIMENTA[redacted]A

Source	Degree of Freedom	[redacted]	[redacted]	F
Subjects	3	[redacted]	[redacted]	
Mode	1	[redacted]	[redacted]	<1*
Subjects X Mode	3	[redacted]	[redacted]	
Conditions	3	[redacted]	[redacted]	1.31*
Subjects X Conditions	9	89.[redacted]	[redacted]097	
Mode X Conditions	3	0.75000	0.2500	<1*
Subjects X Mode X Condition	9	61.06250	6.78472	
Total	31	274.21875		

* Not significant at the .05 level of confidence

TABLE 6

SUMMARY OF THE ANALYSIS OF VARIANCE AND FACTORAL ANALYSIS OF THE EXPERIMENTAL DATA

Source	Degree of Freedom	Sum of Squares	Mean Square	F
Subjects	3	33.40625		
Mode	1	12.50000	12.5000	<1*
Subjects X Mode	3	37.93750	12.64583	
Conditions	3	39.09375	13.03125	1.31*
Subjects X Conditions	9	89.46875	9.94097	
Mode X Conditions	3	0.75000	0.2500	<1*
Subjects X Mode X Condition	9	61.06250	6.78472	
Total	31	274.21875		

* Not significant at the .05 level of confidence

TABLE 7

PARTITION OF CONDITIONS SUM OF SQUARES

Contrast	Condition Totals C_1 157.0	C_2 173.0	C_3 181.0	C_4 166.0	Total	Divisor	Sum of Squares
Fingers within right ear	-1	0	1	0	24	16	36.00000
Fingers within left ear	0	-1	0	1	-7	16	3.06250
Ears Ignoring fingers	-1	1	-1	1	1	32	0.03125

TABLE 8

ANALYSIS OF VARIANCE OF THE
PARTITION OF CONDITIONS SUM OF SQUARES

Source	Degree of Freedom	Sum of Squares	Mean Square	F
<u>Conditions</u>	3	39.09375		
Fingers/Right Ear	1	36.00000	36.00000	3.62*
Fingers/Left Ear	1	3.0625	3.0625	<1*
Ears Ignoring Fingers	1	.03125	0.03125	<1*
Subjects X Conditions	9	89.46875	9.94097	

* Not significant at the .05 level of confidence

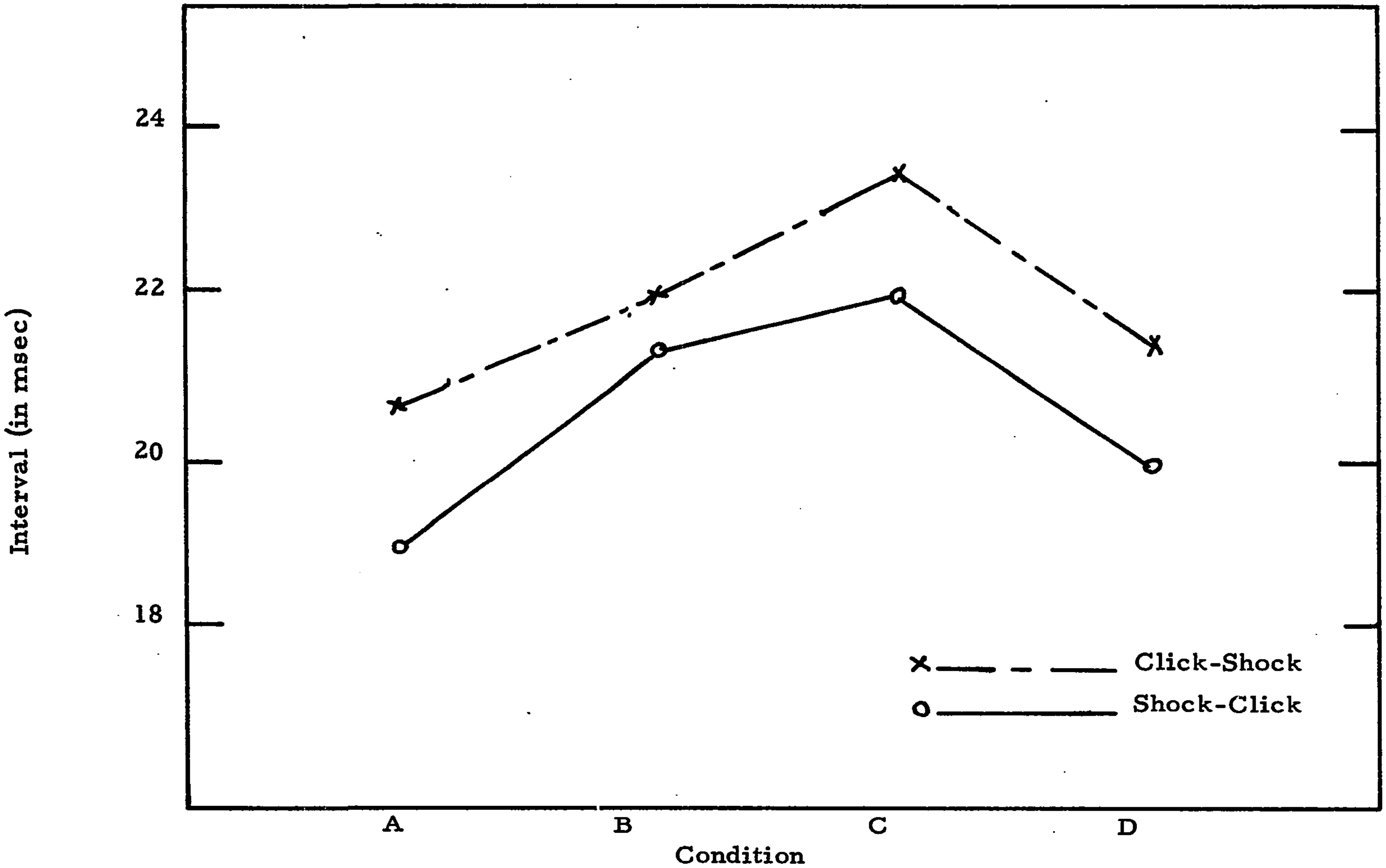

Fig. 4 - Mean Critical Interval as a function of mode of presentation

experimental condition when the shock was presented first than when the click was presented first. Second, the interval was always smaller when the click and the shock were presented to the same side as in conditions A (click right ear - shock right finger) and D (click left ear - shock left finger) than when the stimuli were presented to opposite sides as in conditions C (click right ear - shock left finger) and B (click left ear - shock right finger). Finally, the relationships among the conditions was the same for both modes of presentation.

Discussion

The results of this investigation are in good agreement with the findings of Hirsh (17) and Hirsh and Sherrick (19), although both the signal events and the procedures employed differ. Hirsh and Sherrick (19) determined in a series of experiments the temporal interval between two events necessary for the observer to correctly identify which occurred first seventy-five per cent of the time. This interval was established for the visual, auditory and tactual systems and also for paired modalities. The temporal interval was found to be on the order of 20 msec regardless of which modality was stimulated. Pairing two modalities, visual - tactual, auditory-visual, auditory - tactual, did not yield a different result than when the two events occurred within the same modality. Hirsh and Sherrick (19) concluded that:

> ..."the judgment of order requires that two pieces of information must be organized with respect to time and that it does not matter where these two pieces of information come from; that is, they may come from different parts of the same sensory mechanism or they may even come from different sense modalities".

In an earlier study, Hirsh (17) reported that the critical interval for pure tone auditory stimuli was 20 msec. Broadbent and Ladefoged (4) were critical of the work. They stated that as the magnitude of the temporal interval between sounds already close in time is changed a quality difference will be noted. It was suggested by these authors that the subjects in Hirsh's study were making their judgments on this quality change rather than the true order of occurrence. The results of the present investigation, as well as the studies of Hirsh and Sherrick (19) , suggest that this was not the case. A judgment on the basis of a quality change when the two stimulus events arise from separate sense modalities seems unlikely.

One of the purposes of the present study was to determine if the critical interval for judgment of temporal order would differ according to which finger and which ear was being stimulated. Efron (8) paired visual and tactual stimulus events and investigated laterality conditions like those studied in this experiment pairing auditory and tactual modalities. The data from the present experiment are compared to Efron's data in Table 9.

The important comparisons are to be made not among the nominal values, but across conditions. It should be pointed out that the critical interval in Efron's study was established by obtaining a judgment of simultaneity whereas the interval in the present study is based on judgments of correct order. The intervals obtained in this investigation pairing auditory and tactual events were larger than those obtained by Efron (8) for paired visual and tactual events. It is doubtful that the magnitude of the difference between Efron's data and the results of this study can be attributed to the difference in the kind of judgment required of the subjects. It seems logical that when the inter-signal interval was shortened to a point where the observer could no longer correctly judge the order of stimulus occurrence, the two events are judged at that point to be simultaneous. Since the critical interval in this study was measured to the nearest 0.5 msec, a judgment of simultaneity was said to have occurred at CI minus 0.5 msec. Figure 5 shows a graphic comparison of the two studies. The

TABLE 9

COMPARISON OF EFRON'S DATA WITH THE RESULTS OF THE PRESENT STUDY

Efron	LS - RS	LVF - RVF	RS - RVF	RS - LVF	LS - RVF	LS - LVF
	2.50	9.75	11.25	18.00	13.25	17.25
Present Study			RF - RE	RF - LE	LF - RE	LF - LE
			19.60	21.60	22.60	20.80

LS=Left Index Finger Shock; RS=Right Index Finger Shock; RVF=Right Visual Field Flash; LVF=Left Visual Field Flash.

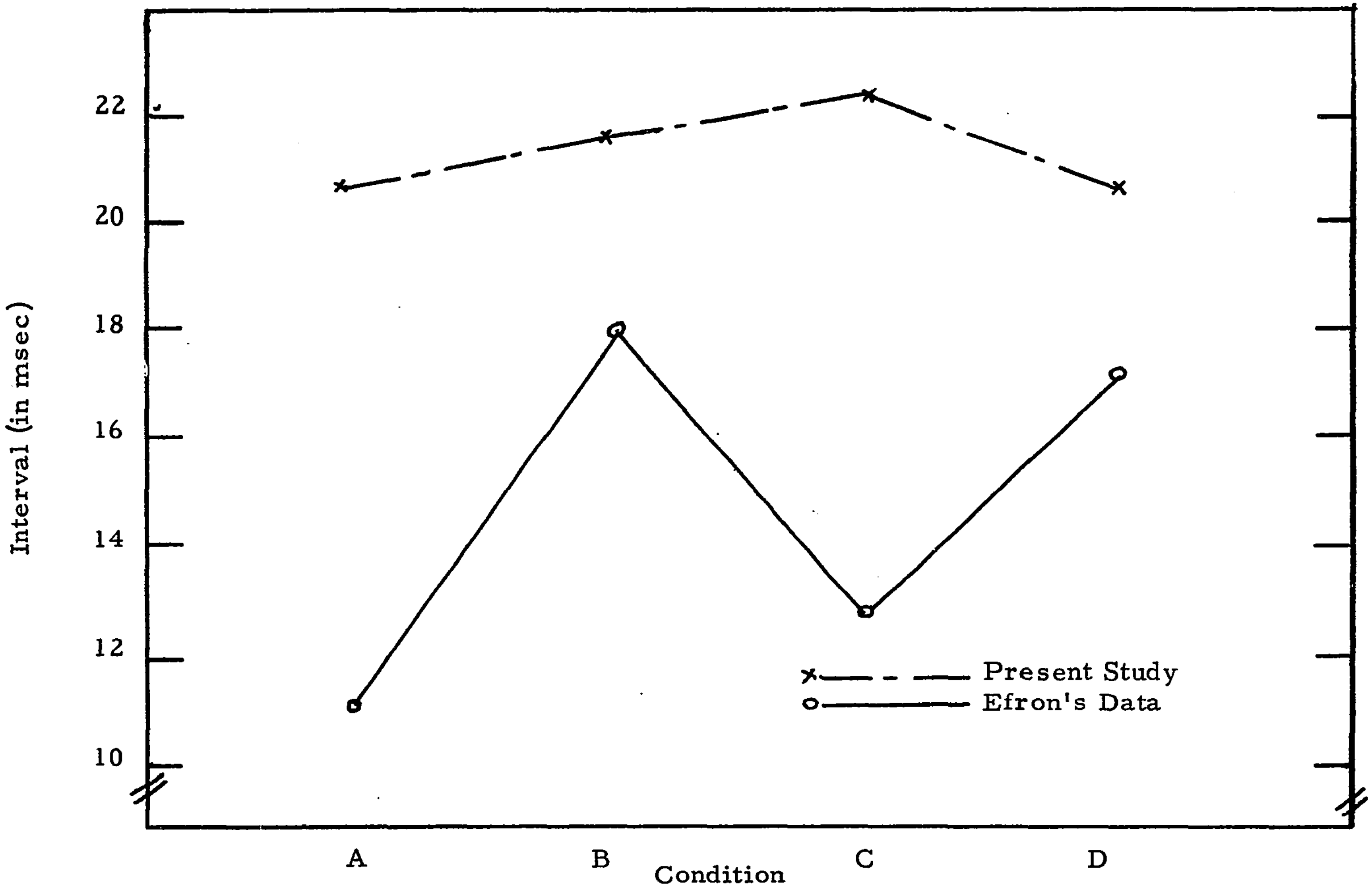

Fig. 5 - Comparison of present study with Efron's data

data points displayed on the graph for the present study are mean averages of the two modes of presentation for each experimental conditions. Although there are some similarities in the two curves, the same relationships among conditions do not hold.

Efron constructed a model in which he hypothesized that the discrimination of temporal events takes place in the dominant hemisphere for speech. If a signal was presented to the right side of the body, right finger or right visual field, the sensory message would be transmitted directly to the left or dominant hemisphere. If the signal on the other hand was presented to the left side, left finger or left visual field, the stimulus would be transmitted first to the non-dominant hemisphere and then transferred by way of an "interhemispheric pathway" to the dominant hemisphere in order for discrimination to take place. Efron (8) had found in previous experiments that subjects judge shocks delivered to the left hand and the right hand to be simultaneous when the shock to the left led by 2.50 msec. The same experiment using light flashes to stimulate the right and left nasal retina resulted in a simultaneous judgment when the left nasal retina was stimulated 9.75 msec before the right. Efron (8) concluded that the shift from real-time simultaneous presentation represented the time interval necessary for the stimulus to be transmitted from the non-dominant to the dominant hemisphere by way of some interhemispheric pathway. The results of these initial experiments were then used to predict the results shown in Figure (5). The results of condition B minus the results of condition A would represent the interhemispheric transmission time for the visual stimulus, whereas condition C minus condition A would represent the interhemispheric transmission time for the tactual stimulus. The predicted result for B minus A was 9.75 msec while the observed result was 6.75 msec. The predicted result for C minus A was 2.50 msec while the observed value was 2.00 msec. When the results of the present study are treated in the same way, C minus A equals 3.00 msec which would represent the interhemispheric transmission time for the shock stimulus. This is in good agreement with Efron's data. B minus A equals 2.00 msec in the present study and would represent the interhemispheric transmission time for the auditory stimulus. The statistical analysis of the data in this investigation do not allow such a conclusion to be drawn since no significant differences were observed among the conditions tested.

It is concluded from the present study that: (1) the critical interval for judging the temporal order of a click to the ear and a shock to the finger is on the order of 20 msec (2) the critical interval remains constant regardless of ipsilateral or contralateral pairing of the auditory and tactual stimuli and (3) the critical interval is not affected by which modality is stimulated first.

CHAPTER V

SUMMARY AND CONCLUSIONS

Auditory perception is dependent upon the temporal organization of stimulus patterns. Communication in the form of speech depends upon man's ability to discriminate changing auditory signals over time. It is known that alterations in temporal sequencing affects the perception of a set of simple sounds. In spite of the knowledge of the importance of temporal clues to auditory perception the study of time perception through the auditory sense has received limited attention.

By investigating the ability of human observers to judge the order of temporal events, it is possible to determine one aspect of the resolving power of the sensory mechanism. Furthermore, it is possible to determine if this resolving power is affected by changing the point of stimulation within one modality or by pairing two modalities.

The few studies of temporal order that have been reported in the literature present the reader with varying results. Only one author (8) has reported the effect of ipsilateral and contralateral pairing of two modalities for temporal judgments. The two modalities used in that study were the visual and tactual senses. Until the present investigation it was not determined if ipsilateral or contralateral pairing of the auditory sense with another modality had an effect on the critical interval for the judgment of temporal order. The present study was designed to obtain information concerning the critical temporal interval which will allow normal observers to judge the order of occurrence of an auditory event paired with a tactual event.

Experimental Design

It was the purpose of this investigation to determine the critical temporal interval by which a click to the ear and a shock to the finger must be separated to allow normal subjects to correctly judge their order of occurrence. This critical interval was established under four experimental conditions: (A) click, right ear-shock, right finger; (B) click, left ear-shock, right finger; (C) click, right ear-shock, left finger; (D) click, left ear-shock, left finger.

A modified psychophysical method of limits was employed using a two-alternative forced-choice technique to obtain judgments from four normal-hearing female subjects who were extensively practiced in the experimental task. The experimental apparatus was programmed to provide the following stimulus pattern test set: click, interval, shock or vice versa. The click or the shock could occur first with equal probability. The subjects task was to judge which came first, the click or the shock. The inter-signal interval was initially set at a duration which yielded one-hundred percent subject performance. The inter-signal interval was reduced in 2 msec steps until the subject failed the task. At this point a bracketing procedure was employed and the critical interval for the correct judgment of the order of occurrence of the acoustic and tactual events was measured to the nearest 0.5 msec. A table of sequential analysis determined the pass or fail criterion.

Results and Conclusions

The results of this study show the minimum temporal separation between a click to the ear and a shock to the finger necessary to allow normal subjects to judge their order of occurrence is on the order of 20 msec. Intervals obtained under the four experimental conditions in this study ranged from 18.88 to 23.25 msec. These values are in good agreement with the results reported by Hirsh (17) and Hirsh and

Sherrick (19) .

Although the critical interval was always smaller when the two modalities were paired on the same side than when they were paired contralaterally, the differences among the four experimental conditions were not statistically significant. Likewise, the interval was always smaller when the shock was presented first than when the click was presented first, however, this difference also was not significant.

The results of this study do not confirm the existence of a pathway in the auditory system for transfer of stimulus events such as Efron (8) has described for the visual and tactual systems. One must conclude that such a pathway does not exist in the auditory system or that the measures employed in this study were not sensitive enough to detect the differences among the experimental conditions that would have to exist in order to support such a hypothesis.

Suggested Further Research

Since man's auditory experience is dependent on changing patterns over time, the need for continued study of the temporal resolving power of the auditory system is self evident. The following topics are offered as suggestions for further investigations:

1. Effects of intensity on the critical interval for judgment of temporal order for paired auditory and tactual stimuli.

2. Effect of ipsilateral and contralateral pairing of the auditory and visual modalities on the critical interval for judgment of temporal order.

3. Replication of the present study with measurement of the interval to the nearest 0.1 msec instead of the nearest 0.5 msec used in the present study with increased sample size.

4. Replication of the present study using subjects with known cortical pathology.

Further research, in addition to extending our knowledge concerning temporal resolving power, may contribute to knowledge concerning the neurological mediation of auditory temporal events.

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APPENDIX A

INSTRUCTIONS TO SUBJECTS

General Instructions

You are participating in a research project that is expected to provide important information concerning how the human auditory system functions. Upon completion of the entire experiment you will be informed of the results. Your task will call for exact and consistent judgments. Therefore, your sustained attention and alertness are essential. The test session will take approximately two hours. There will be frequent rest periods during which you may relax. Please do not interrupt a test sequence that is in progress. If it should become necessary to stop the procedure, just tell me. You can be heard in the control room at all times.

Instruction for Shock Threshold

You will feel a shock from the electrode on your finger. It will be strong enough for you to feel it clearly. Indicate that you feel the shock by raising your other hand. The next shock that you feel will be very weak. Each time you feel the shock, no matter how weak, raise your hand and then put it back down. Make your response definite.

Instructions for Equal Magnitude Balance

First, you will feel a shock then you will hear a click. Your task is to match the loudness of the click to the magnitude of the shock. The magnitude of the shock will not change throughout the procedure. If the click seems louder than the magnitude of the shock, report your judgment by saying "louder". If the click seems softer than the magnitude of the shock, report by saying "softer". If you judge the click and the shock to be of equal magnitude, respond by saying "same". You may have as many presentations of the shock and the click as you wish before making your judgment. You may feel that you do not know how to perform this balance. It may surprise you that people are able to perform this task quite well and with a great deal of consistency. Are there any questions?

Instructions for the Experimental Task

The task you are to perform now is to judge the order of the click and the shock, that is, which of the two (click or shock) occurred first. The series of events that you will experience are as follows. You will hear a burst of noise. This burst of noise is an alerting signal. Approximately 2 seconds after you have heard the noise you will hear a click in the ear opposite the one where you heard the noise or you will feel a shock in your finger. If you hear a click 2 seconds following the noise, a shock will follow. If you get a shock following the warning signal you can expect a click. Your task is to tell which came first, the click or the shock. If the click is first, press the lever of the switch on the response box to the position labeled, "click". Likewise, if you think the shock preceded the click, push the lever to the position labeled, "shock". Whenever you are correct in your judgment the blue light on the response box will light. If you are incorrect in your judgment the red light will light. Do not change your judgment once a response has been made. Your first impression usually will be the better one. Approximately 2 seconds following each response you will be presented with another burst of noise followed by a click then a shock or vice versa. Once again, indicate with the switch which came first, the click or the shock. A number of these pairs will be presented. After each pair you will make your judgment and respond by moving the switch to the position which coincides with your decision. Take as much time as you need before making your response. Be sure you do not change your response once you have made it. A given pair cannot be repeated, therefore, a response must be made for each pair presented. Do you have any questions?

APPENDIX B

TABLE 10

TOTAL NUMBER OF STIMULI AND CORRESPONDING NUMBER OF CORRECT RESPONSES TO PASS AT .05 LEVEL OF CONFIDENCE OR FAIL AT .01 LEVEL OF CONFIDENCE

Number Pairs Presented	Limits Pairs Correct		Number Pairs Presented	Limits Pairs Correct	
	Fail	Pass		Fail	Pass
7	1	7	41	22	28
8	1	7	42	23	29
9	2	8	43	23	29
10	3	9	44	24	30
11	3	9	45	25	31
12	4	10	46	25	31
13	5	10	47	25	32
14	5	11	48	27	33
15	6	12	49	27	33
16	6	12	50	28	34
17	7	13	51	29	34
18	8	14	52	29	35
19	8	14	53	30	36
20	9	15	54	30	36
21	10	15	55	31	37
22	10	16	56	32	38
23	11	17	57	32	38
24	11	17	58	33	39
25	12	18	59	34	39
26	13	19	60	34	40
27	14	20	61	35	41
28	15	21	62	35	41
29	15	21	63	36	42
30	15	21	64	37	43
31	16	22	65	37	43
32	17	22	66	38	44
33	17	23	67	39	44
34	18	24	68	39	45
35	18	24	69	40	46
36	19	25	70	41	46
37	20	26	71	41	47
38	20	26	72	42	48
39	21	27	73	42	48
40	22	27	74	43	49

TABLE 10 - continued

Number Pairs Presented	Limits Pairs Correct		Number Pairs Presented	Limits Pairs Correct	
	Fail	Pass		Fail	Pass
75	44	50	88	52	58
76	44	50	89	53	58
77	45	51	90	53	59
78	45	51	91	54	60
79	46	52	92	54	60
80	47	53	93	55	61
81	47	53	94	56	62
82	48	54	95	57	62
83	49	55	96	57	63
84	49	55	97	58	63
85	50	56	98	58	64
86	51	57	99	59	65
87	51	57	100	59	65

Criteria

Pass: 75 percent of the judgments at a .05 level of confidence

Fail: 50 percent of the judgments at a .01 level of confidence

APPENDIX C

Experimental Control

In order to insure that the results obtained in this study represented subject performance that was not contaminated by experimental errors it was necessary to perform calibration checks of the equipment at regular intervals.

Timing Apparatus

Before each experimental session the delay of the pulse generators which generated the pulse for the acoustic and tactual signals were checked with the aid of a counter-timer (Darcy/TSI) to make sure that an equal delay was present for both signals. Two checks insured that the interval separating the two stimulus events was not influenced by faulty settings of the experimental apparatus: (1) the delay between the firing of the waveform generators and the pulse generators which controlled the stimulus events were checked before each experimental session and adjusted so that the delay between the two sets of waveform and pulse generators was equal. (2) the delay between the output control of the modular series and the output from the pulse generator for each stimulus was checked for equality. The inter-signal interval for each experimental run was set with the aid of the counter-timer. The interval was monitored continuously during the test run by this instrument.

Monitoring of Shock Level

The level of the shock stimulus was set by measuring threshold voltage with an oscilloscope (Tektronix 561-A) and adjusting the level until the threshold voltage was doubled. The voltage was again checked at the end of each experimental run to make sure that the output was stable.