SELECTIVE ATTENTION, ORDER JUDGEMENT AND THE PRIOR ENTRY HYPOTHESIS

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" All science is the modification of old theories; if old theories seem ridiculous to us now, it is because we regard them in their isolation, neither seeing their necessity as preliminary stages of thought, nor the long series of slight modification they have undergone to reach our present and vaunted stage of progress. To future ages, doubtless our vaunted knowledge in many branches of science will be seen as crude and ridiculous".

William James Chidley
Draft manuscript of "The Answer".

Frontispiece: A Transit Telescope

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Summary

The prior entry hypothesis, which arose as an explanation of the findings of the complication experiment of the late nineteenth century, states that attending to one of two sources of signals results in signals from that attended source being perceived as occurring sooner than signals from the other source. Since this idea is intriguing in the light of recent work on attention and short-term memory, the present investigation set out to assess this hypothesis using Signal Detection Theory analyses of order judgement performance.

In Experiments 1 and 2, psychometric functions were obtained in order to establish suitable intervals for the TSD experiments which followed. Experiments 3 and 4 showed significant decreases in sensitivity on order judgement performance, but no significant changes in bias under conditions where the subject was required to decide which of the two lines of the visual display was the longer as well as having to decide whether the visual signal preceded the auditory one. This result, which contradicts the prior entry hypothesis, is further supported by the results of Experiments 5, 6 and 7, which respectively eliminated inadequate masking of the visual stimulus, the type of visual decision and attending to the visual signal rather than the auditory one as possible sources of artefactual results. In Experiment 8, subjects were instructed to attend to visual decision or to attend to the order judgement. Unlike previous experiments this produced a significant change in bias in the direction predicted by the

prior entry hypothesis, but no change in sensitivity. Experiments 3 to 7 produced results comparable to those of earlier investigators, and it was concluded that attending to one signal rather than another did not result in its being perceived as occurring sooner, although attending to one source and disregarding the other might produce this effect.

Having established that the prior entry hypothesis was unable to account for the order judgement data, the complication experiment was re-examined with a view to clarifying its findings and exploring the judgement strategies adopted by subjects. In Experiment 9, subjects had to judge the position of a radius arm on a briefly-exposed semi-circular display. The pattern of errors obtained, though consistent, bore no relation to the pattern of errors subsequently obtained with dynamic displays, showing that the systematic pattern of displacements with static displays is not a possible explanation of the complication experiment. Experiments 10 and 11 were closely modelled on the classical complication experiment, subjects being required to judge the position of a moving pointer at the onset of an auditory signal. Both experiments gave rise to a similar pattern of errors as a function of the onset position of the complicating stimulus. As with the classical studies, a predominance of negative or anti-clockwise errors was found. This anti-clockwise error increased from the starting point on the semi-circular dial, eventually levelling off. It was hypothesised that subjects generated this pattern of errors by working back round the dial until they arrived at a scale position which they were certain the pointer had passed before the onset of the auditory signal. This notion was tested and confirmed in Experiment 12, which involved the reversal of the rotation direction of the pointer. Finally, in Experiment 13, the effect of the intensity of the auditory signal on constant error was examined. No significant effects were found for intensity with either regular block or random presentation. Though this finding conflicts with the commonly-reported findings of intensity effects on perceptual delay, it can be reconciled with them when the strategy outlined above is taken into account.

The results of these experiments and the results of the order judgement experiments are both considered as cases where a bisensory array confronts the subject with information overload.

Statement

To the best of my knowledge this thesis contains original material presented by the author, except where reference is made in the text to findings previously published or written by another person; no material is cited which has been accepted for the award of any other degree or diploma in any University.

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CHAPTER 1.

SENSORY INTERACTION IN PSYCHOLOGICAL RESEARCH

It is becoming increasingly recognised that studies of perception and performance have in the past neglected to explore situations where information is presented in more than one sensory modality (e.g. Loveless, Brebner and Hamilton, 1970; Lindsay, 1970). Nevertheless, compared with the large proportion of experimental psychology which is comprised of such studies, the literature of intersensory effects is small indeed.

Why this state of affairs should have come about is not difficult to understand. To begin with, our ordinary experience of the external world consists of distinct impressions of things we have seen, heard, smelt, tasted, touched or felt: sensory modalities are phenomenologically distinct. This compartmentalisation of the senses received further support early in the history of psychology from electrophysiological studies of the localisation of sensory function, which tended to indicate that different modalities had relatively independent centres in different parts of the brain (Boring, 1950).

A second and more logical reason is that a relatively full understanding of functioning of individual modalities and an adequate metric for the study of this functioning must precede any consideration of how sensory modalities interact. It would seem that this stage has long been surpassed in psychology, intersensory research dating back some forty years (London, 1954). Despite the potential which this area of investigation has for illuminating the manner by which inputs in different modalities combine with one another and with central processes to give rise to our total experience of the external world, studies of these phenomena have been relatively slow in forthcoming.

Recent theories of perception have tended to emphasise that experience is an active process of construction based on selected aspects of the available input and similarly selected aspects of the contents of a long-term memory (e.g. Neisser, 1967). It seems that understanding perception as a whole would then require an understanding of the way in which the information selected from the inputs in different sensory modalities is integrated, and it is difficult to agree with Hochberg (1970) who, in the course of propounding a theory of attention and perceptual organisation similar to Neisser's, states "It is the set of problems posed by the effects of selective attention <u>within</u> a given sense modality that offers the primary challenge to any psychological theory, ...". This point of view denies the possibility of correspondence between the inputs in different modalities such that events in one modality may have an important effect on the way events in another modality are perceived.

There is good evidence from both physiology and practical situations to suggest the importance of such correspondences. For example, the relative difficulty encountered in comprehending a message spoken by an unseen speaker is a familiar everyday experience, especially to telephone users. Similarly, non-correspondence between visual and auditory cues to speech is both detrimental to understanding and thoroughly annoying, as when the sound track of a motion picture is out of synchrony with the film itself. In rather different circumstances, Szafran (1951) has shown how older people supplement kinesthetic and tactile information with visual information in tasks where younger people normally dispense with it.

Neurophysiological considerations

Physiological evidence to suggest the close connection of different sensory modalities comes both from gross electrophysiological readings and recordings of the activity within individual cells.

To deal with the gross recordings first, Grey Walter (1964), using both scalp electrodes with normal subjects and implanted electrodes with surgical patients, found that all the prefrontal nonspecific cortical areas he examined showed responses both to visual and to auditory signals, and none of them showed responses to only one modality. More pertinent to the present discussion, however, is his finding that when paired clicks and flashes were delivered with a 1 sec. interval between the pair of signals, then the general result was augmentation of the response to the first signal and a reduction in the response to the second.

Using gross recordings from the optic nerve, Spinelli, Pribram and Weingarten (1965) have shown that firing takes place in the optic nerve in response to both flash and click stimulation, and that surgical intervention anterior to the recording site results in abolition of the response to the clicks while the response to the flash remains unimpaired. Furthermore, a click and a flash presented simultaneously result in a reduction in the amplitude of the optic nerve response compared with unimodal stimulation. Further evidence of the effect of auditory and electrical-somesthetic stimulation on the visual system comes from Weingarten and Spinelli (1966), who showed that 80% of the receptor fields of individual cells that they mapped in the retina changed when an auditory stimulus was presented at the same time as the visual signal. This modification generally comprised both an increase in the area over which the receptor was sensitive to a light spot and an increase in the frequency of firing which it elicited. An electric shock stimulus produced similar effects, the change in the firing characteristics of the cells being comparable to that occasioned by the auditory stimulus, while the receptor field again increased, though to a lesser extent than was found with the auditory stimulus.

On the basis of this and previous investigations, these authors suggest "Contrary to what has been supposed by others.... it seems reasonable to assume that the efferents to the retina serve as a programmed control system necessary if visual stimuli are to be processed meaningfully."

Most studies of intersensory effects using individual cell recording techniques have examined sites in the visual cortex. Before proceeding to these studies, consideration will be given to intersensory effects demonstrated at two other locations using individual cell recording techniques. Hotta and Kameda (1963) found that responses of individual units in the lateral geniculate nucleus of the thalamus to visual signals were generally facilitated, and responses to auditory input were generally inhibited, when an electrical impulse was delivered to the exposed radial nerve of cats.

Gordon (1972), using intra-cellular recording techniques, found some cells in the deep layers of the superior colliculus which were receptive to only auditory or somesthetic stimuli, while others were responsive either to both visual and auditory or to both visual and somesthetic stimuli. Moving stimuli, whether visual, auditory or somesthetic, generally elicited more frequent responses. Most interesting amongst Gordon's suggestions is the possibility that representations of auditory stimuli are topographically organised in the superior colliculus in a fashion similar to that in which visual stimuli are represented, though to date she seems not to have put forward any evidence to support this contention. Nevertheless, the suggestion from all these studies is that sensory information in one modality does affect activity in other modalities at a number of cortical and subcortical levels.

Turning now to intra-cellular studies of cortical neurons, Horn (1965) and Murata, Cramer and Bach-y-Rita (1965) found cells in the visual cortex which responded to stimuli in other modalities as well as to visual stimuli, electrical-somesthetic stimulation in the case of the former and auditory and somesthetic in the case of the latter. Cells tended to show similar patterns of response to both somesthetic and auditory stimulation (Murata, Cramer and Bach-y-Rita, 1965) while some showed similar responses to electrical-somesthetic stimulation and a diffuse flash (Horn, 1965). While responses to auditory and somesthetic stimuli tended to be larger and more variable than responses to light stimuli (Murata, Cramer and Bach-y-Rita, 1965), responses to paired flash and electrical somesthetic stimuli were different from the pattern of firing elicited by either.

Morrell (1967) not only confirmed that a large proportion of cells in the prestriate cortex (Brodmann area 19) were responsive to multi-modal stimulation (tactile and/or auditory), but also succeeded in demonstrating that the pattern of firing in some of these multimodal cells changed with repeated presentation of paired visual and auditory stimuli. Other cells which apparently responded only to highly specific signals showed comparable changes in firing pattern when other signals were paired with the preferred signal.

A pattern of firing similar to that obtained with the paired stimuli could subsequently be elicited only by the preferred stimulus of the pair for both types of cell although after a time this reverted to the pattern of firing elicited by unimodal stimulation. These cells which show persistent modification to their firing patterns with bimodal stimulation are in sharp contrast to most of the polymodal cells whose responses to paired stimulation were constant over a large number of trials and showed no signs of persisting when unimodal stimulation replaced bimodal stimulation.

To summarize, we may say that the neurophysiological evidence indicates that inputs in different sensory modalities interact at several points in the brain, from the thalamus to the visual cortex. Relatively long-lasting modifications to the firing patterns of neurons in the pre-striate cortex can be brought about by pairing of visual and auditory signals, and both auditory and somesthetic inputs are received by the superior colliculus, a centre which is thought to play an important role in the control of eye-movements. Since changes in the efferent firing to the retina can also be demonstrated with auditory and electro-somesthetic stimulation (Spinelli, Pribram and Weingarten, 1965; Weingarten and Spinelli, 1966); it seems highly likely that information from these other modalities does play an important part in orienting the visual receptors, whatever other effects it may have on the visual system. To what extent the converse is true, i.e. the precise manner by which the visual system directly affects other sensory systems, is more difficult to conceptualise and investigate, no other system having such a large, compact and accessible array of receptors and such well-defined sensory pathways.

Behavioural Studies of Sensory Interaction

Having established both the importance of bisensory input for some tasks and the extent and variety of inter-modality functional interactions at a neurophysiological level, we may now proceed to review the behavioural studies of sensory interaction, especially the interaction of vision and audition.

Such studies may be thought of as falling into two broad groups:

(1) studies of inter-sensory facilitation or inhibition, and

(2) studies of inter-sensory competition.

In the first group fall those studies in which signals in a particular modality are to be detected, discriminated or recognised while stimulation is presented in another modality. This stimulation may take the form of a constant background, or signals in close temporal relation to the signals in the primary modality, or signals correlated in both time and some other dimension or dimensions with the signals in the primary modality such as intensity or spatial location. On the other hand, experiments in the second group involve situations where information is simultaneously presented in two modalities, but the length of time for which this information is presented is so short that an observer has to attend selectively to different aspects of the stimulus array according to the costs and payoffs implicitly or explicitly laid down in the instructions.

In Loveless, Brebner and Hamilton's (1970) review of inter-sensory effects, they make the distinction between accessory stimulation and functionally related signals in another modality. A number of effects of effects of accessory stimulation are listed on such diverse aspects of sensory functioning as visual acuity, colour vision, dark adaptation, critical flicker frequency and auditory acuity amongst others. The effects are usually facilitatory. Reporting experiments of their own with functionally related signals, they found that in a detection situation, presentation of both auditory and visual signals resulted in a marked improvement in detection performance over presentation of either signal alone. This improvement approximates fairly closely the performance which would be expected if the observer were combining the output of independent visual and auditory systems, so that the probability of a detection given both inputs is equivalent to the probability of a detection when either or both systems are in a state such that a signal would be reported, this relationship (referred to as the independence model) being most conveniently expressed by the equation $P_{av} = P_a + P_v - P_a P_v$ where P_{av} is the probability of a detection given both inputs and P_a and P_v are the probabilities of a detection given only auditory or visual input respectively. Furthermore, they report that attending to two separate modalities does not reduce detection performance on either, and that the detection of weak visual signals is improved by presentation of a simultaneous strong auditory signal. This last finding, in addition to the fact that the independence model overestimates the actual improvement in detection performance in this situation, indicates that probability summation is not an adequate account of bisensory detection performance. Similar results are reported for a bisensory vigilance task by Buckner and McGrath (1961) who found that simultaneous auditory and visual signals resulted in better detection performance than with either alone, but worse than the performance predicted by calculating the joint probability of a detection.

To show physiological summation in Loveless, Brebner and

Hamilton's terms, i.e. to establish that information from both modalities is being integrated before a decision is made rather than separate decisions about each modality which are being combined, it is necessary to show bisensory detection performance which is better than that predicted by the independence model. Doherty, Jones and Engel (1971) have argued that the signals used by Loveless _et al_. and other investigators who have shown results which approximate to probability summation (e.g. Fidell, 1970) may have been matched on some physical parameter (e.g. dB above threshold) but were in no way cognitively equivalent. As a result, decisions about each modality are processed independently and the final outcome is the result of the independence model probability summation. Cognitively equivalent signals, in contrast, should share common decision axes and be processed integratively. In order to test this prediction, they presented three-letter nonsense syllables visually, aurally and bimodally, and found bimodal performance much higher than the independence model would predict. In a second experiment, the subject's task was to detect _either_ of two nonsense syllables out of an ensemble of fifty. The nonsense syllables were presented in a unimodal, a bisensory uncorrelated (different syllable presented visually and aurally), or a bisensory correlated (same syllable visually and aurally) condition. Bimodal performance was found to be superior to unimodal performance in both conditions: however, the data from the uncorrelated condition was best fitted by the independence model expressed in the form $d'_{AV} = \left[(d'_A)^2 + (d'_V)^2\right]^{\frac{1}{2}}$ while the data from the correlated condition provided a good fit to an integrative processing model described by the formula $d'_{AV} = d'_A + d'_V$ (Green and Swets, 1966). This finding confirms Loveless et al.'s result with unrelated signals, but shows that with verbal material at least, presentation of cognitively equivalent signals in two modalities results in better performance than can be accounted for by the addition of independent decisions about each modality.

In short, it seems we can conclude that with bisensory detection tasks, bisensory signals which are correlated in time alone result in performance which approximates to the sort of statistical summation described by the independence model, while signals which are cognitively equivalent give rise to performance which closely matches that predicted by integrative processing on a common decision axis.

The question then arises, what constitute cognitively equivalent signals? For example, could simultaneously presented auditory and visual signals of equivalent subjective intensity in an absolute judgement task be regarded as equivalent, and would they give rise to performance better than that predicted by the independence model? Many such questions become evident, but there is as yet no unifying theoretical framework which we can use either to predict cognitive equivalence or to explain what it means in terms of the information processing operations involved.

When we come to consider the case of bisensory competition, then perhaps the most direct investigations of this problem have been concerned with the recognition of different dimensions of bisensory displays. For example, Lindsay, Taylor and Forbes

(1968) showed that in a multi-dimensional discrimination task with signals presented in both the auditory and visual modalities, the average amount of information transmitted when two channels or dimensions are attended to is approximately the same as when only one channel is attended to, irrespective of whether the two channels are in the same modality or not. Further, when four channels are attended to, then the total information transmitted is higher than the average for any one of the modalities presented alone. This total, however, falls short of what we would expect if the channels were being processed independently. Comparison of these findings with results from absolute judgement tasks where different values within a channel were much more easily discriminable and performance on two simultaneously presented dimensions was 94% or what would be expected if independent processing of these dimensions were the case suggests that it is not the amount of information as such, but rather the difficulty of discrimination within channels, which limits multi-dimensional performance.

In this class of experiments we can also include some of the earliest work dealing with competing sensory inputs, conducted in the late 19th and early 20th centuries, using the "complication" experiment. The history and details of these experiments will be elaborated in the subsequent chapter: suffice it to say at this stage that the usual experimental paradigm involved a subject observing a pointer going round a dial, his task being to say precisely where, on the dial, the pointer was when an auditory or 'complicating' signal was presented. Typically, subjects tend to report systematic displacements of the pointer, usually anti-clockwise, and an attentional explanation known as the 'prior entry' hypothesis was put forward to account for these displacements. Briefly, the prior entry hypothesis states that if the subject were attending to the visual display, then his perception of the auditory event would be relatively delayed compared to the ongoing train of visual events, and he would tend to judge that the pointer had progressed further round the dial than it actually had when the auditory signal occurred, and a positive error would result. On the other hand, should the subject be listening for the auditory signal, then his perception of the visual events would be relatively delayed and a negative error would result. The prior entry explanation, then, depends on the assumption that different sensory channels cannot be attended to at the same time, and that attention to one channel results in the delay of detection of events in other channels.

Neglected though it has been for some considerable time, the prior entry hypothesis takes on a new significance when considered in the light of recent work on attention and short-term memory.

If we accept, following Sperling (1963, 1967) that effective processing of a signal requires "reading out" from a "trace" or "store" subject to rapid decay, then a mechanism of prior entry which allowed wanted items or dimensions to be selected from the available stimulus array before unwanted items provides a parsimonious way of accounting for many of the effects of selectivity observed, for example, in selective listening tasks. Such a model could possibly account rather neatly for the fate of unwanted information. If items which are held in store decay rapidly as a function of time, they will rapidly become too degraded for the central processing mechanisms to differentiate from noise in the sensory channel, and impaired performance will result. It is known, for example, that where different attributes of tachistoscopic displays have to be reported, performance on the first encoded attribute is superior to performance on subsequently-encoded attributes (Haber, 1964), and it is at least plausible to account for this as being the result of these last-encoded attributes having decayed more in immediate memory. In selective listening tasks, it is commonly found that not all the information (e.g. the characteristics of the speaker's voice) in the unwanted message is lost, and that items of high familiarity or significance to the subject may still be recognised when other items in the unwanted message are not (Moray, 1959). Such effects could be economically accounted for by a mechanism which ensured that the wanted message was processed before the unwanted one: by the time the unwanted message was dealt with, much but not necessarily all of the information it contained would have been lost.

The initial aim of the present investigation was to test this idea of prior entry using an order judgement technique which would enable an analysis of the phenomenon in terms of signal detection measures, and would also allow manipulation of the amount of attention which would have to be given to either the visual or auditory modality. The next chapter reviews the research on the complication experiment, and the one following examines studies of order judgement.

CHAPTER 2.

THE COMPLICATION EXPERIMENT AND THE NOTION OF PRIOR ENTRY

In this chapter, the background to the prior entry hypothesis is explored. Much of the first and fourth sections, dealing with the personal equation in astronomy and early attempts at theoretical explanation of this phenomenon as well as the data from the complication experiment, derives from Boring's (1950) review, which in turn appears to owe much to Sanford's (1888-1889) earlier and lengthier review. As far as the present author is aware, the second and third sections of this chapter provide a detailed discussion of several studies not hitherto brought together in one review. Since the presentation of results in many of the original studies is difficult to follow, some pains have been expended in reconstructing diagrammatic representation of these data.

1. The personal equation

Interest in the idea of prior entry had its origins in observational problems encountered by astronomers of the early 19th century. At that time, stellar transits were observed using the "eye and ear" method, which involved sighting a transit telescope onto the portion of the sky where the particular heavenly body was to be timed. On the eye-piece of this telescope were marked a number of vertical lines, and timing was by counting the beats of an astronomical clock which beat once per second. Before the transit was due, the observer noted the time on the clock and commenced counting beats. As the star approached the central line on the telescope, the observer noted its position on the last beat just before it crossed the line, and then its position on the first beat after it had crossed the line. The relative distances between the two positions and the centre line could then be used to give an indication of the precise moment when the star crossed the line.

Or so the astronomers of the day believed. However, the interest of the astronomer Bessel was aroused by the report of the dismissal some 25 years earlier of Kinnebrook, assistant to the Astronomer Royal at Greenwich, for alleged persistent inaccuracy in his observations. Throughout 1795, Kinnebrook had consistently observed transits later than had Maskelyne, the Astronomer Royal, by some ½ sec., though this discrepancy was brought to the attention of Kinnebrook, the difference between the two observers continued to increase over the next few months, culminating in a difference of ½ sec. in 1796, at which time Kinnebrook was dismissed.

Bessel's concern over this incident prompted him to make a series of comparisons between himself and other highly practiced observers as the opportunity arose on his travels through Europe. The results of these comparisons can hardly have been welcome. For example, Bessel judged transits on average 1.041 sec. earlier than Walbeck, another leading astronomer, and compared with another called Argelander, 1.223 sec. earlier. A fourth astronomer, Struve, had observed with both of the latter, was found to observe transits 0.799 sec. earlier than Walbeck and 1.201 sec. earlier than Argelander.

Bessel arranged a direct comparison between himself and Struve in 1834, which yielded a discrepancy of .770 sec. Old data, including previous joint observation, allowed for further direct and indirect comparison between the two which showed that the difference between them ranged between .044 sec. in 1814 to a maximum of 1.021 sec. in 1823.

Such revelations must have been disquieting, not only because of the scientific concern of astronomers, but also out of practical concern for the calibration of the world's time-pieces which in those days depended on the timing of stellar transits in the manner described above. In order to minimise these observer effects, Bessel pursued his researches on the personal equation in an attempt to identify the relevant variables. Besides drawing attention to the personal equation, as he called this characteristic difference between individuals in their perception of the temporal relations between events in this bisensory situation, and its variability within the same individual, at least over long periods of time, his work indicated the following:

(1) the discrepancy between observers was not affected by the rate at which the star crossed the line, a finding later confirmed by Wundt and more recent workers;

(2) the error was less when a clock which beat in half seconds was used;

(3) sudden events such as emergences and occlusions gave rise to larger personal equations than did highly predictable events such as transits, a finding which finds considerable support from recent studies which have shown a high degree of

accuracy in synchronising a response with a point in a predictable signal sequence (Slater-Hammel, 1960; Schmidt, 1969).

The recognition of these individual differences led astronomers to take account of the personal equation in their published observations, their efforts being directed towards eliminating this source of variability. The real difficulty in making appropriate correction for observer effects lay in the absence of any objective means of determining when the transit actually took place.

Kaiser (1863, see Boring, 1950) attempted to get round this difficulty by having observers time the transit of an artificial "star", the transit time of which was known exactly. The discrepancy between the observer's report and the time at which the "star" crossed the line on the telescope then provided a measure of the individual's personal equation with reference to an objectively determined signal, which could be used as a correction factor which allowed close approximation of the timing of physical events from a particular observer's report of them.

In the end, astronomers solved their problem not by devising a suitable means of determining a correction factor for different individuals, but by adopting a transit reaction-time procedure for timing stellar transits, this being made possible by the development of the chronoscope in the mid-nineteenth century. Instead of being faced with the difficult task of making two spatial judgements in response to auditory signals, the astronomer had simply to press a key when the star crossed the line on the telescope leaving a mark on the revolving drum of the chronoscope. The recent studies by Slater-Hammel (1960) and Schmidt (1969) indicate that this task can be performed with a constant error as small as 4-6 msec.

However, as we shall see, the issues raised by this essentially practical problem were of considerable interest to the developing psychological science.

2. The Complication Experiment

Wundt was the first psychologist to recognise the potential of the personal equation situation for the study of the temporal course of ideas. Previous accounts of the "coming and going, the rise and fall, of ideas" (Wundt, 1894, p.266) had been based entirely on the evidence of introspection and were devoid of any consideration of the succession of ideas aroused directly by external stimuli, the assumption being that perception corresponded exactly with the time course of these external events. The evidence from the astronomical studies showed the inadequacy of this assumption, since the perceived time course of events differed from individual to individual.

The transit-timing situation, however, did not allow any direct comparison between the perceived and the objective succession of events, since the timing of these objective events could never be known. To overcome this difficulty and permit the study of the relationship of perceived and objective succession, Wundt developed his complication apparatus which was the prototype for most subsequent work in this area. The term "complication" was first used by Herbart, and is more or less synonymous with "bisensory" (Boring, 1950).

The version of Wundt's apparatus reported in his "Physiological Psychology" (1874) consisted of a pendulum, the top end of which swung to and fro over a semi-circular dial, rather like the top half of a clock face. As it swung on the clockwise beat, the pendulum brushed a contact which closed an electrical circuit and caused a bell to ring. This contact could be set at a number of different positions and the subject's task was to report the position of the pointer when the bell rang. A slightly different version of the apparatus appears in Wundt's "Lectures" (1894), and according to Burrow (1909), there was also a complication clock version of the apparatus.

Wundt's main findings were as follows. Very few accurate results were obtained, the errors being both clockwise or positive (putting the pointer too late) and anti-clockwise or negative (putting it too soon), the anti-clockwise errors being more frequent. Rotation speed determined the direction of the error, clockwise errors predominating at high speeds (less than 2 sec. per rev.), and anti-clockwise errors predominating at slower speeds (as slow as 8 sec. per rev.). Minimum errors were found at speeds between 5 and 2 sec. per rev. No data are reported for speeds greater than 2 sec. per rev., Wundt claiming that no readings were possible below this speed.

Wundt also noticed that there was a tendency to more anti-clockwise errors if the bell sounded when the pendulum was accelerating on the upstroke, and an opposite tendency to more clockwise errors as it decelerated on the downstroke. Unfortunately, no actual data is reported in presently available sources, so we have to rely on incomplete and often vague quantitative statements about the results by Wundt and other early investigators. The only data on the magnitude of the effect presently available to the author from Wundt's work is reported in his "Lectures" where he reports a time displacement of the order of 0.125 sec. with a slow vibration rate.

Wundt's pupil von Tschisch (1885) carried these investigations further using similar apparatus. His results do show the same trend as did Wundt's, i.e. a tendency to smaller anti-clockwise errors for all the speeds he used, which were faster than those used by Wundt (2 sec., 1.5 sec., and 1 sec. per rev.). The latter, it will be recalled, found most clockwise errors at his fastest speed. Unfortunately, neither investigator appears to have employed any subjects other than himself so this discrepancy may be the result of individual differences; at least the direction of the changes with increasing speed is consistent.

The really interesting feature of von Tschisch's investigations is his use of other than auditory complicating stimuli, both alone and in combination. Employing a tactile stimulus in place of the bell-stroke, the data exhibited essentially the same characteristics. When complicating stimuli were delivered in two modalities at once, then the error shifted in a clockwise direction (i.e. became smaller), and when three complicating stimuli were delivered, the error shifted again in the same direction and became clockwise (Burrow, 1909). The positive shift with each additional complicating stimulus became less, up to the maximum of five separate stimuli employed by von Tschisch. The extent of this clockwise displacement was affected by how disparate the stimuli were, i.e. the greater the spatial distance of tactile stimuli, or the greater the difference in frequency between two tones, then the greater the clockwise displacement of the judgement.

The findings of these two investigators were confirmed by the work of Pflaum (see Burrow, 1909). Using similar apparatus and two other subjects besides himself, he found a preponderance of anti-clockwise errors which became progressively less anti-clockwise with increasing pointer speed.

Conflicting results are reported by Angell and Pierce (1892). They abandoned the Wundtian pendulum complication apparatus with which they commenced their research because of the distracting noise of the pendulum, the confounding variable of changing pointer speed as the pendulum swung to and fro, and because of the long time over which the bell-stroke persisted. Instead they constructed their own apparatus, using a kymograph to provide a constant rotation speed for the pointer and substituting the click of a telephone relay for the bell-stroke. Besides improvements in apparatus, these investigators introduced procedural innovations, instructing the subject to maintain fixation in the region of the point at which they heard the click on the first revolution. They also used unpracticed observers, a feature of their experiments which was later taken up by Geiger (1902).

Contradictory to Wundt's findings, Angell and Pierce report a predominance of clockwise errors, with a tendency to increasing positive error with practice. In common with the above-mentioned reports, however, is the inadequacy with which the data is reported: "The first twenty-five final readings of each new subject generally show a predominance of negative errors then the positive errors come rapidly to the front", is the only quantitative statement in the whole of their paper. Secondly, and again in direct contradiction to Wundt and his colleagues, they report that pointer speed had no effect on either the direction or the amount of error.

In addition to this main experiment, Angell and Pierce report a rather different version of the complication experiment. Unsure of whether the classical complication experiment allows us, as Wundt claimed, to study what happen "when we receive a series of impressions separated by a distinct interval into the midst of which a heterogeneous impression is suddenly brought", they modified their apparatus so that a series of letter stimuli (i.e. a series of distinct impressions) were presented sequentially to the subject, whose task was then to say with which letter the click stimulus coincided. Although the account of their findings is once more far from explicit, it would seem that they failed to find any systematic error in this situation, though they did find that after-images persisted for long periods and that the subject sometimes reported the click as coinciding with the after-image of a previous stimulus letter. A further weakness in the study is the omission of any explicit reference to the rate at which the letters were presented.

A very similar experiment is reported by Haines (1906). White letters on a black background revolved in front of an observation tube, and the auditory stimulus was "the stroke of an electric hammer". Like Geiger (1902) he found that both rotation speed and practice affected the errors (see Burrow, 1909).

The apparent conflict between the results of Angell and Pierce on the one hand, and Wundt, Pflaum and von Tschisch on the other, were largely resolved by a series of experiments by Geiger (1902; see Burrow, 1909). Geiger's investigation aimed at separating out the hitherto confounded effects of pointer speed and practice. Subjects first underwent a series of trials on which the rotation speed increased on each session from a starting speed of 8 sec. per rev. to a final speed of 0.9 sec. per rev., followed by a descending series on which the speed decreased session by session over the same range. If practice were the important variable, as Angell and Pierce suggest, then the clockwise errors should have continued to increase throughout both series; if, as Wundt claimed, speed was the important variable, then the clockwise error should have diminished throughout the second series as the pointer speed slowed down. In fact, Geiger's results show neither an increase nor a decrease in clockwise errors following the slowing down of the pointer, suggesting that both factors are operating. Geiger suggests two main effects of practice:

(1) with constant velocities it increases the tendency to clockwise error;

(2) maximum anti-clockwise error tends to occur at greater speeds than previously.

On the basis of introspective reports, Geiger was able to classify his subjects according to the strategy they employed; first, the "naive" subject who passively "permits the impression of the region of probable similtaneity of sound and index-hand to arise within him", selecting the position more exactly on subsequent rotations; secondly, the reflecting type of subject, who tries to make a definite judgement on the first rotation, correcting if necessary on subsequent ones. Characteristically, the naive subjects tended to make more anti-clockwise errors, while the reflecting subjects tended to make clockwise ones. When we consider the instructions given to Angell and Pierce's subjects to follow the pointer round and then fixate in the region where the click seemed to come on the first revolution, it is apparent that the strategy they were directed to follow corresponds closely to the reflecting subjects' strategy described by Geiger, whereas the less definite instructions or set common to Wundt, von Tschisch and Pflaum would encourage a naive strategy. This would then account for the predominance of clockwise error reported by Angell and Pierce.

Von Tschisch, Wundt and Pflaum had earlier drawn attention to the tendency to make different sorts of error on different sides of the dial. Anti-clockwise errors tended to occur with accelerating upward movement on the left hand side of the dial, while clockwise errors tended to occur on the downward decelerating movement on the right hand side of the dial.

These results they attributed to the effects of acceleration rather than position. Geiger, however, replicated these results with a complication clock apparatus in which the index-hand moved round the dial with uniform velocity. An ingenious series of control experiments, involving presentation of a pendulum display via an inverting telescope and a reversing mirror, gave similar results for different quadrants as did direct displays, confirming that the effect was due to spatial factors rather than acceleration.

Klemm (see Burrow, 1909), also attempted to disentangle the confounded variables of position and acceleration, using the traditional pendulum apparatus under two presentation conditions. Under one condition, the pendulum accelerated on the upswing and decelerated on the downswing , as in the experiments of Wundt and others. Under the second condition, the pendulum was inverted, so that it accelerated on the downswing and accelerated on the upswing. His results are consistent with Geiger's, in that anti-clockwise errors tended to occur on the upswing, i.e. on the left hand side, clockwise ones on the downswing.

The earliest available report of a complication experiment in which data is adequately reported would seem to have been conducted by Burrow (1909). Burrow was primarily concerned with testing Wundt's assertion that in a complication situation temporal displacement of the complicating stimulus by the observer only occurs when the "impressions" are "disparate" (or the signals are presented in separate channels,

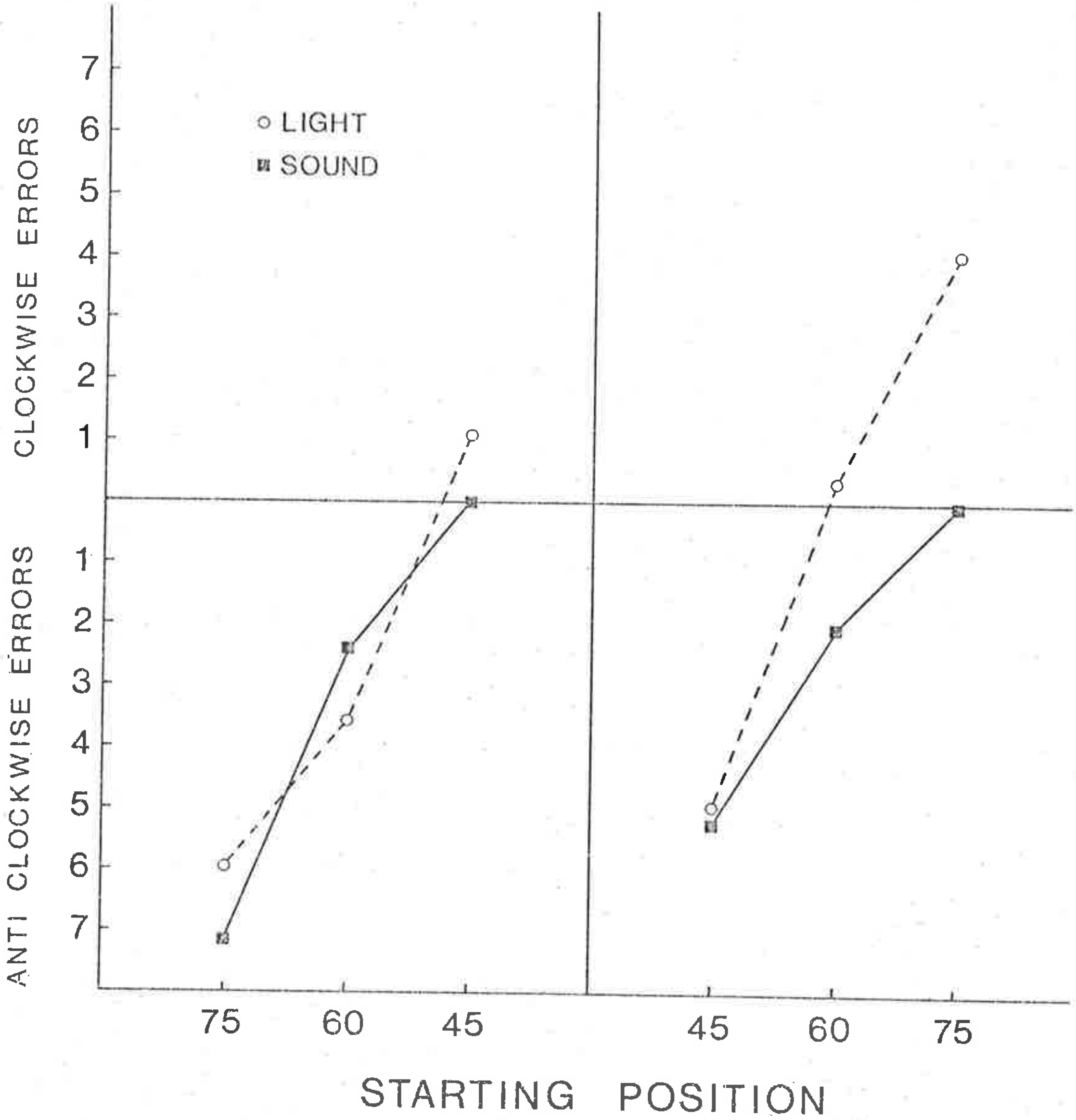

FIG. 2.1, Mean Error in final adjustment in relation to starting position of the complicating stimulus. (Derived from Burrow, 1909, Tables 3 and 4).

to use more recent terminology), i.e. the background train of events and the complicating stimulus are presented in different sensory modalities, or to different organs of the same modality.

Burrow used apparatus similar to that used by Geiger, an index-hand sweeping a semi-circular dial at a constant speed. He completely departed from previous investigators, however, in his use of an adjustment rather than an estimation method. On each trial, the onset of the complicating stimulus was varied, and the subject's task was to adjust its onset until it appeared to coincide with the pointer passing a fixed mark in the centre of the semi-circular dial. This technique eliminates the interfering effects of both scale divisions and eye movements. Two different complicating stimuli were used; (1) the stroke of a sound hammer, giving an auditory signal; (2) the flash of a Geissler tube, giving a visual signal. Six different starting positions of the complicating stimulus were used, these being 45°, 60° and 75° to either the right (A determinations) or the left (B determinations) of the observer.

Burrow's main results are illustrated in Fig. 2.1. In Fig. 2.1, starting positions for the complicating stimulus are placed along the x-axis, and the mean displacement associated with each starting point is plotted on the y-axis, positive values representing positive or clockwise displacements, negative values representing negative or anti-clockwise displacements. Two features of the data are apparent: (1) a tendency to over-correct on the smallest displacements,

i.e. the 45° A determination, involving an anti-clockwise adjustment and the 45° B determination, involving a clockwise adjustment both represent over-adjustment, with a corresponding tendency to under-adjustment on the largest displacements.
(2) A consistent tendency to judge the point of coincidence to be more negative for auditory signals, i.e. to judge them as coming sooner than the visual ones. However, the overall similarity in the results for visual and auditory complicating signals contrasts with the results of a study by Burgess (1965) who found that the displacements in the constant error occurred only with an auditory complicating signal and not with a visual one.

A subsidiary experiment conducted by Burrow deserves mention. In an attempt to assess the contribution of intensity to the amount of error, he tested four of his subjects under two conditions using the loudest and softest possible strokes of the sound-hammer. No difference was found between conditions, a surprising result in view of Sanford's (1971) recent report of definite differences in the apparent displacement of the index-hand with auditory complicating stimuli of different intensity.

Dunlap (1910) reports a series of experiments using Burrow's apparatus. While serving as a subject for Burrow, he noticed that sometimes the pointer appeared blurred at the moment of coincidence, and sometimes quite clear. This prompted him to examine the effects of eye movements in the complication experiment. A fine mesh placed over the complication apparatus provided feedback as to whether the subject's eyes were moving or not. After some practice, Dunlap and his other subjects managed to avoid any sensation of blurring of the mesh, which he took as evidence that no eye movements were being executed. Under these conditions, constant error was negligible, and absolute errors small. When the mesh was removed, errors again became large, although Dunlap is vague both on the magnitude and direction of the changes.

On the basis of these results and introspective reports, Dunlap proposed three different judgement strategies:

(1) Exact fixation. The eyes are at rest when the judgement is made. The subject then tries either to judge the position of the pointer when the click sounds, or judge whether there is any temporal difference between the click and the arrival of the pointer at a mark on the dial.

(2) Natural fixation or rhythmic reaction. The pointer appears maximally clear at the moment of coincidence; the subject synchronises his eye movement with the onset of the complicating stimulus, and any errors which occur are errors in synchronisation.

(3) Pointer pursuit. The subject tracks the movement of the pointer, the cessation of this tracking with the onset of the complicating stimulus requiring a certain reaction-time. The fixation-point at which the eyes comes to rest is perceived as the point at which the onset of the complicating stimulus occurred. This method characteristically produces clockwise errors; the exact fixation method produces small errors evenly distributed about the point of objective similtaneity, and

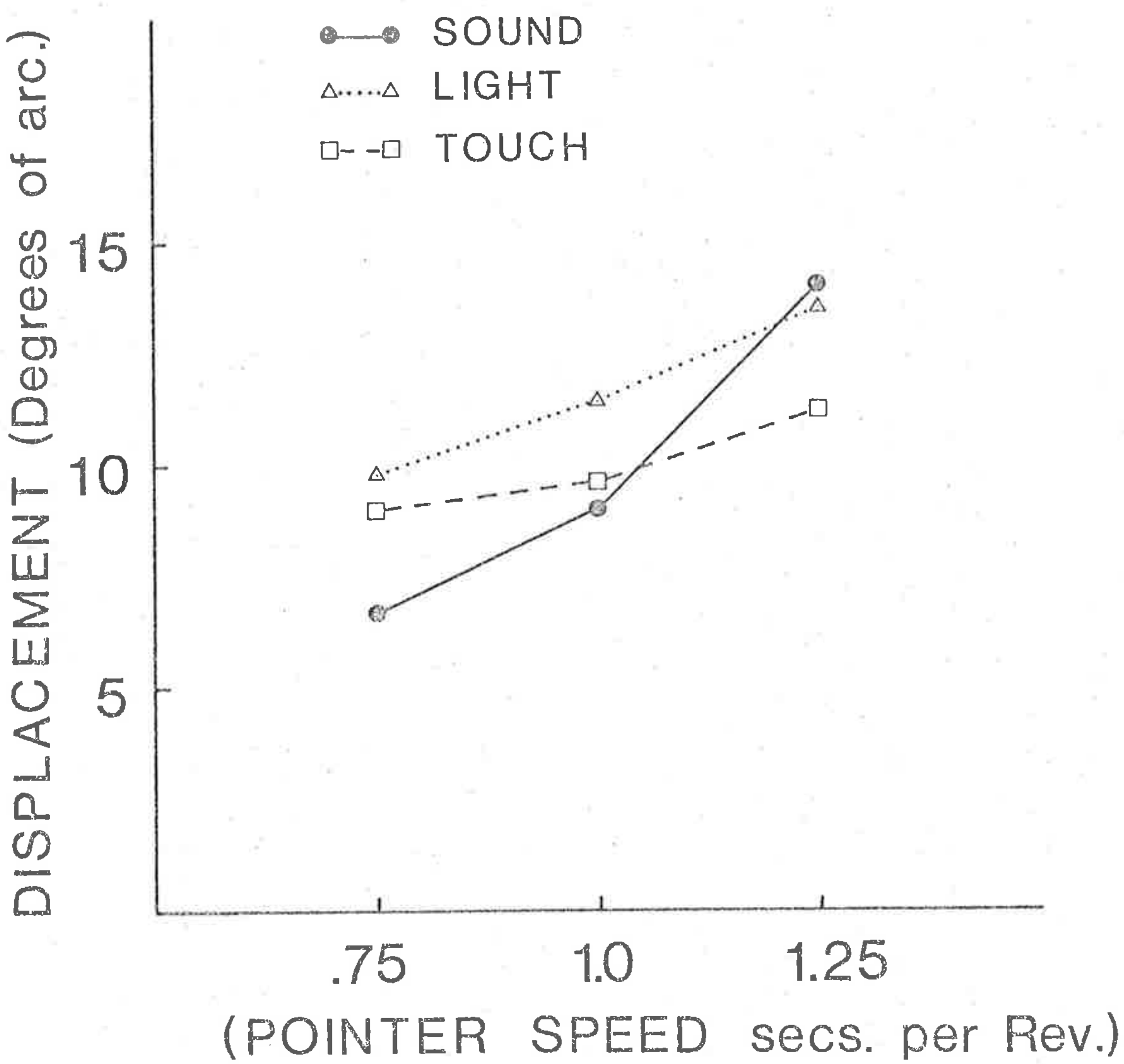

FIG. 2.2, Spatial Displacement of Pointer judgements as a Function of Rotation Speed with Complicating Stimuli in Different Modalities. (Reconstructed from Leatherman's(1940) data.)

natural fixation can produce either sort of error depending on whether or not the subject makes anticipatory responses to the rhythmic series.

The importance of eye movements in the complication situation is questionable, since the sorts of manipulations Dunlap undertook would almost certainly involve changes in the distribution of attention, if for no other reason. Similar effects have been demonstrated in situations which do not involve any visual input, so the effects discussed in the experiments above would seem to be at least in part independent of the effects of eye movements.

Perhaps the most comprehensive study of the complication situation has been conducted by Leatherman (1940). Using an improved electric complication clock apparatus, Leatherman confirmed the general tendency to anti-clockwise error reported by previous investigators, and found that auditory, visual and tactual complicating stimuli gave patterns and magnitudes of errors which differed very little (see Fig. 2.2). Two additional findings, unreported up to that time, are of particular interest. First, when a warning signal preceded the complicating stimulus by 139 msec., there was an increased tendency to clockwise errors. Second, and more important, when Leatherman varied the rotation speeds of his pointer, he found the smallest errors at his fastest rotation speed (0.75 sec. per rev.). Since the errors were predominantly anti-clockwise, this finding agrees well with that of von Tschisch, while the direction of the changes would seem to be consistent with Wundt's findings. However, if the displacements are

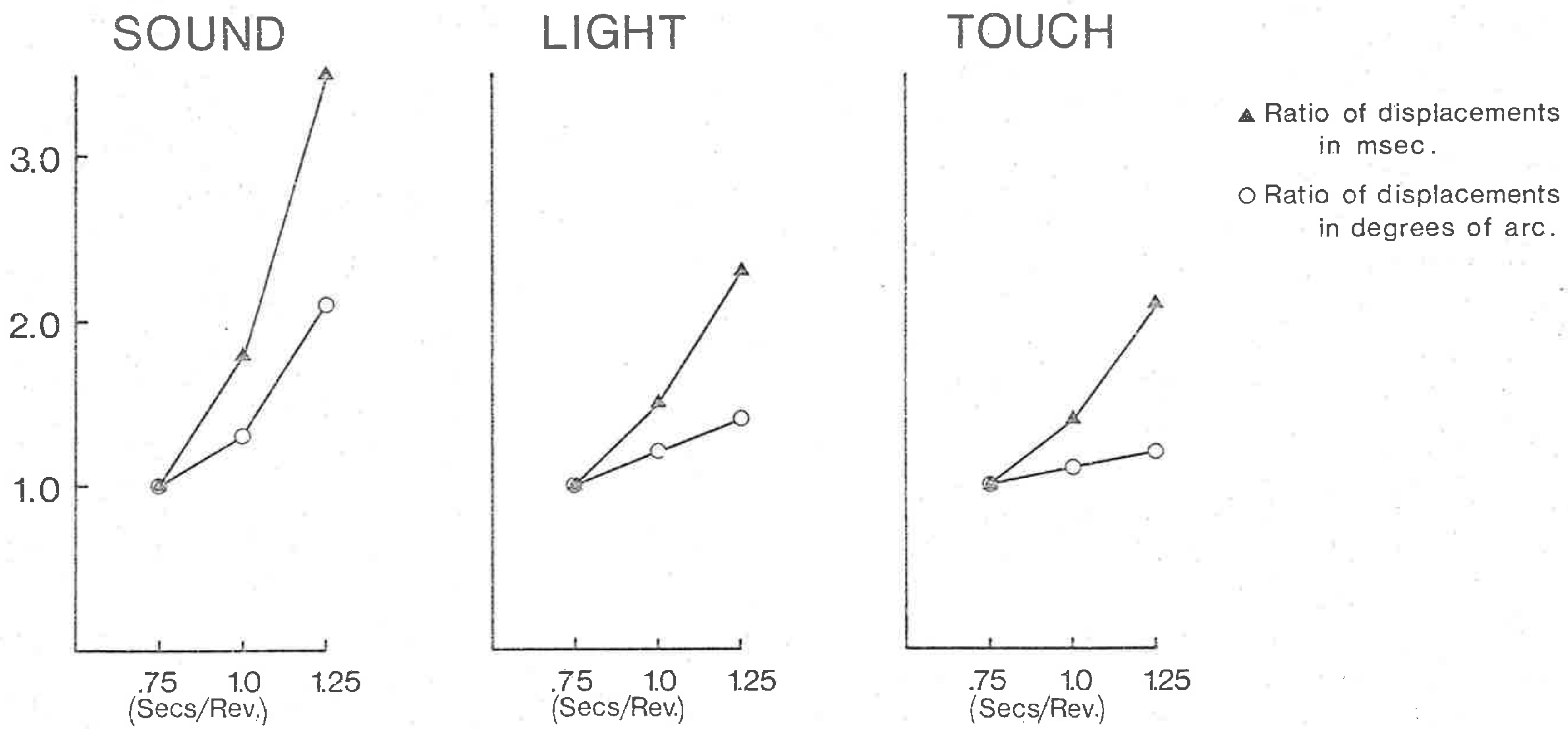

FIG. 2.3, Ratios of Spatial and Temporal Displacements at Different Rotation Speeds. (Reconstructed from Leatherman's (1940) data).

expressed as spatial displacements in degrees of arc, then the differences between the three speeds used by Leatherman is small. If they are expressed as temporal displacements in terms of milliseconds then the difference between the slowest and the fastest speed is very much greater. This is clearly brought out in Fig.2.3, where the displacements at 1.0 and 1.25 sec. per rev. are expressed as ratios of the displacement at 0.75 sec. per rev., in terms of both degrees and milliseconds for each of three different complication signals. The steeper slope of the milliseconds line in each case suggests that the spatial displacement rather than the temporal displacement is stable at different speeds.

The latest addition to the literature on the classical complication experiment comes from Sanford (1971) who was interested in using a complication situation as a measure of perceptual lag to discover whether delayed perceptual processes could be used as an explanation of intensity effects on RT to auditory signals. The complicating stimulus in his experiment was an increase of 2, 3, 7 or 18 dB in the intensity of white noise played continuously through a pair of ear-phones at a level of 60 dB. Increasing intensity resulted in both a reduction in simple RT to the auditory signal and a tendency to less positive judgements on his complication task, both effects being statistically significant. However, the magnitude of the effect on RT (83 ms. across the range of intensities), was much greater than the effect on the constant error on the pointer judgement task (49 ms. across the range of intensities), which indicates that delay in the detection of an auditory signal is not enough to account for the effects of intensity on auditory RT. The possibility of the subject adopting a higher criterion on RT trials (in order to eliminate anticipatory responses) was ruled out by a supplementary experiment which required the subject to give both a key-pressing response and a pointer judgement on the same trial. It may be noted, however, that Sanford, unlike other investigators, allowed subjects only one revolution per judgement.

On the basis of the experiments reviewed so far, employing similar apparatus and procedures, but varying enormously in the competence of their design and selection of subjects as well as in the adequacy of the data reported, the following features of the complication situation would seem to be well established, either because they have been found in satisfactorily designed and reported studies or because they have been found independently in more than one of the less certain investigations:

(1) Most investigations report a predominance of negative errors (Wundt, 1874; von Tschisch, 1885; Leatherman, 1940).

(2) Pointer speed affects the constant error; the faster the rotation speed, the less negative the error (Wundt, 1874; von Tschisch, 1885).

(3) However, the difference in spatial displacements with different speeds is slight, whilst the temporal displacements vary considerably, suggesting a relatively stable spatial displacement over different speeds (Leatherman, 1940).

(4) The amount and type of constant error depends on the position of the pointer when the complicating stimulus is presented, negative errors tending to occur on the left hand side of the dial, positive errors occurring on the right hand side; admittedly, this is only substantiated by qualitative statements (Wundt, 1874; von Tschisch, 1885; Geiger, 1902).

(5) A warning signal results in a tendency towards more positive errors (Leatherman, 1940).

(6) When an adjustment method is used, the biggest adjustments tend to be underestimated, the smallest overestimated (Burrow, 1909).

(7) The modality in which the complicating stimulus is presented appears to make no appreciable difference to the amount or direction of the constant error (von Tschisch, 1885; Burrow, 1909).

(8) With auditory signals at least, more intense signals may give rise to lessclockwise judgements (Sanford, 1971).

3. Variations on the Complication Experiment

With the exception of Sanford (1971), no recent experiments of the classical complication type have appeared in the literature. However, some rather similar experiments have appeared which could still properly be called complication experiments, in that they involve the judgement of the temporal relation of some disparate signal to a reference signal or series of signals.

Stone (1926) conducted a very straightforward complication experiment in which the subject had to judge the order of tactile and auditory stimuli under different attentional conditions. Subjects were presented with a brief auditory click and a momentary touch on the right forefinger, separated by intervals of 60, 30 or 0 msec. Stimulus combinations were presented following the method of constant stimuli, with either signal coming first in a random fashion. Under one condition, the subject was instructed to attend to the sound, under the other, to the tactile stimulus, his task being to say whether

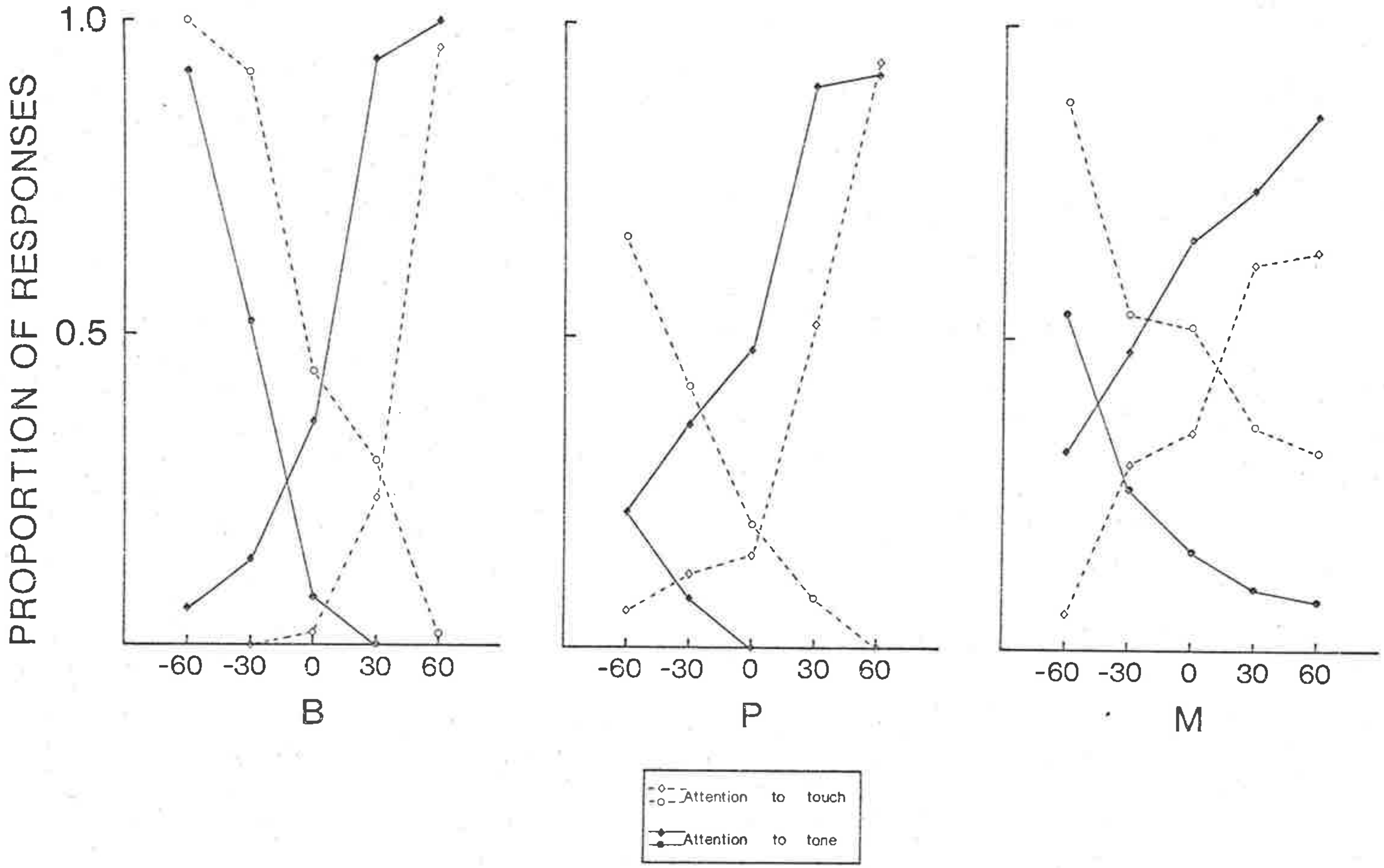

Fig. 2·4 Psychometric Functions for Bisensory Order Judgement for the three subjects in Stone's (1926) Experiment. Negative values on the X-axis indicate Touch signal presented first: diamonds represent 'Sound First' judgements, circles represents 'Touch First' judgements. Reconstructed from Stone's (1926) data.

the touch stimulus or the auditory stimulus came first or whether they were simultaneous. Psychometric functions generated by Stone's three subjects have been reconstructed in Fig. 2.4. It is apparent that both the touch and sound functions are shifted across to the right under the condition where touch is attended to, indicating a change in the relative frequency of both sorts of judgement for the same amount of temporal separation. Under conditions of attention to the touch stimulus, "touch first" judgements persist at shorter intervals from the auditory stimulus than they do under conditions of attention to the auditory stimulus. In other words, instructions to pay attention to one stimulus makes it more likely that that particular stimulus will be reported by the subject as coming first. When the tone is attended to, the point of subjective equality (PSE) precedes the tactile stimulus by as much as 60 msec., but when the tactile stimulus is attended to, the PSE comes after the tactile stimulus by up to 30 msec. The difference in PSE for the two conditions range from 38 msec. to 60 msec. depending on the subject. This, Stone claims, represents a quantitative measure of the effect of attention, though it would seem that such a direct instruction to the subject as to pay attention to one signal rather than another and then judge its order relative to that other is a procedure which is fraught with the risk of experimenter bias (Rosenthal, 1966).

A completely different type of experiment, involving only auditory signals yet still classifiable as a complication experiment, is reported by Needham (1934, 1936). Like Stone's experiment, this procedure avoids any of the possible effects

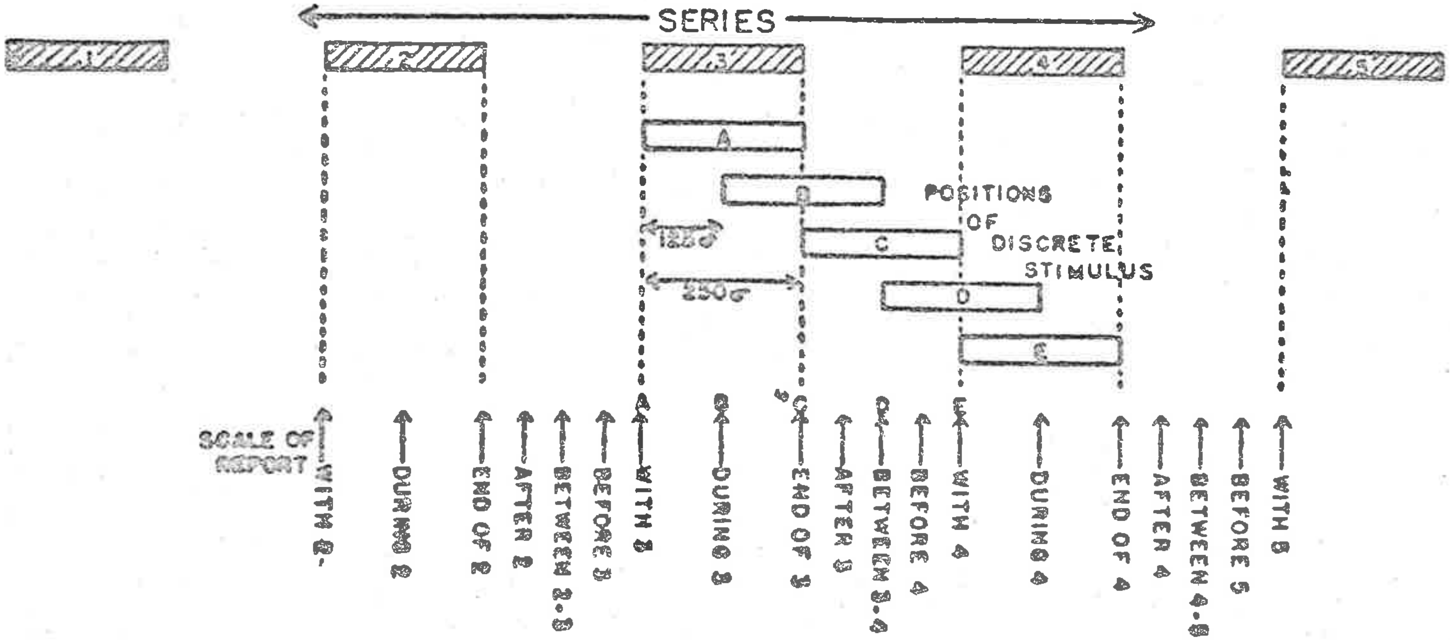

Fig. 2·5 Representing positions of the discrete stimulus and of reports upon it in reference to the series. (From Needham. 1934) of eye movements mentioned by Dunlap; unlike Stone, the risk of experimenter effects is minimal, and the procedure requires the subject to judge the onset of a discrete signal in relation to a series of background signals, as in the traditional complication experiment. The basic method is the same for all his experiments. A train of five auditory pulses, each of 250 msec. duration with a 250 msec. ISI, is delivered. At one of five fixed points in this series (see Fig. 2.5) the discrete stimulus is presented, and the subject's task is to say where in relation to the background series the discrete stimulus was presented, with the response alternatives as shown in Fig. 2.5.

In his first report, Needham (1934) used a pure tone (1100 Hz.) as the series stimulus and a buzzer as the discrete stimulus. As a control, on a few trials he used the buzzer as the series stimulus and the tone as the discrete stimulus, but observed no difference in the results. The most salient feature of Needham's results (see Fig. 2.6) is the very large number of negative judgements, i.e. judgements where the discrete stimulus is reported as occurring earlier than it actually did. Significantly more "early" judgements were recorded than either positive ones or correct ones for all positions of the discrete stimulus except C.

Using the same general method, Needham (1936) set out to resolve some of the questions raised by this first investigation. The discrete stimulus was a 1000 Hz. pure tone instead of a buzzer, delivered in twelve different positions against a background of 3000 Hz. pulses. Paralleling the results of

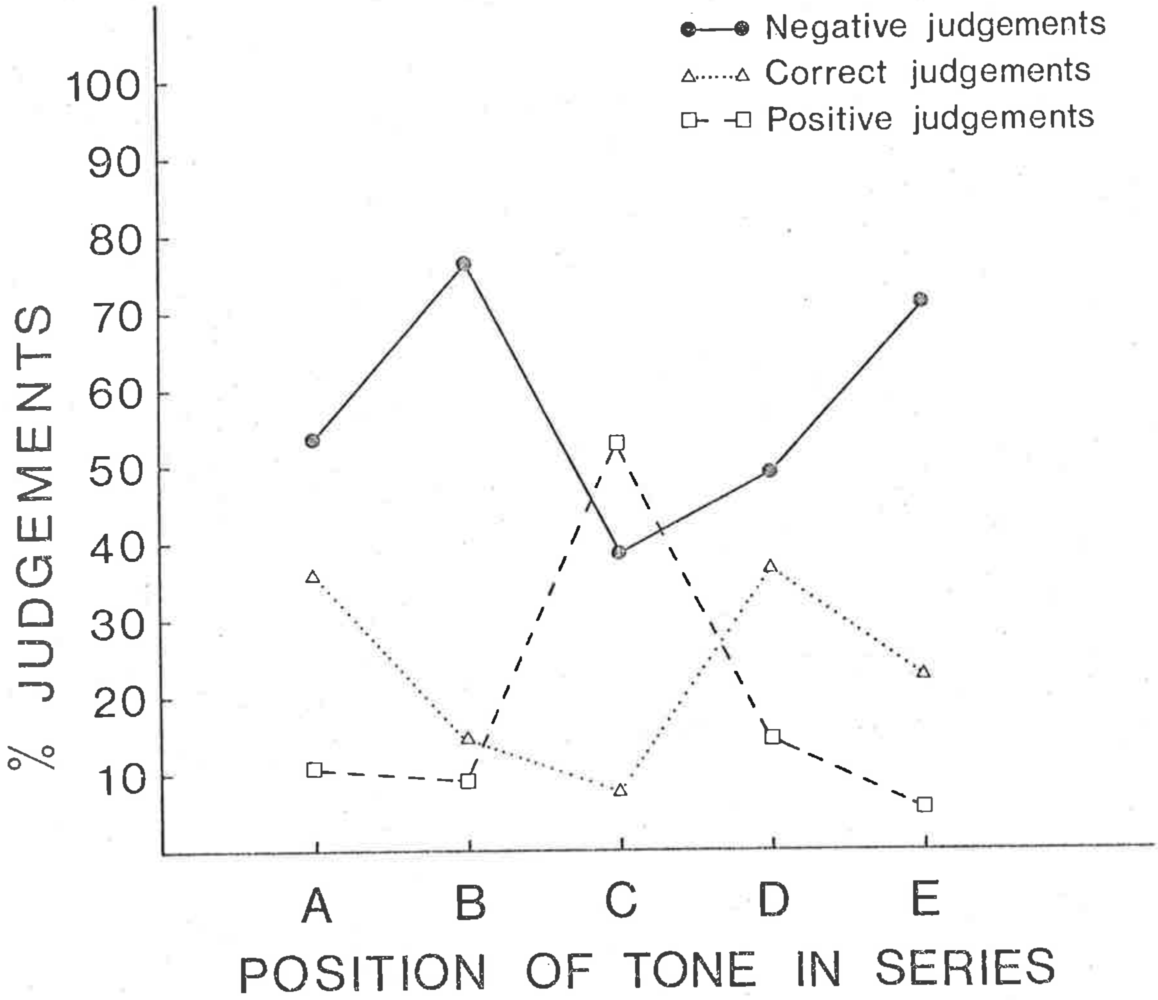

FIG. 2.6, Percentages of Negative, Correct and Positive judgements with Different Positions of the Discrete Stimulus in a series of Tones. (Reconstructed from Needham, 1934).

the previous experiment, fewest negative errors were found with the middle stimuli. Needham suggests some sort of expectancy mechanism to explain this feature of the data, which is supported by his subjects' introspective reports. If the discrete tone comes early in the series, it is accompanied by feelings of "surprise", while if it comes late in the series, there is "anxiety" about its appearance.

As well as the effects of position on the direction of errors, Needham also investigated the effects of intensity and pitch. Using the following four combinations of series and discrete stimuli:

	Series	Discrete
Part 1	3000 Hz./60 dB	1000 Hz./60 dB
Part 2	1500 Hz./60 dB	1000 Hz./60 dB
Part 3	3000 Hz./30 dB	1000 Hz./60 dB
Part 4	3000 Hz./75dB	1000 Hz./45 dB

and four positions of the discrete stimulus, he obtained judgements of the position of the discrete stimulus as before. Though there are differences in the absolute totals for different subjects, the direction of the differences between conditions is consistent. As can be seen from Fig. 2.7 most negative reports were obtained from Parts 1 and 4, which show similar proportions of judgements of all three categories. Subjects reported Part 3 to be the most difficult; apparently the loud discrete stimulus disrupted the rhythm of the series. Fewest negative responses were reported for Part 2, where there is no intensity difference, and the difference in pitch is minimal. In Part 1 there is a greater difference in pitch but

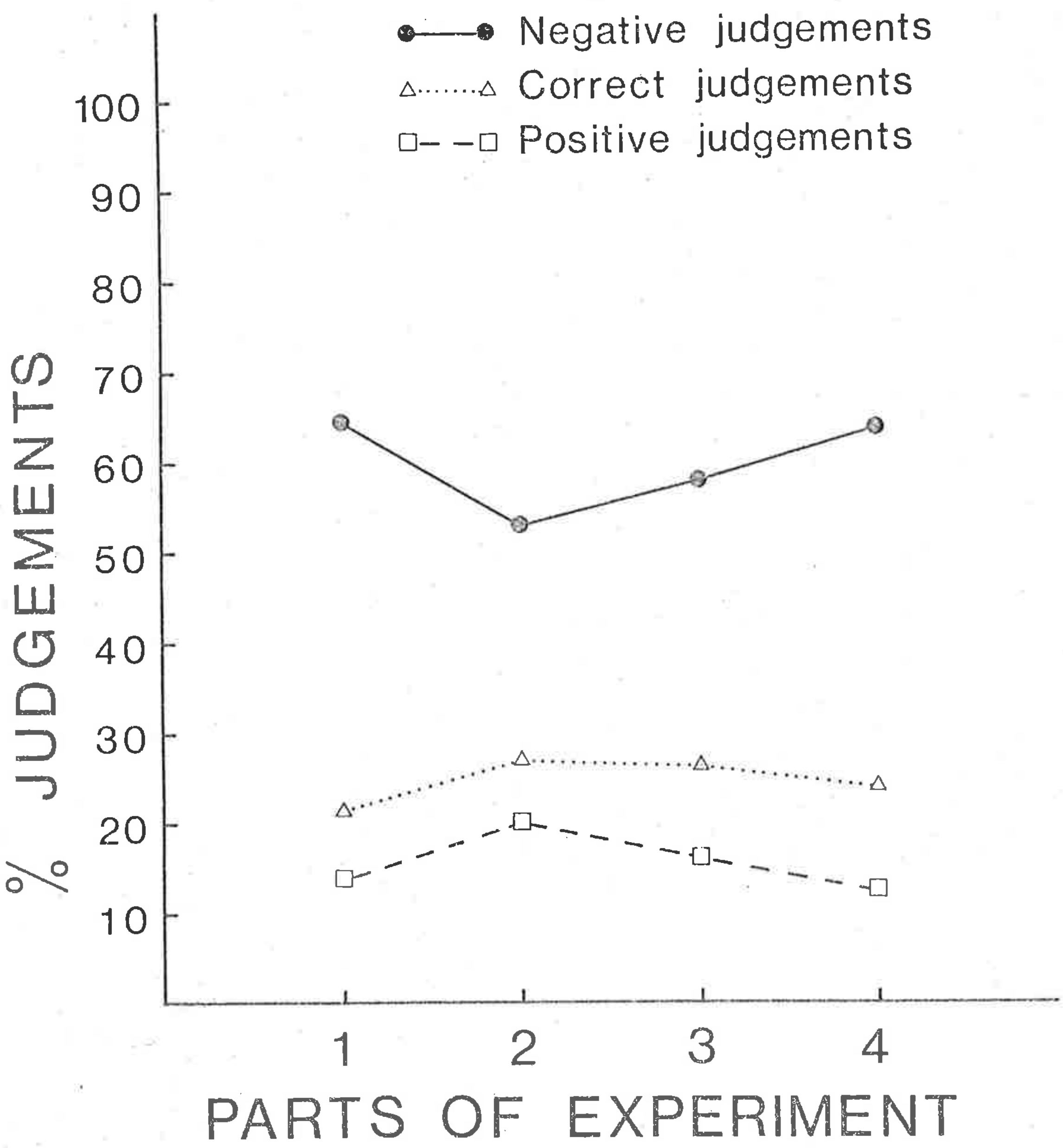

FIG. 2.7, Proportions of Negative, Correct and Positive judgements in Needham's experiment (from Needham, 1936).

no difference in intensity. Though it should be emphasised that the differences in proportions of responses between conditions is small, it would appear that differences in pitch are more important than differences in intensity.

A rather similar experiment which used different sensory modalities is reported by Welford (1948)who, although primarily concerned with simulating the heart-beat judgement commonly employed as a diagnostic technique in medical practice, did recognise the relevance of the classical complication experiment to his own, and considered his results in relation to the findings of Hartmann (1858, see Boring, 1950) and Stone (1926).

Welford's subjects were presented with series of ten pairs of pulses, the first of the pair being a low hum, the second a louder and harsher sound. At one of ten points between the onset of successive sound pairs, the subject was presented with a light tap on the right index finger, his task being to say where in relation to the sound pair this complicating signal occurred. Each tap and tone combination was repeated ten times before the subject made his response. Three different cycle speeds were used, speeds and positions being presented randomly.

High absolute errors but small constant errors were found, i.e. when the direction of the error is taken into account in computing the mean error, then the error is very small. Constant errors for all positions of the complicating stimulus save one were positive, the one negative constant error occurring midway between the end of one pair and the onset of the next. Uncertainty about the calibration of his apparatus at different speeds prevented

Welford from making comparisons of constant errors as temporal displacements at different speeds since they were so small, although absolute errors were found to increase in magnitude with increasing cycle speed, a finding which is directly contradictory to the results of Leatherman. When the absolute errors were converted into temporal errors, no such difference was found for different rotation speeds; this applied to most but not all of Welford's subjects so caution must be exercised in making any generalisations about stable time-errors. However, such a finding is consistent with Leatherman's results where a stable spatial displacement was found when the discrete stimulus had to be judged in relation to a moving pointer; since Welford's reference series had only a temporal dimension, a similar stable displacement in the relevant dimension might be expected.

A second experiment was carried out in order to determine the effect of instructing the subject to pay attention to one source of signals. The increase in absolute errors was small, and the increase in constant error negligible, having a mean of only 3.5 msec. when the instructions were changed from attention to sound to attention to touch. This fails to replicate the results of Stone mentioned above, but agrees with Hartman's (1858) finding that repeated presentation of the stimulus combination before the judgement is made results in a judgement of much greater accuracy (Welford, 1948).

4. Theoretical explanations of the results of the Complication Experiment

Psychophysiological explanations of the personal equation were sought from the earliest. For example, Bessel (1822) suggested the following: "If it is assumed that impressions on the eye and ear cannot be compared with each other in an instant, and that two observers use different times of carrying over the one impression upon the other, a difference originates; and there is a still greater difference if one goes over from seeing to hearing, and the other from hearing to seeing. That different kinds of observation are able to alter this difference need not seem strange, if one assumes as probable that an impression on one of two senses alone will be perceived either quite or nearly in the same instant that it happens, and that only the entrance of a second impression produces a disturbance which varies according to the differing nature of the latter." (Boring, 1950). In this statement we see foreshadowed three ideas which sooner or later became influential in psychology. First, we have limited capacity and single-channel operation implicit in the statement assumption that an impression on only one of two senses will be perceived nearly in the same instant that it happens. Second, there is a suggestion of the perceptual moment hypothesis, i.e. that we take in information about the world in discontinuous samples, such that we are unaware of any difference in the onset of different signals if they both fall within the time-span of one sample, inherent in the idea that we cannot take in and compare auditory and visual impressions in the same instant. Finally, there is the suggestion of the prior entry hypothesis in the contention that the difference between observers will be greater if one "carries over" from seeing to hearing and the other does the opposite. This prior entry explanation was perhaps furthest developed by Titchener (1908), and is concisely summarised by Boring (1950) in the following fashion: "What actually happens in the phenomenon of prior entry is that attentive predisposition favours earlier clear perception. If you are expecting the bell, listening for it, then the sound comes into consciousness more quickly than does the visual appearance of the pointer, and conversely." In other words, if we attend to the pointer, we become aware of the bell only after the point of actual coincidence and positive errors result. If, on the other hand, we are listening for the bell, then our perception of the pointer lags behind and we judge the bell-stroke to have occurred earlier than it actually did, giving rise to negative errors. This is an attractive explanation on the grounds of its generality, being applicable to stimulus combinations in all modalities or even in the same modality. Eye movement explanations, such as Dunlap's (1910), are unable to explain the generality of the effect across modalities, as are explanations based on the reflex times of different sense organs, e.g. Nicloai (1834, see Boring, 1950).

The other influential explanation of the complication experiment phenomena was advanced by Wundt (1874). He claims that the mind is so occupied with the bell-strokes that "apperception" (maximum sensory clearness) "ripens" following each bell-stroke in anticipation of the next (James, 1950).

The "ripening of apperception" follows its own set time-course; if the pointer speed is such that complicating stimuli are delivered before this "ripening" has been completed, then positive errors will result. With slower speeds, so that apperception ripens before the bell-stroke is delivered, negative errors result. Translating fairly literally into more modern concepts, Wundt seems to be advocating a "time course of preparation" argument. According to him, it takes a certain fixed time to prepare ourselves to perceive the bell stroke with maximum clarity; if the bell-stroke comes before this preparation can be completed, then it is judged as coming later than it actually did; if preparation is completed before the bell-stroke is delivered, then the subject anticipates and the bell-stroke is judged early.

There are two objections to such an explanation. First, more recent studies of the effect of warning signals on RT indicate that maximum facilitation of RT occurs with a fore-period in the region of 200 msec. (e.g. Bertelson and Tisseyre, 1968), which argues that the period required for optimal preparation is much less than the 2 sec. which intervened between the bell-strokes at Wundt's fastest pointer rotation speed. Second, a constant time-displacement rather than a constant angular displacement would be expected with different rotation speeds. It may be recalled that Leatherman found the opposite of this.

Of the explanations, only the prior entry explanation would seem to find much support for the data, though it must be admitted that it, too, is open to the last objection rasied to Wundt's account. It was the initial purpose of this thesis to test the prior entry hypothesis using quite a different experimental paradigm. Since no support was found for the prior entry hypothesis in either the review of the order judgement studies which follows in the next chapter, or in experiments reported in the succeeding two chapters, a further examination of the complication experiment itself was undertaken. The results of this are are reported in the final chapters, where a new theoretical explanation of the complication experiment is put forward.

CHAPTER 3.

ORDER JUDGEMENTS AS A TEST OF THE PRIOR ENTRY HYPOTHESIS

1. Rationale for Order Judgement as a Test of the Prior Entry Hypothesis

The theoretical appeal of the prior entry hypothesis has already been discussed in the first chapter, and its origins and the data it was used to explain have been dealt with in the second chapter. Of the explanations of the phenomena of the complication experiment, the prior entry hypothesis emerged as the only one advanced so far which is not contradicted by the data, as well as being the explanation with the widest generality. However, none of the experiments cited so far could be regarded as a critical test of the prior entry hypothesis. In the classical studies of complication experiments, prior entry is very much a post hoc explanation, of no predictive value. In Stone's (1926) experiment, which comes nearest to a critical test of the notion, the prior entry hypothesis was confirmed; the objection that her procedure may well have produced the results by an experimenter bias effect rather than an attentional effect has already been made.

What then would constitute an adequate test of the prior entry hypothesis? It will be recalled that the prior entry hypothesis, in its simplest form, asserts that if we are attending to one source of information, then signals coming from that source will be perceived sooner than simultaneous signals coming from other competing sources. It follows that any satisfactory test of this idea must (1) manipulate attention to one of at least two sources of information, but not in such a way as to directly bias any order judgement required of the subject, (2) be capable of showing a change in the perceived temporal relation of signals from the attended source to signals from other sources. That is to say, for the hypothesis to be confirmed the onset of signals from the attended source would have to be perceived as happening relatively sooner than the onset of signals from the unattended source.

It would seem that these conditions can be met by using an order judgement situation, somewhat similar to Stone's, in which the subject is required to make a decision about the nature of a signal from one source and judge the onset of each of these signals in relation to the onset of a signal from another source. This procedure has the advantage of directing the subject's attention to one source of information without explicitly telling him to do so, thus minimising the risks of effects other than attentional ones affecting the subject's performance.

One further improvement over Stone's method is adopted in the present investigation, and that is the adoption of Signal Detection Theory (TSD) measures in the design of experiments and the treatment of results. Two main advantages result from this methodology. First, it breaks performance down into both sensitivity and bias components instead of confounding them as the classical threshold methods do. When the psychometric function is the measure adopted as the dependent variable, we have no means of determining to what extent changes are due to alterations in the subject's capacity to order signals and to what extent they are due to alterations in the subject's willingness to report one or other of the alternatives. As will become clear in a later section of this chapter, temporal judgements, particularly those involving bisensory judgements, show both marked differences between individuals and instability over time. It would seem particularly desirable in this situation, then, to have sensitivity measures which are independent of any bias effects. Furthermore, TSD methods allow the use of rating-scale data which makes for very economical data-collection, important in view of the relative instability of temporal judgements.

The present situation, where the subject has to judge the order of two signals in different modalities, has some of the features of a Two-Alternative Forced-Choice Task. Let us assume that the amount of time intervening between the onset of a signal and its detection is such that over a series of trials these delays form a normal distribution, and that the distributions from Auditory-Visual or Visual-Auditory combinations overlap. The observer may then be thought of as taking, say, the visual signal as a reference and deciding whether the difference in time between the detection of the visual reference signal and the auditory signal is positive or negative. Both the Visual-Auditory and the Auditory-Visual presentation orders give rise to a distribution of differences in much the same way as the two alternatives do in the usual 2AFC situation. The observer's task on any trial is then to decide to which of the two distributions of differences the difference between the detection times on that particular trial belongs.

These assumptions may or may not be realistic; it could be, for example, that the auditory-visual order generates a distribution of differences completely different from that generated by the visual-auditory presentations. The above exposition is merely illustratory, intended to clarify the rationale behind applying TSD measures to order-judgement data. The non-parametric TSD measures used in this study, the area under the ROC curve, P(A), and the non-parametric bias measure, B, require no assumptions about the normality of underlying distributions of sensory effects. They do, however, provide useful measures of discrimination in terms of sensitivity and bias in Yes-No and 2AFC situations.

Conceived in TSD terms, the prior entry hypothesis predicts an increase in both the probability of "hits" (reporting a visual signal as coming before an auditory signal when this was the true state of affairs) and the probability of "false alarms" (saying the visual signal came first when the auditory one actually did) under the condition where the subject has to make an additional decision about one of the signals (in this case the visual one). Since both hits and false alarms increase, no prediction can be made about the sensitivity measure in this case, since any change in sensitivity would depend on the change in the probability of hits relative to the change in the probability of false alarms. However, a shift in the bias measure would follow if both hits and false alarms increase.

The predictions from the prior entry hypothesis, then, are

(1) no change in the sensitivity measure; (2) an increase in bias towards 'visual first' responses.

These predictions are tested in the experiments reported in Chapters 4 and 5.

Since the methodology employed in the first part of this investigation is based on an order-judgement paradigm, it is convenient to review previous studies of order-judgement at this stage prior to reporting the experimental work. It is recognised that this review falls short of a complete coverage of the literature on order judgement; nonetheless, it is hoped that this review will be sufficient to outline the main findings of order-judgement studies which are comparable to our own experiments. With this in mind, the review concentrates upon bisensory order-judgement studies or studies which indicate a distinct difference between bimodal order-judgements and some others.

2. A Review of studies of Order-Judgement

Some investigators have been interested in establishing man's capacity for temporal resolution for its own sake, but most have been interested in using order-judgements as a means of testing hypotheses about peripheral or central mechanisms of the nervous system. This being the case, it has been found convenient in the present review to group studies according to the theoretical interests of the investigator rather than on the basis of the experimental technique or type of situation. Such a taxonomy gives rise to the four main areas of investigation listed below. Since results included under one heading are often pertinent to the discussion in another section, frequent cross-referencing between sections will be evident.

1) Order judgement in the study of hearing. The ability to order sounds plays an important part in our perception of speech. The only critical difference between many words is the order in which certain phonemes occur, e.g. "bets" compared with "best". Hirsch (1959) drew attention to this feature of speech perception, pointing out that the ability to order sounds had received little attention by comparison with the vast amount of experimental literature on the detection and recognition of individual sounds.

Using a forced-choice procedure, Hirsch obtained psychometric functions for the judgement of the order of high-pitched and a low-pitched auditory signal over a range of inter-stimulus intervals (ISIs) from - 60 msec. (i.e. low pitched signal preceding by 60 msec.) to +60 msec. (high-pitched signal first). Good straight line fits were obtained for the plot of normalised proportions of "higher first" responses against ISI. An ISI of "a little less than 20 msec." permitted accurate ordering of the signals, this value representing the 75% correct threshold; no constant error was observed, the point on the function representing 50% correct responses being at the point of objective simultaneity. Very similar results were found using tones of different frequency, or white noise and a tone. Results using a click and a tone, or a high-pitched and a low-pitched click were again similar, though the slope of the function was steeper.

Green (1971) has reviewed more recent studies of temporal auditory acuity. Although the ear can integrate energy in such a fashion that detectability is constant so long as the product of signal intensity and signal duration is constant for durations up to 100-200 msec. (Zwislocki, 1960), this is no reason to expect that observers will be unable to distinguish the order of events within that interval. The significance of this point will be pursued in a subsequent discussion of the "perceptual moment".

What then are the limits of temporal resolution within a single modality, such as audition? Using a straightforward order-judgement paradigm, Ronken (1970) has shown that observers can distinguish the order of clicks separated by intervals as short as 2 msec., a finding which is confirmed by several other more elaborately conceived investigations.

Patterson and Green, (1970), confirmed this upper limit for temporal resolution using particular types of waveforms called Huffman sequences, which are waveforms in which the energy at one particular frequency is delayed. The energy spectra (i.e. the distribution of energy at different frequencies) of these waveforms are identical; the only way in which they differ is in the order in which the energy at different frequencies occur, so that the ability to distinguish between these sequences is a test of temporal resolution. Patterson and Green used Huffman sequences with phase delays at 200 Hz. and 1000 Hz.; both waveforms sounded rather like a click, but the sequence with the 1000 Hz. high frequencies delayed sounded rather like "tick", while the sequence with the 200 Hz. low frequencies delayed sounded more like "tock". The more the overall duration of the sequence is reduced, the more both of these sequences will come to sound like a brief burst of white noise, and the more difficult it will be for a listener to distinguish between them. The duration at which the sequences can no longer be distinguished represents the limits of the auditory system's temporal resolving power. Patterson and Green report that listeners can achieve approximately 100% correct discrimination with sequences of 10 msec. duration, and about 75% with durations as short as 2-3 msec., which agrees well with Ronken's findings.

Further support for an upper limit of temporal resolution of the order of a few milliseconds comes from experiments by Leshowitz (1971), and Miller and Taylor (1948). Leshowitz's experiment involved the perception of synthetically produced fricatives i.e. speechlike sounds having energy over most of the audible spectrums. Half of these fricatives were produced by reversing the order of the filtering or noise bursts which produced the sounds, so that effectively, they were the same sounds in reverse and the energy spectrum of any pair of waveforms was identical. With total durations of 50 msec., Leshowitz found that subjects could discriminate between the fricatives when the reversal was as short as 5 msec.

Miller and Taylor presented subjects with white noise which was interrupted at various frequencies, the subject's task being to set an oscillator to match the interruption frequencies. Subjects could make reliable matchings with interruption rates up to 500-1000 Hz., which again suggests an upper limit on temporal resolution of the order of 1-2 msec.

Clearly then, under some circumstances, our ability to order sounds is of a very high level indeed. As we shall see, this is in marked contrast to our ability to order signals in most bimodal and some unimodal situations.

2) Order Judgements as a means of Estimating Latencies of Sensory Processes. The second main group of studies has been concerned with using judgements of order as a means of assessing the latencies of different signals in the same modlity or signals in different modalities. The rationale behind the procedure is as follows: the onset asynchrony which only just results in the signal with the shorter latency being perceived as coming after the signal with the longer latency is assumed to represent the difference in latency between the two signals. By using one particular signal as a reference, comparison between latencies of different signals can be made relative to that reference signal.

Most studies of sensory latency have used reaction time as a measure, a procedure which must be viewed with some caution. For example, Sanford (1971) in his complication experiment, has shown that under some circumstances the effect of intensity on reaction time is disproportionate to its effect on perceptual delay. Temporal order judgement procedures then are a necessary supplement to RT studies in this area.

Roufs (1963) did in fact use both order judgements and RT in his investigation of the effects of luminance on perceptual delay. Though previous investigations have shown that latency increased with lower signal luminance, no agreement had been reached on the precise relationship between luminance, adaptive state and latency, and it was this relationship which Roufs sought to clarify by directly comparing methods used by different experimenters. Three different ways of estimating delay were used; RT, adjusting flash onset in relation to another flash, and adjusting flash onset in relation to a tone. With the double flash method, the subject had to adjust the onset of a bright light patch in relation to a dimmer light patch so that the apparent movement in the direction of the dimmer light disappeared. The delay selected increased with increasing difference in intensity. Similarly, the delay chosen by subjects so that the onset of the light appeared to be simultaneous with the onset of a constant tone stimulus decreased as a function of luminance. In this case, the tone always appeared to precede the light over the range of luminances used by between 20 and 50 msec., and the results obtained using this method were much more variable than those obtained using the double flash method. Comparing estimates of perceptual lag obtained from RT to different luminances to the estimates derived from the order judgement data revealed similar results, and data obtained by all three methods were well fitted by the equation

$$\mathcal{T} = t - t_o = -T \log_e E/E_o$$

where $\mathcal{T}$ is the perceptual lag, t and t_o the perceptual delays of the signals with retinal illumination of E and E_o respectively, and T is a constant (of the order of 10 msec.).

Rutschmann and Link (1964) extended this rationale as part of an attempt to replicate the findings of an experiment by

Hirsch and Sherrick (1961), discussed later. Subjects were required to judge the order of a visual signal (an increase in the luminance of a fixation target) and an auditory signal (10 msec. burst of white noise). Reaction times were recorded for both signals separately in different blocks of trials. Rutschmann and Link reasoned that if the "temporal organiser" had the same input as the "response mechanism", then the ISI which results in most uncertainty in the order judgements would be equal to the difference in RTs to the two signals i.e. fewest correct order judgements would occur when the signal with the longer RT preceded the signal with the shorter RT by an ISI equivalent to the difference in RT. On the basis of the RT data, maximum uncertainty should have occurred when the visual signal preceded the auditory one by about 40-50 msec. In fact, the point of maximum uncertainty occurred when the auditory signal preceded the visual by 40-50 msec. Further examination of the signal characteristics employed by Hirsch and Sherrick indicated that had they also collected RT data from their subjects on the basis of other reports in the literature, the difference in RT would have been of the order of 80-95 msec. Now if, as Rutschmann and Link's data show, the auditory signal has to come some 80-100 msec. earlier than the RT data would predict to achieve 50% auditory first responses, then signals which differ in RT by 80-95 msec. would be expected to give rise to maximum uncertainty when they were approximately simultaneous, which was in fact what Hirsch and Sherrick found.

Pursuing this course of investigation further, Rutschmann (1966) has demonstrated that visual signals of equal intensity tend to be judged as coming first when they are presented foveally rather than 30° to the nasal or temporal retina, the 75% threshold for "foveal first" responses being found at intervals up to -40 msec., depending on the subject. Though this finding is in agreement with data reported by Poffenberger (1912), they are in marked disagreement with the data of Hirsch and Sherrick (1961) who found similar psychometric functions for order judgements of visual signals which were separated by 5°, 10° or even 20°.

Gibbon and Rutschmann (1969) once again attempted to predict order judgement functions using RT data. This time, only visual signals were used, a constant change in luminance (-0.1 mlam.) being presented to the nasal region of the right eye, 50° from the fovea, and a variable change in luminance (+2.1 mlam., -0.1 mlam., or -1.2 mlam.) being delivered foveally to the left eye. These values were chosen so as to provide foveal latencies which would range from longer than to shorter than the latency for the peripheral standard. The psychometric functions were in all cases significantly different from the functions predicted by the RTs to these stimuli, though the shape of the functions was quite similar. The 50% threshold for order judgement varied as a function of signal luminance, the foveal signals tending to be judged as coming earlier as the luminance increased.

Some evidence from order judgement studies indicates that the order of stimulus offsets can be accurately judged with shorter ISIs than can the order of stimulus onsets. Oatley, Robertson and Scanlan (1969) obtained psychometric functions for the onset order of two relatively long-lasting (2 sec.) visual signals which were about half as steep as previously reported functions for similar judgements which used signals of shorter duration. This finding prompted Walsh (1973) to investigate psychometric functions for order judgement using an onset and an offset signal. His results indicate that the PSS (i.e. the point at which the function for 'onset first' responses reaches a value of 0.5) occurs when offsets precede onsets by about 40 msec., demonstrating that under some circumstances at least offsets have shorter latencies than onsets. If in previous experiments subjects had been responding to the offsets of brief signals rather than onsets, then functions steeper than those obtained by Oatley _et al_. would have resulted.

In apparent conflict with these results is Efron's (1970a,b) finding that offsets of a light have to precede onsets by some 110 msec. to be judged as simultaneous. In addition to the doubts that Efron himself has raised concerning the psychophysical technique he used, we may also note that judgements of simultaneity give rise to psychophysical functions rather different from those obtained for order-judgements (e.g. Hirsch and Fraisse, 1964): this point will be developed in a subsequent section. Asking subjects to judge whether the onset or the offset of a light was simultaneous with a brief click signal, Efron (1970c) showed that the onset of the light was judged correctly no matter what its duration. Offsets tended to be judged late with stimuli of 130 msec. duration or less, the offset being judged later the shorter the duration of the stimuli. This Efron takes as supporting the main point of his previous two papers, viz. that perceptions have a minimum duration, and the shorter the duration of a stimulus below a certain critical level, the longer its "persistence". However, Walsh points out that this finding as well as his own can be accounted for by supposing that the evidence for an "on" response may sometimes take longer to accumulate than the evidence for an "off" response: if the regularity of firing depends on the strength and duration of a stimulus, then stimuli of shorter duration would tend to generate less regular firing with the result that the cessation of this firing would be more difficult to detect.

3) Order Judgements as a measure of the capacity of the central processing mechanisms. This is another area which has more usually been studied using RT methods and where again order judgement data is a valuable supplement. Just as the minimum interval required to respond to successive signals provides us with a measure of the limits of performance on the output side, so the interval for correct order judgement of two successive signals provides an indication on the limits of central processing on the input side.

Probably the earliest interest in order judgement was evinced by Exner (1875), who, according to James (1950), was concerned with "the minimum amount of duration which we can distinctly feel". Exner reports both judgements of simultaneity versus successiveness and order judgements in his attempt to measure this. In the simultaneity versus successiveness judgements, identical signals are used, and Exner reports that the minimum duration to produce reliable judgements of successiveness is 2 msec. for auditory clicks, and 44 msec. for brief flashes of light. With the order judgements, signals must be used which are distinct in terms of intensity, location or quality so that they can be identified and ordered. Exner used heretomodal stimuli and found the "smallest perceptible interval" for various combinations to be as follows:

From sight to touch	71 msec.
From touch to sight	53 msec.
From sight to hearing	16 msec.
From hearing to sight	60 msec.

When dichotic click stimuli were used, the interval required was 64 msec. All these values are rather high by comparison with the findings of other investigators, the reason being that Exner required 10 successive correct reports from his subjects before he considered the judgement to be reliable, and as Hirsch and Sherrick (1961) point out, this corresponds to the 98% point on the psychometric function.

Hirsch and Fraisse (1964) report psychometric functions for bisensory stimulus combinations which show that subjects can order stimuli correctly although they still seem to be simultaneous. Using a click and a light which were adjusted to be of equal subjective intensity, they found that the PSS for order judgements was found when the light preceded the click by 20-30 msec., while stimuli were judged successive rather than simultaneous when the click preceded by 60 msec. or the flash preceded by 90 msec.

Comparable results are reported by Dinnerstien and Zlotogura (1968) who report somewhat lower values for 50% thresholds. The values reported by Exner are not inconsistent with the 98% point on functions reported by Hirsch and Sherrick, though the marked asynchrony Exner reports between modality combinations is in contrast to their findings. With binocularly viewed visual signals, monaurally and dichotically presented clicks, vibrotactile impulses and combinations of all possible pairs of signals, Hirsch and Sherrick found, as did Hirsch (1959) in his earlier experiment mentioned above, that the psychometric functions passed through the point of objective simultaneity, and the 75% threshold corresponded to an ISI of 20 msec. for all signal combinations. They conclude "The judgement of order requires that two pieces of information must be organised with respect to time, and the results of the present studies seem to indicate that it does not much matter where the 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. The time required to insure, for example, judgements that are 75% correct is approximately 20 msec. It is much longer than the resolution times that give rise to successiveness in any of the modalities....".

However, results which contradict this view have already been cited. For example, Rutschmann and Link (1964) found psychometric functions for audio-visual order judgements in which the point of subjective simultaneity occurred when the auditory signal preceded the visual by 40-50 msec., contrary to what would be expected in view of faster RT to auditory signals. Since Hirsch and Sherrick did not vary the stimuli they employed in a systematic fashion, it seems probable that their results are an artefact of the stimulus parameters they used, and have little generality. Certainly, the studies by Roufs and by Gibbon and Rutschmann, discussed in the previous section, have demonstrated the effect of luminance on perceived order, and it seems reasonable from data on RT as a function of intensity (e.g. Chocholle, 1945) that similar effects would occur in other modalities.

The general findings of Green's (1971) review that the auditory system is capable of ordering signals separated by intervals as short as 2 msec. would seem to be almost matched by the temporal resolving power of the visual system, at least when dichoptic viewing is used. Robinson (1967) reports that subjects were 100% accurate in ordering visual signals presented dichoptically by means of polarising filters when the ISI was only 5 msec., a finding which Thor (1967) at first was unable, but later succeeded in replicating (Thor, 1968). Although Thor maintained that subjects used the cue of direction of apparent movement to decide which stimulus came first, Robinson (1968) pointed out that it mattered little whether the central processing mechanisms discriminated order or direction: the fact remains that at 5 msec. separation, the two signals can be treated discriminatively. With monocular viewing, Robinson obtained results comparable to those of Hirsch and Sherrick; with an ISI of 20 msec., 60-80% of the judgements were correct.

Though in this case the results of Hirsch and Sherrick were confirmed, the question which now arises is which of the two different methods is the more appropriate measure of the temporal resolving capacity of the central processing mechanisms. That is to say, is temporal resolving power more adequately represented by our ability to order diffuse and rather different signals in the same modality or in different modalities, or by our ability to order rather similar signals presented to different receptors in the same modality? It would seem that this latter course, judging by Robinson's methodology and the studies of auditory order judgement eliminates peripheral factors as far as possible and, hence, is a better way of measuring the temporal resolving power of the central nervous system.

There is one point on which data reported by Hirsch and Sherrick and the data reviewed by Green are in direct contradiction. While Hirsch and Sherrick report for clicks, as for most other stimulus combinations, 75% correct judgements with an ISI of 20 msec., Ronken, for example, reports a threshold of no more than 2 msec. A study by Babkoff and Sutton (1963) resolved this apparent paradox. They found that subjects could accurately discriminate order with ISIs of 12 msec. or less, and that accuracy <u>declined</u> with increasing ISI. From loudness judgements of the two clicks obtained in blocks of trials interspersed with the order-judgement trials, it was apparent that the tendency to judge both clicks as being equally loud increased with increasing ISI, and thus it seems probable that the diminution of the loudness cue can account for the reduced order-judgement accuracy. Data from the one subject that Babkoff and Sutton tested with ISIs between 12 msec. and 20 msec. does agree well with the findings of Hirsch and Sherrick, for the ISI they found which corresponded the 75% threshold was approximately 17 msec.

The study of information processing capacity with ageing is another area which has traditionally relied heavily on studies of RT, and here again there have been few attempts to supplement this RT data with studies of temporal resolution. Two at least are worth considering here, because of the support they give to the data already discussed.

Weiss and Birren (1957) found a difference between the interval required by old and young subjects to discriminate two 0.25 msec. clicks at 30 dB. above threshold from one such click. This change was apparently unrelated to either absolute threshold or to performance on a temporal numerosity task. Results were generally comparable to Exner's findings; for the older subjects the median interval required for the judgement of two clicks was 1.72 msec. and for the younger subjects, 1.80 msec.

Dinnerstein and Zlotogura (1968) compared the performance of old and young subjects on RT tasks, inter-modality order-judgement tasks and a battery of tasks involving skilled performance. The correlations between temporal ordering ability and performance on the skilled performance battery were significant only for the older subjects in the sample. Of more immediate interest for our present purposes, however, are the values they report for order-judgement thresholds. The 50% thresholds obtained for auditory-visual judgements (visual preceding by 71 msec.), auditory-tactile judgements (tactile preceding by 66 msec.), and tactile-visual judgements (visual preceding by 16 msec.) are markedly different from Hirsch and Sherrick's repeated finding of coincidence of subjective and objective simultaneity with an interval of no more than 20 msec. necessary to produce 75% correct judgements, but it can be seen that the auditory-visual judgements did produce results consistent with those of Hirsch and Fraisse. In both cases, the PSS occurred when the visual stimulus preceded. Presumably the different intervals can be accounted for by the different stimulus parameters.

4) Order Judgement as a means of testing hypotheses about central functioning. The fourth class of investigations has used temporal judgement, especially order judgement, as a means of testing the mode of functioning of the central processing mechanisms. There are two main issues which have received fairly close scrutiny from investigations using order-judgement paradigms, the Prior Entry hypothesis and the Perceptual Moment hypothesis. The rationale of order judgement as a test of the Prior Entry hypothesis has already been discussed; if it can be shown that manipulation of attention by changing instructions to the subject, or by changing sensory quality or intensity, results in signals of that class being reported as occurring earlier relative to signals of another class, then this can be regarded as supporting the hypothesis. In the second case, order-judgements have been used as a measure of the perceptual moment, or sampling period within which all sensory events are in some sense processed together, the rationale behind this procedure being that subjects will not be able to distinguish

the order of events falling in the same perceptual moment.

i) The Prior Entry Hypothesis

Mention has already been made of Stone's (1926) study, which represents a very direct approach to the problem of Prior Entry. It may be recalled that she found that psychometric functions for heteromodal order judgement shifted in the predicted direction when subjects were directed to attend to the signals in one particular modality, a result which was interpreted as confirming the Prior Entry hypothesis. Apart from the objections which have already been made to her procedure, it appears that data from earlier studies of order judgement are in disagreement with this finding.

Hamlin (1895) reports 75% thresholds for order judgement for pairings of click, flash, and electric shock signals. Flash-shock and click-shock pairings resulted in very variable intervals with marked differences between individuals. Click-flash and flash-click pairings for both of her subjects were more consistent in that the click-flash order always required a greater interval for its correct identification than did the flash-click combination, a result which shows the same trend as Exner's (1875) data, though the intervals are longer. Hamlin followed these determinations with a series in which subjects' attention was directed onto one or other modality, in the first instance by directing the subjects to attend to a particular modality, a procedure which had no effect on the perceived order of signals, and in the second instance by varying the intensity of the auditory stimulus, a procedure intended to involuntarily direct attention to the auditory signals. In fact, one subject's attention seemed to be caught by the weaker sound, so that he gave more correct responses when the weaker sound came first, while the results of the second subject went in the opposite direction.

Whipple (1898) attempted to reconcile the conflicting results reported by Hamlin and Exner by running the same subjects under the different experimental conditions used by Exner and Hamlin. Whereas Exner required ten successive correct judgements from his subjects, Hamlin used single presentations. Using a method similar to Hamlin's, Whipple confirmed her results, the click-flash trials requiring a longer interval (81 msec.) for their correct identification than the flash-click trials (41 msec.). When ten correct repetitions were required of the subjects, a difference between the two thresholds remained, but both the thresholds and the differences between them were very much reduced.

Further support for this result can be found in the work of Smith (1933), who investigated both order-judgement and successiveness thresholds with auditory and visual signals of varying intensity. For most of the intensities used, subjects required a smaller interval to reach 75% correct judgements with flash-click presentations than with click-flash presentations. Intensity was found to affect the order-judgement threshold. In contrast to most other investigators, Smith found less variability in the intervals required for the judgement of successiveness; the interval required tended to be stable over conditions and subjects, with a value for both click-flash and flash-click trials of about 40 msec.

Drew (1896) pursued the effects of voluntary attention further. Using both click and shock stimuli separated by an interval of 24 msec. with unimodal stimulation, he found that directing attention to one sense organ (ear or hand) reduced the proportion of correct responses. With bimodal signal combinations separated by 31 msec. a higher proportion of click first and a lower proportion of shock first trials were correctly judged than was the case with unimodal presentations. When the subject was directed to attend to one modality, it would appear that the judgement of order changed in the opposite direction to that predicted by the Prior Entry hypothesis, though the effect is very slight. Since Drew omits any mention of the physical dimensions of his stimuli, the most that can be concluded from his data are that directed attention does not necessarily change the perceived order of two signals, a result which directly contradicts Stone's findings. It may be concluded then, on the basis of objections to Stone's method and the failure to find any confirmation of her finding in comparable experiments, that order-judgement studies have so far failed to support the Prior Entry hypothesis, a conclusion which foreshadows the results of our own investigations.

ii) <u>The Perceptual Moment</u>

Perhaps the most controversial issue in which judgements of the order of events have been of major theoretical importance has been the perceptual moment hypothesis. Stroud's (1955) initial conception of the perceptual moment was of inputs to the central processing mechanisms which were discontinuous in time, all the events falling in the space of one of these discrete sampling periods being processed together. Kristofferson (1967) has put forward a similar theory based on a single-channel processing mechanism which has the property of being able to switch between functionally separate channels only at certain fixed points in time. It follows from this that the interval required to discriminate the order of events in different channels can be used to estimate the time required before the central processor can switch attention between channels. If the central processor does admit inputs from separate channels in temporally discrete samples, the probability of correctly ordering signals from different channels should rise linearly as a function of ISI. The increment in ISI required to produce an increase in the proportion of correct responses from chance level (0.5) to completely correct (1.0) is then equivalent to the interval required to switch attention between channels.

Using the offset of light-tone pairs as signals, Kristofferson adopted a 2AFC procedure in which subjects had to say in which of two light-tone pairs the offset of the signals was asynchronous. The standard pair always had objectively simultaneous offsets. Such a procedure, which in effect measures the subject's ability to discriminate successiveness, would obviously tend to minimise the interval required for correct judgement, and in fact 50% correct judgements were found with ISIs of only 10 msec., and completely correct judgements were found with asynchronies in the region of 65 msec., though individuals did vary. This yields an estimate of approximately 55 msec. for the time required to switch between channels. Kristofferson then went on to consider his data in relation to electrophysiological and RT data. It is not intended to give consideration to all the data relevant to the perceptual moment hypothesis here; this has already been extensively covered in recent reviews by Sanford (1970) and Sternberg and Knoll (1973). These latter authors consider varieties of the perceptual moment hypothesis along with other possible models of the order judgement process, and point out the difficulty of deciding between different models on the basis of the psychometric functions they predict, which differ little.

Particularly relevant to the methods used in the present investigation with regard to this problem is Baron's (1969) use of ROC curves for the judgement of the order of the movement of two light signals, the movements being separated by some 32 msec. Baron's results seem to favour the view that the time taken to detect an event is normally distributed, rather than the view that events fall into separate quantal units of time, since the normalised ROC curves he obtained tended to be straight lines rather than bow-shaped outward curves predicted by the moment hypothesis. Straight lines for normalised ROC curves have been found in a wide range of perceptual and memory tasks, and are consistent with the notion of an observer moving a cut-off point across two overlapping normal distributions of sensory effect (McNicol, 1972). However, it is worth pursuing a few of the questions which the present review of order studies raises for the perceptual moment controversy.

To begin with, we may note that the duration of the moment given by Kristofferson is about half that accorded to it by other investigators, Stroud putting the value at about 100 msec. on the basis of quite different evidence. Lichtenstein, White, Siegfried and Harter (1963) found that subjects adjusted the cycle time of four successively flashing lights to 125 msec. in order to make all the elements in the display appear simultaneous, a result which held whether the display elements were evenly or irregularly spaced. The results of Thor and Spitz (1968) similarly support the idea of total presentation time of the stimulus display as the most important determinant of the judgement of order. They found that correct judgement of the order of an upright and an inverted triangle presented at the same spatial location was related to the overall duration of the stimulus combination rather than to the ISI.

The involvement of peripheral factors in these two studies just mentioned does raise serious doubts as to their relevance as measures of the temporal resolving powers of the central mechanisms. Sufficient studies have already been referred to in which the effects of peripheral factors have been eliminated as far as possible, resulting in quite a different picture of the limits of temporal resolution. For example, the work of Exner (1875) and Ronken (1970) has shown that in some circumstances auditory signals can be perceived as successive and correctly ordered with ISIs as small as 2 msec., and Robinson (1967) has demonstrated thresholds of a similar order for vision. However, these results can be accommodated by Kristofferson's theory. This requires us first to assume that, in those instances where very low order and successiveness thresholds are found, the two signals can be regarded as being in the same functional channel, since Kristofferson did stress that this attention-switching was between channels. We must further assume that so long as events occur in the same channel, they can then be ordered within a discrete temporal sample to a much finer degree than hitherto proposed. It would seem reasonable to classify most of these auditory temporal resolution studies as being cases where the signals belong to the same functional channel, the presentations being monaural or binaural rather than dichotic. When Exner (1875) did present clicks dichotically, which in effect can make the ears behave like different channels, then the 75% threshold for correct order judgement rose to 44 msec., a result not discrepant with Kristofferson's findings, bearing in mind the difference in the tasks and the psychophysical methods.

The cross-modal order judgements in the preceding section on the prior entry hypothesis are similarly consistent with the findings of Kristofferson, though again they are concerned with the judgement of order rather than successiveness.

However, there remains one inconsistency in the case of visual order judgements. Thor and Spitz (1968) report that total presentation time mainly determines the proportion of correct order judgements, and that this total presentation time must be of the order of 100-120 msec. for perfect performance under conditions of binocular viewing. By way of contrast, Robinson (1967) reports that with brief (10 msec.) signals dichoptically presented by means of polarising filters, an ISI of only 5 msec. yields 100% correct order judgements. Certainly, in Robinson's case, it is possible to argue that since the signals were presented in the same spatial location, they belong to the same functional channel, as with the monaural clicks which have similarly small order thresholds. Peripheral factors (i.e. avoiding stimulating the same receptor cells in the eye, with their long recovery time) can then account for the discrepancy between the results of Robinson and of Thor and Spitz. It does seem somewhat paradoxical that visual signals should have to be presented to separate eyes in order that they can be shown to be handled by the same channel, and this should serve to make us wary of Kristofferson's potentially circular definition of a channel as "a set of all messages which can be admitted simultaneously into the central processor", and encourage much thought about the functional characteristics of signals before we decide whether they belong to the same or different channels.

CHAPTER 4.

TESTING THE PRIOR ENTRY HYPOTHESIS

The advantages of a TSD methodology were discussed in some detail in the previous chapter, so it is unnecessary to reiterate the conceptual basis of our means of testing the prior entry hypothesis here. To establish suitable intervals at which the signals in different modalities were to be presented, it was found necessary, following Experiment 3 which was actually the experiment completed first, to determine the thresholds for order judgements using the same apparatus and physical signal parameters which were to be used in the subsequent series of TSD experiments. Such determinations under conditions both of attention directed to one modality and of attention not specifically directed to either modality do incidentally constitute a test of the prior entry hypothesis although, for the reasons earlier discussed in relation to Stone's (1926) experiment, a somewhat unsatisfactory one. In this chapter the results of these psychometric function determinations and the principal TSD experiments are reported. As these experimental procedures require considerable amounts of time on the part of subjects, and as these procedures offer something less than fulfilling experiences to many of them, considerable organisational difficulties such as timetabling and subject attention were encountered in running the extended series of experiments reported in this chapter and the next. Since the aim of the investigation was exploration of the relationships between attentional conditions rather than the estimation of parameters, the non-uniform selection criteria for subjects in different experiments and the different numbers of subjects who completed the various experiments may be seen as relatively unimportant.

Since the apparatus and procedure remained essentially the same throughout the series of experiments reported in this chapter and the next, a detailed account of the apparatus and general procedure comes before the reports of individual experiments. Any subsequent changes in apparatus or procedure are described along with the relevant experiments.

APPARATUS

The visual signal was a pair of lines presented in the centre of the field of a Cambridge tachistoscope, and the auditory signal was a brief click presented binaurally through a pair of cushioned headphones. The experimenter started each trial by pressing a start button which released a pulse to a modular delay timer and to a Mallory Sonalert Audible Signal Generator, the latter delivering a warning signal immediately (100 msec. duration, 2000 Hz, 75 dB S.P.L.). After a delay of 1 sec., the delay timer triggered both the first signal (either the auditory signal or the visual one) and a second delay timer which later triggered the second signal. The inter-signal interval (ISI) was set manually by the experimenter before each trial. The visual signal in most of the experiments to be reported consisted of a pair of vertical lines, drawn from the top of the visual field one or either side of the centre line: where one line was longer than the other, the longer one reached the same distance below the horizontal mid-point as the shorter stopped above it. The auditory signal consisted of a click (2 msec. duration, approximately 70 dB S.P.L.) presented through the binaural headphones.

The experimenter recorded the subject's verbal responses on response sheets which designated the sequence of visual first and auditory first trials following a prepared random order.

GENERAL PROCEDURE

Under the first experimental condition, the subject was always presented with the same pair of lines in the tachistoscope and was required simply to judge whether the click or the lines came first. Under the second condition, the visual display was varied so that the longer line appeared as either the left-hand line or the right-hand line of the pair. The subject's task was first to judge which of the two lines was the longer, then to report the order in which the lines and the click occurred. A few trials with feedback preceded each experimental session; no feedback about the order of judgements was ever given during a session, but errors on the length judgement task were always pointed out to the subject. In order to ensure that the subject was attending to the visual signal under the second condition where the length judgement was required, it was emphasised that he should try not to make any mistakes about the length judgement.

1. PSYCHOMETRIC FUNCTIONS FOR ORDER JUDGEMENT WITH AND WITHOUT ATTENTION DIRECTED TO ONE MODALITY.

Experiment 1

Experiment 1 was intended to provide an estimate of the range of intervals over which uncertainty about the order of occurrence of the auditory and the visual signal was evident under both attentional conditions. The psychometric functions constructed from the subjects' responses show the changing probability of a "Visual First" (<VA>)[1] response with changing intervals between the two signals. The prior entry hypothesis predicts that paying attention to one modality results in signals in that modality being perceived relatively sooner than events in the other modality. Consequently, we would expect that a relatively later visual signal would produce the same probability of a <VA> response. Hence, we would expect that the threshold (or point on the function at which the probability of a <VA> response is .50) would occur when the visual signal is later in relation to the auditory signal under the condition where subjects have the additional decision to make about the visual signal.

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[1] The notation used to designate 'Visual first' and 'Auditory first' stimulus combinations and responses is uniform throughout the following chapters, and is an adaptation of conventional TSD notation for 2AFC tasks, where the subject has to say whether the signal interval preceded the noise interval or vice versa. Angled brackets < > enclose two letters which correspond to the order of the signals or to the subject's reported order of the signals. Lower case letters represent stimuli, e.g. <av> indicates that the auditory signal preceded the visual. Upper case letters represent responses, e.g. a 'Visual First' response is written <VA> . Extending this notation, first stimulus consideration, a 'hit' or correct 'Visual first' response is represented by $\langle VA \rangle /_{\langle va \rangle}$, a 'false alarm' or incorrect 'Visual first' response by $\langle VA \rangle /_{\langle av \rangle}$.

Method and Procedure

The apparatus was as described in the preceding section. In this experiment, the visual signal consisted of a pair of vertical lines, 0.5 mm wide, 10 mm apart, the longer line (71 mm) and the shorter one (69 mm), varying from left to right in a random fashion. The signal was presented for 10 msec., a masking card covered with vertical lines 0.5 mm wide and 10 mm apart being visible in the tachistoscope for the remainder of the time.

The procedure adopted was the Method of Constant Stimuli, different ISIs throughout the range being presented in random order. Initially, ISIs ranging from -40 msec. (i.e. auditory signal preceding by 40 msec.) to +40 msec. (visual signal preceding) in 20 msec. steps were used. This range was altered during practice sessions to accommodate individuals who experienced difficulty in perceiving trials as being mainly either ⟨VA⟩ or ⟨AV⟩ at the extremes of the range, so that functions for different individuals cover a different range of intervals.

All subjects commenced with two full practice sessions, followed by five sessions under Condition 1 (order judgement only). Subjects were then given training on the length discrimination task at the exposure duration used in the experiment until they reached a criterion of eight successive correct length discriminations, after which they commenced with Condition 2 (length decision and order decision) for one practice and five experimental sessions. Each session consisted of ten trials at each interval, so that each point on the psychometric function is based on fifty trials at that interval. Seven postgraduate and Honours students from the Psychology Department served as subjects, six male and one female.

Results

The probabilities of a ⟨VA⟩ response associated with different intervals are shown in Table 4.1, and the normal deviates corresponding to these probabilities are shown in Table 4.2. Straight lines were fitted to the data by the least squares method, and the point at which the normalised function crossed the x-axis was found by substitution in the regression equation. This represents the 50% threshold, or the point at which an ⟨AV⟩ or ⟨VA⟩ response is equally probable (Woodworth and Schlosberg, 1954). The thresholds obtained in this way are shown in Table 4.3. The difference between conditions is the same for all subjects, except two who experienced extreme difficulty with the order judgements, especially Condition 1. Comparison by the Sign Test shows this difference not to be significant ($N = 7$, $x = 2$, $p = .227$). However, considerable differences are evident in both the absolute values and the extent of threshold shift between conditions for different subjects.

Although this experiment and the following one would have constituted a more adequate test of the prior entry hypothesis had they included a second group of subjects who were presented with the two conditions in reverse order, the large investment of both subjects' and experimenter's time in the psychometric function procedures was not felt to be justified. The main purpose of Experiments 1 and 2 was to establish suitable intervals for the following series of TSD experiments. In view of the marked individual differences it was felt that this could be achieved better by having the limited number of subjects in each experiment undergo conditions in the same order, rather than confusing the issue by counterbalancing for order as well.

Table 4.1. Proportions of ⟨VA⟩ responses at different intervals between a and v signals in Experiment 1. Minus sign before the interval signifies that a signal preceded v signal.

Interval (msec.)	-100	-80	-60	-40	-20	0	20	40	60	80	100	120
Subjects												
NB					.02	.56	.72	.84	.94	.94	.98	
			.24	.56	.70	.82	.82	1.0				
AR					.18	.36	.56	.54	.54	.62	.74	
			.24	.50	.62	.52	.50	.63	1.0			
TN					.22	.78	.82	.80	.86	.88	.98	
			.32	.80	.93	.87	.73	1.0				
JT				.28	.54	.78	.76	.92	.92	.90	.92	
	.28	.48	.60	.70	.76	.78	.70	1.0				
JS					.04	.26	.32	.46	.42	.48	.78	
			.18	.38	.46	.42	.60	.58	1.0			
MS					.28	.40	.50	.50	.36	.36	.40	.40
					.40	.36	.48	.36	.46	.50	.54	
RD					.14	.54	.90	.92	.96	.98	1.0	
		.37	.55	.65	.98	.90	.97	1.0				

Table 4.2. Normal Deviates of Data Points for Psychometric Functions in Experiment 1.

Subject	Interval (msec.) / Condition	-100	-80	-60	-40	-20	0	20	40	60	80	100	120
NB	1					-2.06	.15	.58	1.00	1.56	1.56	2.06	
	+2			-.71	.15	.53	.92	.92					
AR	1					- .92	-.61	.15	.10	.10	.31	.65	
	+2			.71	.00	.31	.06	.00	.34				
TN	1					- .78	.78	.92	.85	1.09	1.18	2.06	
	+2			-.49	.85	1.48	1.13	.62					
JT	1					.59	1.10	.77	.71	1.41	1.41	1.29	1.41
	+2	-.59	-.65	.26	.53	.71	.77	.53					
JS	1					-.176	-.65	-.47	-.10	-.20	-.05	.78	
	+2			-.92	-.31	- .10	-.20	.26	.20				
MS	1					.58	.26	.00	.00	.36	.36	.26	.26
	+2					.26	.53	.06	.36	.11	.00	.11	
RD	1					-1.09	.11	1.29	1.41	1.76	2.06		
	+2		.33	.13	.39	2.06	1.29	1.89					

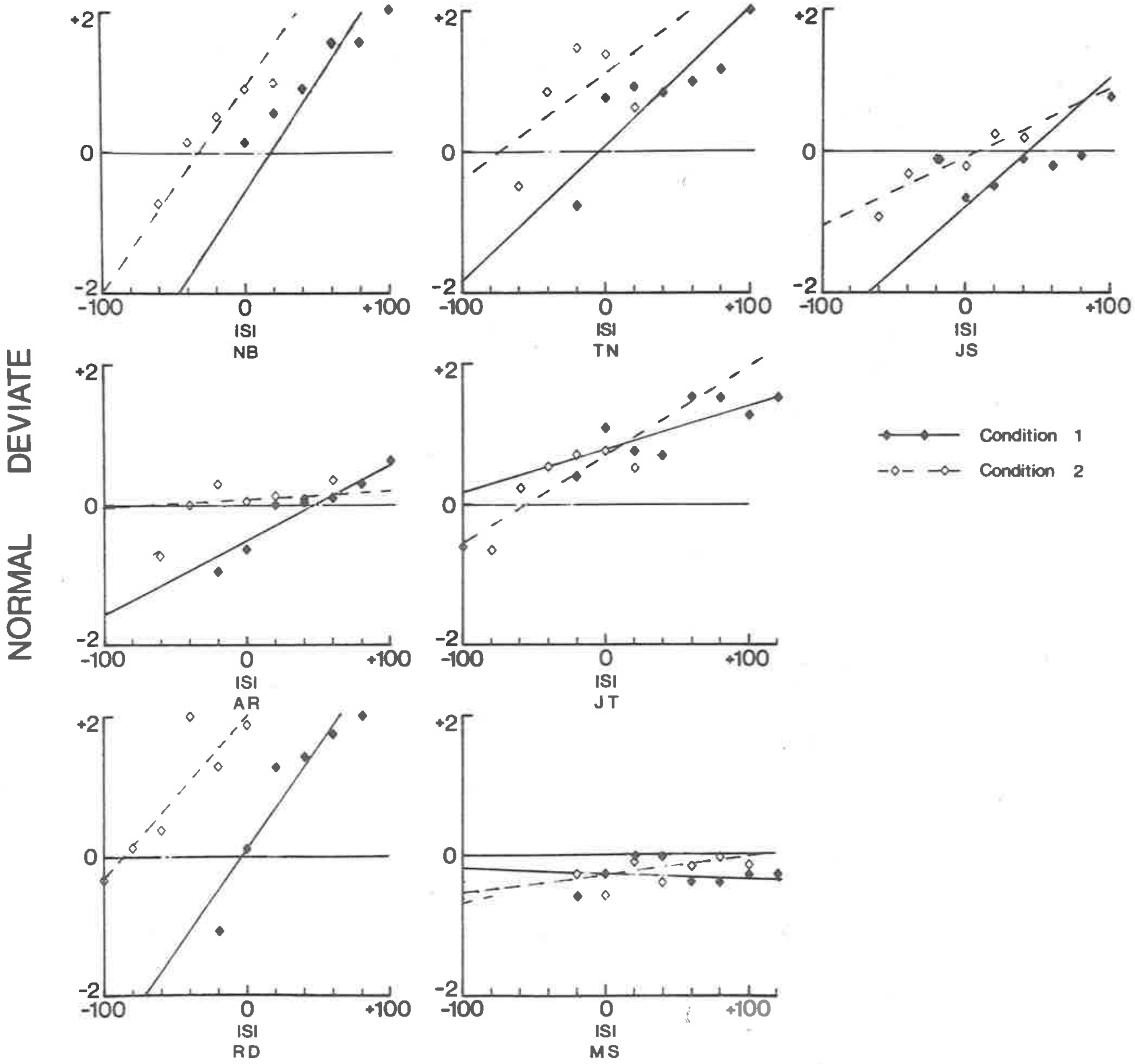

Fig. 4·1 Normalised Psychometric Functions for Individual Subjects in Expt. 4.

Table 4.3. Threshold for order judgements for all subjects under both conditions in Experiment 1.

Subject	Condition 1 (m.sec.)	Condition 2 (msec.)
NB	17	- 38
AR	43	- 90
TN	- 11	- 77
JT	-131	- 62
JS	- 42	8
MS	-470	116
RD	- 1	- 84

Experiment 2

Experiment 2 was undertaken as a more controlled test of the prior entry hypothesis, using a range of intervals based on the results of Experiment 1. Method and procedure are generally similar to that used in the previous experiment, the main difference being that all subjects were presented with the same range of intervals under both conditions.

Method and procedure

The apparatus was the same as that used in the previous experiment, with the exception that a masking field with lines 5 mm apart replaced the masking field in the previous experiment in which lines were 10 mm apart.

As in the previous experiment, subjects commenced with two practice sessions, followed by five sessions under Condition 1 (order-judgement only). Practice was then given on the length judgement task, again to the criterion of eight successive correct responses, a practice session under Condition 2 following. Finally, five test sessions under Condition 2 completed the experiment.

Intervals ranging from -100 (auditory signal first) to 140 msec. (visual signal first) were used, this time in steps of 40 msec., making a total of seven different intervals. Each session again consisted of ten trials at each of the intervals, and the psychometric functions were based on the last two sessions under each condition, so that each point on the function was based on twenty determinations.

Six undergraduate and postgraduate students served as subjects. They were recruited by the offer of a dozen bottles of beer for the best overall performance, in terms of points deducted for wrong decisions. One point was to be lost for each wrong order judgement and five points were to be lost for each wrong length judgement. It was hoped that this explicit cost-payoff matrix would ensure that the subject attended to the visual signal.

One subject never learned the length discrimination, so his results have not been included in the statistical analysis. His results are, however, quite consistent with the prior entry hypothesis and they have been included in Table 4.4 for the sake of completeness.

Results

Probabilities of a ⟨VA⟩ response at different ISIs obtained from the last two sessions under each condition are given in Table 4.4. All subsequent data analysis is based on the data from these last two sessions since this represents a practiced, stable level of performance. The best-fitting normal ogive was determined for each subject under each condition using a FOCAL program for a cumulative Gaussian Curve Fitting Procedure. This computer program finds, by an iterative least squares procedure, the mean and standard deviation of the normal ogive which best fits the psychometric function data (Willson, undated), and these means and standard deviations are given in Table 4.5. The means calculated in this fashion are equivalent to the 50% threshold for order judgement i.e. the mean represents the ISI at which the probability of a ⟨VA⟩ response is 0.5.

Table 4.4. Probabilities of a ⟨VA⟩ response for different ISIs in Experiment 2.

ISI (msec.)		-100	-60	-20	+20	60	100	140
Subjects								
RS	1	.05	.05	.20	.60	.85	.85	1.0
	2	.05	.10	.30	.65	.75	1.0	1.0
MB	1	.05	0.0	.20	.85	1.0	1.0	1.0
	2	0	.10	.35	.90	.85	.90	1.0
JG	1	.05	.15	.55	.75	.85	.90	1.0
	2	.10	.90	1.0	1.0	1.0	1.0	1.0
RH	1	.00	.30	1.0	.90	.75	.85	.95
	2	.00	.50	.75	.60	.70	.95	.95
AB	1	.00	.10	.60	.95	.95	1.0	1.0
	2	.50	.85	.85	1.0	1.0	1.0	1.0
LO	1	.05	.00	.15	.60	.45	.75	.95
	2	.95	1.0	.95	1.0	.95	1.0	1.0

Table 4.5. Means and Standard Deviations of Best-fitting normal ogives for psychometric function data in Experiment 2. All values in msec. Negative values indicate a signal precedes v signal.

	Condition 1		Condition 2	
Subjects	$\bar{X}$	SD	$\bar{X}$	SD
RS	13.5	50.00	6.8	56.0
MB	1.7	49.8	-7.4	54.2
JG	0.9	67.8	-29.4	94.1
RH	61.5	72.3	-80.6	78.8
AB	-21.4	58.00	-122.3	100.9

Following the rationale of the previous experiment, if the prior entry hypothesis is correct we would expect a shift in these values in a negative direction under Condition 2, i.e. the 50% point would occur when the visual signal was relatively later. From Table 4.5, it can be seen that all shifts in threshold between conditions are in the predicted direction, and comparison by the Sign Test confirms the significance of this difference ($N = 5$, $x = 0$, $p = 0.031$). It can also be seen that the standard deviation of the best fitting ogive increases under Condition 2. This means that the psychometric functions are generally flatter under Condition 2 and we may also note that the same seems true of the data from Experiment 1 (Fig. 4.1). This reflects a decrease in the rate of change of ⟨VA⟩ responses over the range of intervals used, which suggests that subjects had relatively greater difficulty in distinguishing the two orders under Condition 2.

Turning to performance on the visual task, the number of errors made and the shift in order threshold for each subject are shown in Table 4.6. The rank-order correlation between threshold shift and number of errors is high ($N = 5$, $r_s = 0.85$, $p > .05$) but, with such a small sample, fails to reach significance. The same is true for the rank-order correlation between number of errors on the visual task and change in standard deviation between conditions ($N = 5$, $r_s = 0.85$, $p > .05$). Though no relationship is evident between the number of errors on the visual task and thresholds under Condition 1 ($N = 5$, $r_s = 0.18$, $p > 0.05$), the number of errors does correlate quite highly with the standard deviation of the psychometric function under Condition 1 ($N = 5$, $r_s = 0.68$, $p > 0.05$) though once more this falls short of statistical significance.

Table 4.6. No. of errors made on visual judgement task under Condition 2 and shift in order threshold in Experiment 2.

	No. Errors	Shift (msec.)
RS	0	6.7
MB	0	9.1
JG	1	30.3
RH	4	142.1
AB	5	100.9

Discussion

It would seem that the predictions of the prior entry hypothesis are confirmed by the results of Experiments 1 and 2. In both cases, the 50% thresholds of nearly all subjects shifted in the predicted direction. The one exception is the subject in Experiment 2 who never learned the discrimination task, but whose results are still consistent with the hypothesis. Under Condition 2, this subject made hardly any ⟨AV⟩ responses, which might be predicted from the prior entry hypothesis if he were giving over a lot of his capacity to the length-judgement task.

With all other subjects, we can detect an increase in the standard deviation of the psychometric function and hence a decrease in the slope of the function. This is consistent with the visual task making extra demands on processing capacity and the degree of temporal resolution on the order judgement decreasing as a result. In other words, as well as a 'prior entry' effect, the effect of sharing capacity is also evident. Suggestive support for a capacity sharing effect comes from the high but not statistically significant correlations between the number of errors made on the visual task and the changes in parameters of the psychometric functions. The more errors the subject makes on the visual task, the more the threshold shifts, suggesting that the more difficult the subject finds the task, i.e. the greater the demands it makes on his capacity, then the more likely at any given interval he is to make a <VA> response. A similar correlation is observed between the number of errors on the visual task and the increase in the standard deviation between conditions, indicating that the more difficult the subject finds the visual task, the more his performance on the order task declines. This relationship between difficulty of the visual task and order judgement performance is explored in more detail in Experiment 4.

2. NON-PARAMETRIC SIGNAL DETECTION MEASURES FOR ORDER JUDGEMENT WITH AND WITHOUT ATTENTION DIRECTED TO ONE MODALITY.

The rationale for using TSD measures in this situation has already been dealt with so it is not necessary to expand on this further here, but a more detailed explanation of the actual measures themselves is perhaps desirable. A fuller treatment of the measures discussed below may be found in Chapters 2 and 5 of McNicol (1972).

The sensitivity measures, i.e. the area under the ROC curce, P(A), has been derived in the following experiments from rating scale procedures rather than Yes-No procedures. For each rating category, the proportion of "hits", defined as the proportion of visual first responses when the visual signal did actually precede the auditory signal, or $P(\langle VA\rangle /_{\langle va\rangle})$, and the probability of a false alarm, defined as the probability of a visual first response when the auditory signal precedes the visual signal, or $P(\langle VA\rangle /_{\langle av\rangle})$, are calculated. The path of the ROC curve can then be determined by plotting the cumulative totals of hits on the y-axis against the cumulative total of false alarms on the x-axis, starting with the category which corresponds to the greatest certainty that a visual signal came first; the higher the proportion of hits relative to false alarms for each rating category, the greater the area bounded by the ROC curve will be. The area under the ROC curve, conveniently known as P(A), can be found geometrically using the formula for the area of a trapezium. The maximum possible value for P(A) is 1 which represents perfect performance, and the range of values for P(A) usually lies between this value and 0.5, which represents performance at a chance level.

The non-parametric measure of bias, B, represents the point on the observer's rating scale at which he is equally disposed to signal and noise responses. B is defined as the rating scale category at which $P(\langle VA\rangle / \langle va\rangle) + P(\langle VA\rangle / \langle av\rangle) = 1$; since the sum of $P(\langle VA\rangle / \langle va\rangle)$ and $P(\langle VA\rangle / \langle av\rangle)$ at any point is twice the proportion of $\langle VA\rangle$ responses at that point, then this is equivalent to the point at which $P(\ VA\ ) = .5$, i.e., the point on the rating scale where $\langle VA\rangle$ and $\langle AV\rangle$ responses are equiprobable. The measure B differs from the parametric bias measure, beta, in that it is an overall measure of performance, whereas beta is a likelihood ratio calculated separately for each rating category. One result of this is that B can only detect changes in bias which are the result of the subject moving all his criteria up or down the rating scale, unlike beta which can detect changes in bias which result from the subject spacing his criteria closer together or wider apart on the rating scale.

Two TSD experiments which show highly consistent results are reported in the remainder of this chapter. In the chapter which follows, more supporting TSD experiments are reported which suggest that the main findings of these experiments have some generality in order judgement situations.

Experiment 3

Experiment 3 is the initial test of the prior entry hypothesis using TSD methodology. Since it was conducted before the threshold for order judgement was determined in Experiments 1 and 2, the pair of intervals used is not such that unbiased responses for the simple order judgement might be expected as can be seen from the psychometric functions for order judgement obtained in Experiments 1 and 2. Despite this unsatisfactory feature it does nevertheless show the main features of subsequent experiments where the psychometric function data was taken into account.

Method and Procedure

The apparatus was identical in all respects to that used in Experiment 1. The visual signal in this experiment always preceded the auditory, by 20 msec. for ⟨av⟩ trials, and by 60 msec. for ⟨va⟩ trials. These intervals were based on Hershenson's (1962) report of a difference in conduction times for auditory and visual signals of the order of 40 msec., and were chosen to give an effective difference between the signals of around 20 msec. Under Condition 1, subjects were presented with trials on which they were simply required to indicate on a four-point rating scale their degree of certainty as to which signal had occurred first, the four response alternatives being "Certainly click", "Probably click", "Probably lines", and "Certainly lines". Under Condition 2, subjects had first to report whether the left line or the right line was the longer and then express their degree of confidence as to which event had occurred first in a similar fashion. Equal numbers of click first and pattern first trials, and equal numbers of left longest and right longest trials were presented throughout the experiment in random orders independent of one another, the only constraint being that runs of longer than three similar signals were eliminated.

Five sessions, each of 100 trials, followed a first practice session. Subjects were randomly divided into two groups, Group A undergoing Condition 1 first, Group B undergoing Condition 2 first. Practice on the length judgement task to a criterion of ten successive correct discriminations was given to both groups immediately before commencing on the first session under Condition 2. As far as possible sessions were held on consecutive days at the same time each day. Subjects once more gave verbal responses which the experimenter recorded manually on prepared response sheets on which the sequence of signals was designated.

Eight first-year psychology students served as subjects as part of their course requirement.

Results

The proportion of responses in each rating scale category under the two experimental conditions is shown in Fig. 4.2. Proportions of responses were obtained by finding the mean hits ($P(\langle VA \rangle / \langle va \rangle)$) and false alarm ($P(\langle VA \rangle / \langle av \rangle)$) rates over all subjects under each condition. It can be seen from the figure that fewer "Certainly lines" or "Certainly click" responses are given under Condition 2.

Results for the 2 arcsin $\sqrt{P(A)}$ transformation of P(A) for all subjects over all conditions are given in Table 4.7. Since P(A) is a probability with an upper limit of 1, scores tend to cluster round the upper end when sensitivity is high, resulting in a positively skewed distribution of scores. In order to avoid violating the mathematical assumptions underlying ANOVA techniques, this skewness must be removed. One of the most convenient means of achieving this is by applying the 2 arcsin $\sqrt{P}$ transformation commonly applied to probability data. This transformation spreads out the scores at the upper end of the distribution, 2 arcsin $\sqrt{P(A)}$ having an upper limit of Π, so that it more closely approximates a normal distribution.

A two-way ANOVA was conducted on these data, and the results of this analysis are shown in Table 4.8. A significant difference was found between different experimental conditions ($p < .05$), while no such difference was found for the groups

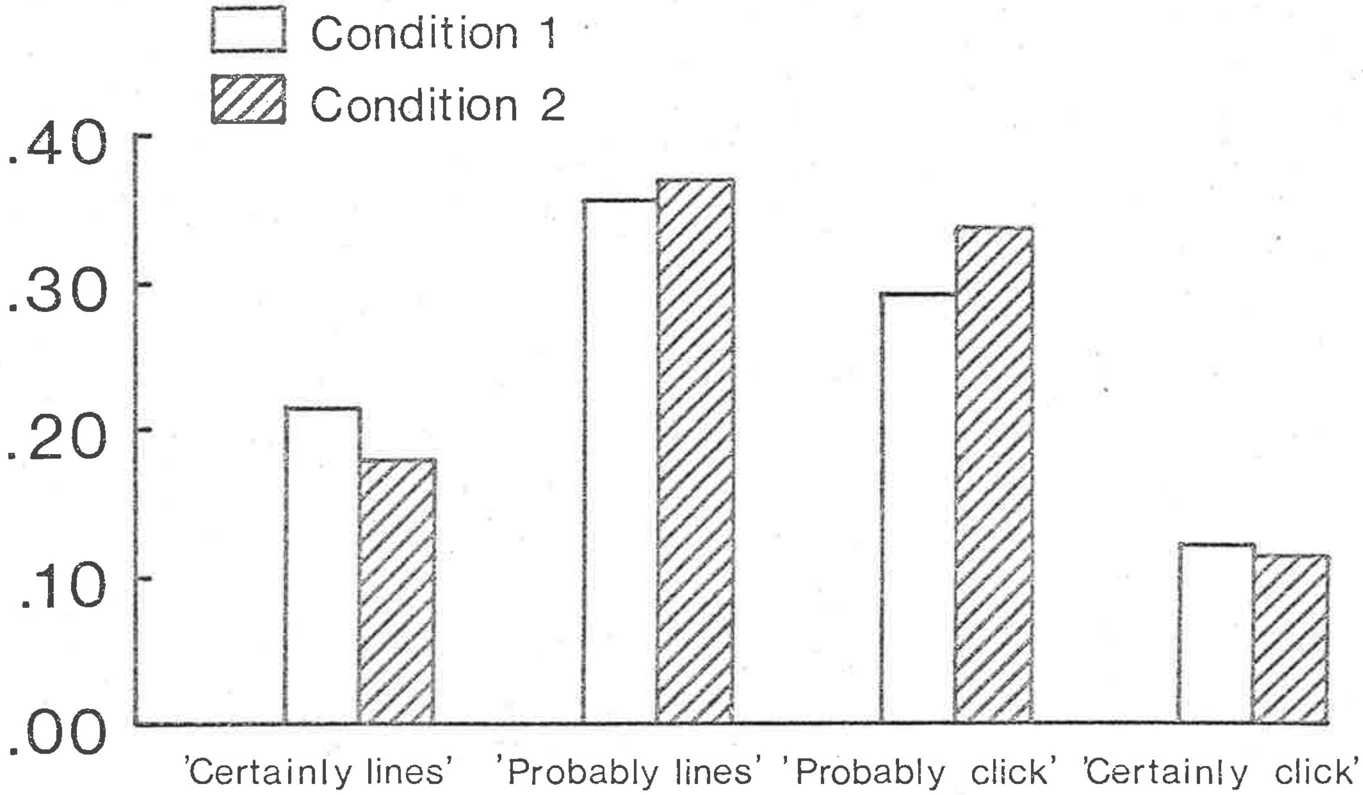

FIG. 4.2, Proportions of Responses in each Rating Scale Category under both conditions of Experiment 3.

Table 4.7. 2 arcsin $\sqrt{P(A)}$ in Experiment 3.

Subject	Condition 1	Condition 2
DS	1.715	1.6000
SD	1.675	1.554
HR	1.717	1.588
AM	1.785	1.655
$\bar{x}$	1.723	1.627
GD	1.606	1.556
DP	1.702	1.601
EF	1.708	1.771
JB	1.824	1.742
$\bar{x}$	1.710	1.668
$\bar{X}$	1.717	1.648

Table 4.8. Table of ANOVA for 2 arcsin $\sqrt{P(A)}$ in Experiment 3.

Source	SS	df	MS	F	p
Conditions	.0191	1	.0191	4.8974	<.05
Groups	.0008	1	.0008	<1	
Conditions x Groups	.0228	1	.0228	5.84615	<.05
Residual	.0473	12	.0039		

factor. The significant conditions x groups interaction ($p < .05$) is largely the result of the marked decline in performance of Group 1 under Condition 2. The difference in performance between conditions for Group 1 was much more marked than for Group 2, perhaps indicating that the order in which conditions are presented affects the level of performance attained.

The response bias measure, B, is shown in Table 4.9 and the results of the corresponding ANOVA are shown in Table 4.10, where the conditions factor, the groups factor and their interaction all failed to emerge as significant.

From Table 4.9 it can be seen that no substantial change in bias occurred between conditions. If subjects were unbiased, i.e. if the point at which they were equally disposed to give ⟨VA⟩ and ⟨AV⟩ responses coincided with the mid-point of the category scale it would be 2. However, it can be seen that the values lie below that for nearly all subjects under both conditions, indicating a slight bias towards ⟨VA⟩ responses. Under Condition 2 the mean bias measure is closer to this position of no bias, whichreflects a reduction in the tendency to give ⟨VA⟩ responses. It can also be seen from Fig. 4.2 that subjects did tend to make fewer "Certainly" responses and more "Probably" responses under the second condition, a change which we have already noted would not be taken into account by the B measure. At least the B measure does show a small but consistent move in the direction of less bias.

Error scores on the visual judgement task are given in Table 4.11. No relationship is evident between error scores and changes in P(A) between conditions ($r_s = .49$, $N = 8$, $p > 0.05$), nor between error scores and changes in response bias between conditions ($r_s = .29$, $N = 8$, $p > .05$). The only significant relationship to emerge would seem to be between the number of errors on the visual task and P(A) under Condition 1, the better performance on Condition 1 being, the more errors the subject was likely to make on the visual task ($r_s = .89$, $N = 8$, $p < 0.01$).

Table 4.9. Response bias B in Experiment 3.

Subject	Condition 1	Condition 2
DS	1.588	1.661
SD	1.731	1.933
HR	1.996	2.242
AM	1.634	1.788
$\bar{x}$	1.737	1.906
GD	1.847	1.800
DP	2.151	1.804
EF	1.654	1.805
JB	1.752	1.847
$\bar{x}$	1.851	1.814
$\bar{X}$	1.794	1.8600

Table 4.10. Table of ANOVA for B in Experiment 3.

Source	SS	df	MS	F	p
Groups	.0018	1	.0018	<1	-
Conditions	.0231	1	.0231	<1	-
Groups x Conditions	.0345	1	.0345	<1	-
Residual	.4308	12	.0359		

Table 4.11. Error scores on length-judgements under Condition 2 in Experiment 3.

Subject.	No. Errors
DS	39
SD	21
HR	33
AM	29
GD	21
DP	23
EF	27
JB	48

Discussion

The suggestion arising from Experiment 3 is that, in this situation at least, the prior entry hypothesis does not hold, since the bias measure shifted (albeit very slightly) in the opposite direction to that predicted by the hypothesis. This conflicts with the findings of the two previous experiments where psychometric functions for order judgements were found to shift in the predicted direction for practically all subjects.

The intervals used were intended to give rise to equal probabilities of ⟨VA⟩ and ⟨AV⟩ responses under Condition 1, assuming a difference in auditory and visual conduction times of the order of 30 msec., e.g. Hershenson (1962). The order judgement studies reviewed in Chapter 3 show how the order threshold depends on the particular combination of intensities and presentation modes of the signals. The data from the present experiments are no exception, to judge from the psychometric function data of Experiments 1 and 2. However, when these psychometric functions are taken into account, it seems that the pair of intervals used in this experiment may have favoured a bias to ⟨VA⟩ responses, with the result that the subject becomes reluctant to give a greater proportion of ⟨VA⟩ responses under the second condition. Certainly, examining Table 4.9 more closely, it can be seen that the only two subjects who showed more bias under Condition 2 belonged to Group B which underwent Condition 2 first, a feature of the data which is consistent with the above suggestion.

One other point of disagreement with Experiments 2 and 3 arises, and that is the question of the relationship between performance on the visual task and performance on the order judgement task. The indications of Experiment 2 were that the more performance changed on the order task, the more errors the subject made on the visual task, while Experiment 3 failed to confirm this finding since no relationship between either the changes in P(A) or B and the number of errors on the visual task was evident. Direct manipulation of the difficulty of the visual task was undertaken in Experiment 4.

Experiment 4

Experiment 4 extends and improves the design and methodology of Experiment 3. A larger ISI was introduced and subjects expressed their degree of confidence about their judgement on a six point scale. These changes allowed the effects of additional decisions to be seen more clearly. Two levels of difficulty in the visual task were used, permitting further examination of presentation order effects as well as an assessment of the effects of the demands of the visual task.

Method and Procedure

The same apparatus was used as in previous experiments, save that the masking field consisted of a pattern of vertical lines, 1 mm wide and 9 mm apart, placed centrally in the viewing field of the tachistoscope. In view of the fact that in the last experiment the values for P(A) for the order judgement rarely exceeded .60, it was felt that a longer ISI would give rise to higher sensitivity, at least in Condition 1, and allow any effects of the extra decision on sensitivity to show more clearly. To this end, the ISI was changed so that on the <va> trials, the visual signal preceded the auditory by 70 msec. and on the <av> trials the auditory signal preceded the visual by 30 msec.

Subjects were required to undergo three experimental conditions: Condition 1, where only an order judgement was required; Condition 2 where the subject had to judge whether the longer of a pair of lines (24 mm and 48 mm) was presented on the left-hand or the right-hand side of the visual field, and Condition 3 which was identical to Condition 2 except that the lines were 35 mm and 37 mm long. Subjects were randomly allocated to four groups, each of which was presented with the three conditions in the order 1, 2, 3; Group 2 in the order 1, 3, 2; Group 3 in the order 2, 3, 1; Group 4 in the order 3, 2, 1. Though this does not exhaust the possible number of presentation orders, it does at least allow an experimental design which can detect any effects of order on the dependent variables. Such effects would be shown by a significant conditions x groups interaction in an ANOVA.

The procedure differed from Experiment 3 in that subjects were required to indicate on a six-point scale the degree of confidence they attached to their judgement by saying whether they thought it had been "Certainly", "Probably", or "Possibly", the lines or the click which had been presented first. Subjects were instructed that they should try to use all the categories on the scale, and that they should not necessarily expect equal proportions of "Visual First" and "Auditory First" trials. One further departure from procedures used previously was the abandonment of a practice session: instead, each session was preceded by a practice block of fifty trials, always twenty-five each of ⟨va⟩ and ⟨av⟩ Condition 1 trials. Two advantages derive from this: first, it tends to stabilize the order-judgement criterion for different sessions; second, it provides a base-line from which we may estimate any systematic changes in performance over time.

Subjects attended three sessions, as far as possible on consecutive days at the same time each day. Each session consisted first of the practice block of fifty trials, followed by a block of one hundred experimental trials, fifty each ⟨av⟩ and ⟨va⟩ , randomly ordered with the constraint that runs longer than three of the same signals were eliminated. The longer line was varied from left to right at random, independently of the order of the auditory and visual signals.

Sixteen male and female first and second year psychology students volunteered as subjects.

<u>Results</u>

Table 4.12 shows 2 Arcsin $\sqrt{P(A)}$ for all subjects under all conditions. These data were analysed by the fixed x random x subjects ANOVA model of Vaughan and Corballis (1969), which pools all the subject interaction terms in the error term.

As can be seen from the corresponding ANOVA table (Table 4.13), the conditions factor has the largest mean square and a highly significant F-ratio, indicating a significant difference among experimental treatments. A large range of individual differences in performance on the order judgement task and lack of matching in the allocation of subjects to

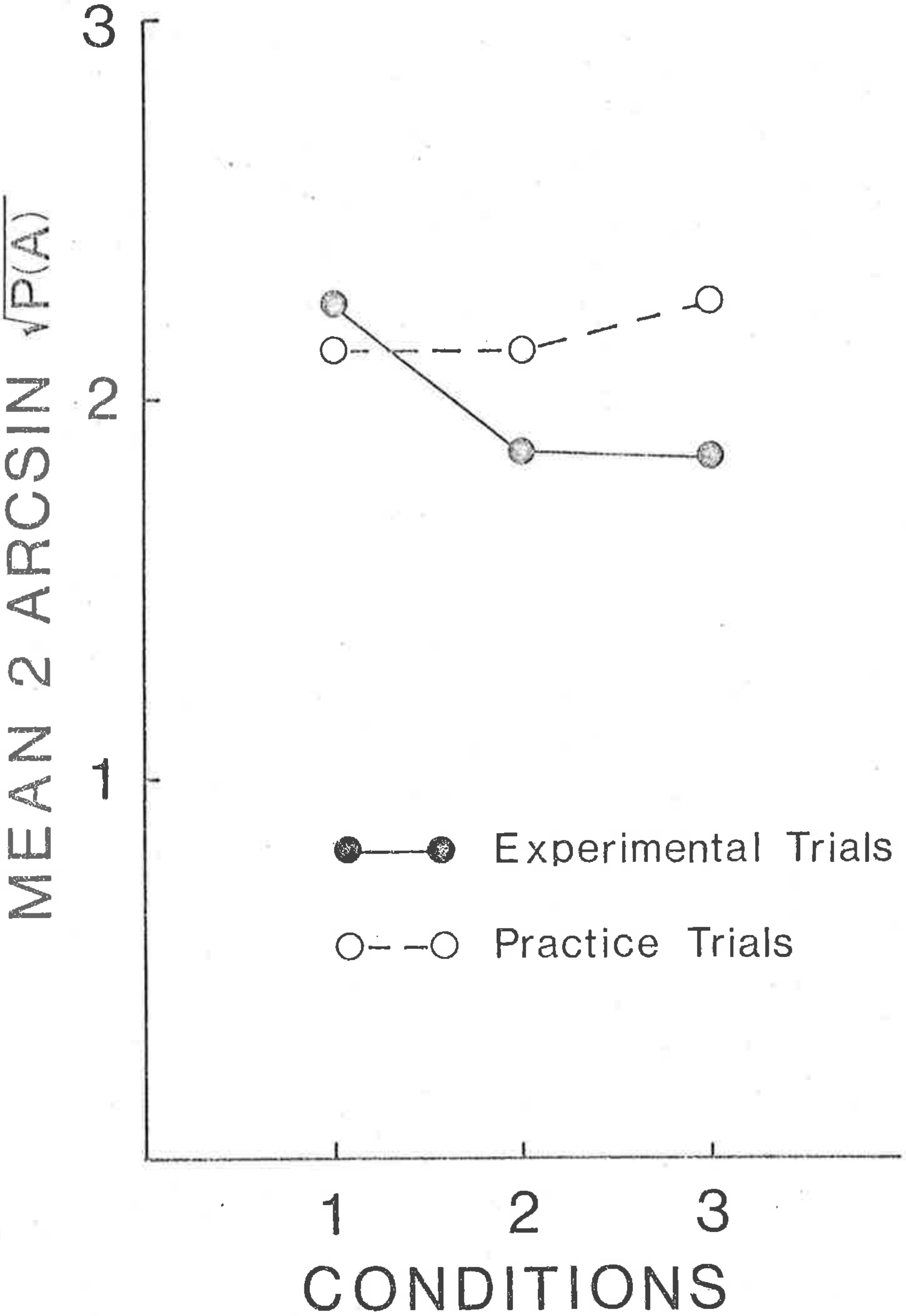

FIG. 4.3, 2 Arcsin $\sqrt{P(A)}$ for experimental trials and practice trials in Experiment 4

groups are evident from the significant subjects and groups factors respectively. The groups x conditions interaction fails to indicate any significant effect for the presentation order of different conditions. This lack of effect of presentation order is further confirmed by the results from the practice trials, Fig. 4.3 showing the relationship between the practice and experimental blocks. 2 arcsin $\sqrt{P(A)}$ is given for the practice block of fifty trials which preceded each of the experimental sessions in Table 4.14 and the results of the corresponding ANOVA are given in Table 4.15. It can be seen from Table 4.15 that the conditions factor falls far short of significance.

Returning to the experimental treatments, differences between mean scores under different experimental conditions were compared using Duncan's New Multiple Range Test, (Edwards, 1960), and the results of this comparison are shown in Table 4.16. The results are significant with $\alpha = .01$, which, with three means, gives a protection level or minimum probability of finding no erroneous significant differences between these three means of .98.

The pattern of differences in sensitivity for different conditions follows that found in Experiment 3 in that Conditions 2 and 3 differ little from one another, but both are very different from Condition 1. The relationship between mean scores under different conditions and mean practice scores is illustrated in Fig. 4.3.

Results for the bias measure B under different experimental conditions are given in Table 4.17 and the results of the corresponding ANOVA are shown in Table 4.18. It can be seen from Table 4.18 that no significant effect was found for the conditions factor, though once again the groups and subjects factors are significant, and that the groups x conditions effect falls short of significance, indicating the lack of any order effect.

Since no difference in 2 arcsin $\sqrt{P(A)}$ was found between the easy and difficult conditions, it may be questioned whether subjects in fact found Condition 2 more difficult. Error scores on the visual task given in Table 4.19 indicate that subjects did find Condition 2 more difficult since they made more errors under that condition, and comparison by the Wilcoxon Matched-Pairs Signed Ranks Test indicates that this difference is highly significant ($T = 15$, $N = 16$, $p < 0.005$).

No evidence of any relationship between individuals' changes in P(A) and number of errors on the visual task was found ($N = 16$, $r_s = -0.027$ and 0.056 for Conditions 2 and 3 respectively, $p > 0.05$), nor between P(A) on the immediately preceding practice session and the number of errors ($N = 16$, $r_s = -0.268$ and -0.374, for Conditions 2 and 3 respectively, $p > 0.05$) though in this case the correlations are at least in the same direction and approach the critical value of r_s. This implies that those subjects best able to cope with the order judgement task were those who also made fewest mistakes on the length judging task.

Table 4.12. 2 arcsin $\sqrt{P(A)}$ in Experiment 4.

	Condition	1	2	3
Subject				
GP.1	OF	2.235	1.753	1.572
	SB	2.272	2.119	2.148
	PT	2.358	1.792	1.852
	IMG	2.546	1.692	1.738
	$\bar{x}$	2.328	1.839	1.814
GP.2	EL	2.708	2.963	2.945
	MN	2.202	1.762	1.934
	PG	1.768	1.675	1.745
	AA	3.085	1.931	1.992
	$\bar{x}$	2.441	2.083	2.654
GP.3	JP	1.780	1.691	1.659
	LA	2.145	1.621	1.562
	HG	2.460	1.807	1.688
	LC	2.014	1.345	1.801
	$\bar{x}$	2.095	1.738	1.675
GP.4	PM	2.354	1.872	1.805
	CH	2.759	2.360	2.071
	IR	1.873	1.527	1.767
	JL	1.442	1.723	1.663
	$\bar{x}$	2.107	1.857	1.812
	$\bar{X}$	2.250	1.879	1.866

Table 4.13. Table of ANOVA 2 arcsin $\sqrt{P(A)}$ under different experimental conditions of Experiment 4.

	Ss	df	MS	F	P
Subjects	3.6523	12	.3250	5.52	<.005
Conditions	1.4883	2	.7441	12.63	<.005
Groups	.9751	3	.2969	5.04	<.005
Groups x Conditions	.1243	6	.0207	< 1	
Error	1.4118	24	.0589		

Table 4.14. 2 Arcsin $\sqrt{P(A)}$ data for practice trials on Experiment 4.

Conditions / Subjects	1	2	3
OF	1.808	1.955	2.043
SB	2.462	2.490	2.530
PT	2.534	2.226	2.577
I.McG	2.616	2.444	2.851
$\bar{x}$	2.355	2.279	2.495
EL	2.366	2.876	3.143
MN	2.253	1.961	2.043
PG	1.792	1.833	1.855
AA	2.901	2.674	2.870
$\bar{x}$	2.328	2.329	2.478
JP	1.759	1.897	1.779
CA	1.975	2.156	1.762
HG	2.366	2.449	2.280
LC	1.995	1.845	1.361
$\bar{x}$	2.024	2.087	1.796
PM	2.363	2.605	1.426
CH	2.764	2.146	2.253
IR	1.919	1.555	1.701
JL	1.746	1.598	1.611
$\bar{x}$	2.198	1.976	1.748
$\bar{X}$	2.129	2.132	2.261

Table 4.15. Table of ANOVA for 2 arcsin $\sqrt{P(A)}$ for practice trials in Experiment 4.

	Ss	df	MS	F	p
Subjects	4.909	12	.40916	8.02	<.005
Conditions	.07656	2	.03828	1	-
Groups	1.9774	3	.65913	12.96	<.005
Groups x Subjects	.67285	6	.11214	2.20	NS
Error	1.22411	24	.05100		

Table 4.16. Duncan's New Multiple Range Test for Means of 2 arcsin $\sqrt{P(A)}$ under different experimental conditions in Experiment 4.

		1	2	3	
		2.250	1.379	1.866	
1	2.250		.3710	.3840	R_2 = .3511
					R_3 = .3611
2	1.879			.0130	

Means not underscored by same line differ significantly from one another.

Table 4.17. Response Bias B by conditions Experiment 4.

Conditions		1	2	3
Subjects	OF	2.800	1.989	1.676
	SB	3.000	4.462	4.177
	PT	4.000	4.200	3.833
	I.McG	4.056	2.875	2.708
	$\bar{x}$	3.464	3.382	3.099
	EL	2.919	3.000	2.639
	MN	1.914	2.667	2.572
	PG	1.839	1.820	2.400
	AA	2.500	1.500	1.754
	$\bar{x}$	2.293	2.247	2.342
	JP	3.146	3.138	3.214
	CA	2.727	2.453	2.403
	HG	1.813	1.778	2.546
	LC	2.613	2.269	2.800
	$\bar{x}$	2.575	2.410	2.741
	PM	2.417	2.534	2.969
	CH	4.500	2.769	1.707
	IR	2.800	3.211	3.163
	JL	2.654	2.429	2.714
	$\bar{x}$	3.093	2.771	2.638
	$\bar{X}$	2.794	2.693	2.794

Table 4.18. Table of ANOVA for B by different experimental conditions in Experiment 4.

Source	SS	df	MS	F	p
Subjects	9.3439	12	.7787	6.18	<.05
Conditions	.0965	2	.0482	2.51	-
Groups	5.6911	3	1.8970	1	
Groups x Conditions	.7609	6	.1268	1	
Error	8.8946	24	.3106		

Table 4.19. Errors on length judgement in Experiment 4.

Condition		2	3
Subject	OF	0	5
	PT	0	0
	SB	0	0
	I.McG	0	0
	$\bar{x}$	0	1.25
	MN	2	2
	EL	1	2
	PG	13	17
	AA	6	11
	$\bar{x}$	5.5	8
	JP	1	1
	CA	33	28
	HG	14	12
	LL	6	5
	$\bar{x}$	13.5	11.50
	PM	0	7
	CH	1	0
	IR	5	12
	JL	2	2
	$\bar{x}$	2	5.25
	$\bar{\bar{X}}$	5.25	6.5

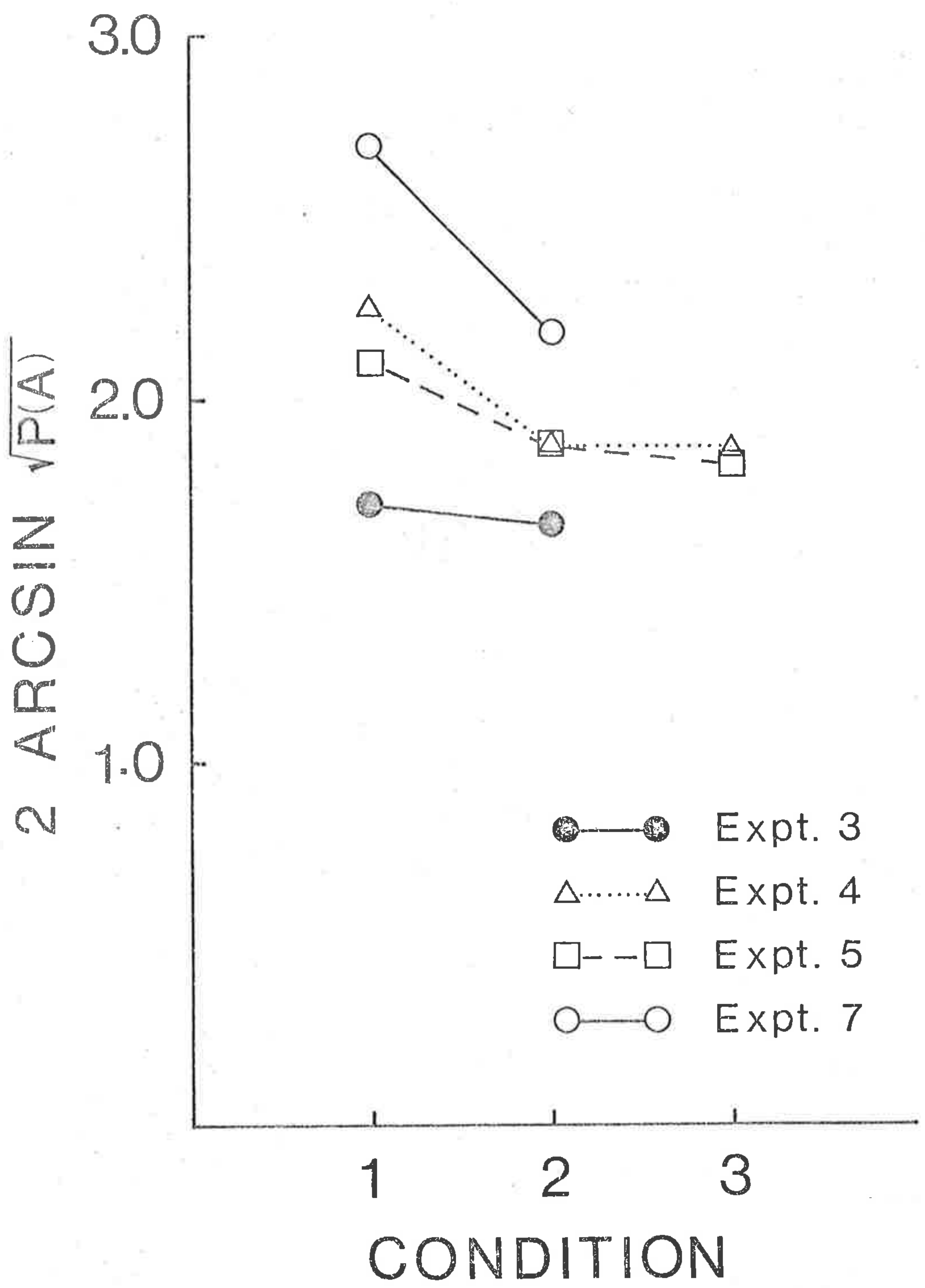

FIG. 4.4, Comparison of 2 Arcsin $\sqrt{P(A)}$ for order judgement in different experiments.

Discussion

The sensitivity data from Experiments 3 and 4 taken together presents a highly consistent picture (Fig. 4.4). Both manifest a drop in sensitivity on the order judgement under the visual decision conditions, and the lack of any substantial changes in B, the bias measure, suggests that this is the result of both a decrease in hits and an increase in false alarms.

It was argued in Chapter 3 that, in terms of TSD measures, only an increase in bias towards ⟨VA⟩ responses would support the prior entry hypothesis. In fact, in both experiments, the opposite happened, and a reduction in bias towards ⟨VA⟩ responses occurred under the visual decision conditions. This is shown by the shift in B for Experiments 3 and 4. Admittedly, the changes in bias are small and not statistically significant, but the conclusion from this series of experiments can hardly be other than that the prior entry hypothesis does not hold, at least for this order judgement situation.

3. GENERAL DISCUSSION

So far, the psychometric function data and the TSD data give apparently contradictory results, the psychometric function data supporting the prior entry hypothesis while the TSD data fails to do this. How can these two apparently conflicting results be made consistent? No immediate reconciliation seems possible. Indeed, when we consider the nature of the task being demanded of the subject under the two different experimental procedures, we can begin to appreciate just why the two results fail to agree. When psychometric functions are derived using the method of constant stimuli, the subject is presented with a range of randomly-ordered stimulus intervals and asked to classify these intervals according to whether they belong to one class of events rather than the other, and the resulting function is a cumulative plot of the probability of increasing stimulus intervals being assigned to one of these two classes. Under the TSD procedure, the subject is presented with one of only two stimulus events and, at least under the rating scale procedure, is asked to state his degree of confidence as to which class of stimulus events a particular stimulus interval belongs. The ROC curve is then found by plotting the probability that one of the stimulus events will be allocated to a particular category against the probability that the other event will be allocated to the same category. In other words, the psychometric function procedure takes no account of the observer's degree of certainty. As we can see from the rating scale data of Experiments 3 and 4, under the conditions where the extra decision is demanded of the observer, the effect is to lessen his degree of confidence about the order judgement. It would be reasonable to suppose the same effect obtains with the psychometric function procedure, so that the subject is less certain about the intervals occupying the middle of the stimulus range than he was under the simple order-judgement condition. It then only requires the additional assumption that under these circumstances where only the one choice is permitted that when the subject is uncertain about a trial, he tends to judge it as belonging to the class he reports most frequently, in this case as $\langle VA \rangle$, to account for the shift in the psychometric function and corresponding threshold. When the subject is allowed to attach confidence ratings to his judgements or when the two stimulus intervals are sufficiently different with no intervening mid-range values, then this effect does not show.

This leaves us with the problem as to which procedure is the most valid test of the prior entry hypothesis. Since it is now generally recognised that thresholds constitute an unsatisfactory measure of performance in that they fail to separate the two parameters of performance, sensitivity and bias, and since it does seem possible to explain our own findings with the threshold procedure in terms of what was found about the subject's confidence from the TSD procedure, this argues strongly for the TSD measures as the more appropriate test of the hypothesis.

At this point the generality of these findings and their relationship to previous investigations may be queried. Specific points about experimental procedure, such as the relative ineffectuality of the visual mask and the nature of the extra decision task lead to doubts about the generality of these findings, but hopefully these will be dispelled by the series of experiments discussed in the next chapter which were conducted with the express purpose of eliminating such possible artefacts.

To take the psychometric function data of Experiments 1 and 2 first, it may be noted that Stone (1926) found comparable changes in her psychometric functions for the judgement of the order of two signals in different modalities when attention was directed to one or other of the modalities. The inadequacies of Stone's methodology have already been discussed in the previous chapter, and indeed it seems that her results are rather unusual, in that none of the other investigators who used discrete pairs of signals to test the prior entry hypothesis seem to have found any evidence in support of it.

Both Hamlin (1895) and Drew (1896) investigated the effect of directing attention to one sensory modality or organ in order judgement with negative results; Hamlin reports simply that directing attention to one modality had no effect on bimodal order judgement, while Drew, with a fixed interval task, found that directing the attention to one hand or ear with electrical and auditory signals reduced the proportion of correct responses. Drew's findings agree with the reduced sensitivity found in Experiments 3 and 4 in this chapter.

The bias towards reporting more ⟨VA⟩ responses evident with Condition 1 throughout the series of experiments has been confirmed by other investigators. Hamlin (1895) found that click-flash combinations required a greater separation for their correct identification than did flash-click pairings, and Smith (1933) found that the 75% correct threshold was reached with a smaller interval with flash-click pairs than with click-flash pairs. Rutschmann and Link (1964) found the 50% threshold for order judgement when the auditory signal preceded the visual by 40-50 msec. It must be recognised, however, that such effects do depend on the relative strengths of the two signals, and that these tendencies can be reversed by altering the signal characteristics.

One final point arising from these experiments remains to be cleared up, and that concerns the relationship between performance on the order judgement task and number of errors on the visual task. This relationship is important for the implications it has for the way in which capacity is shared between the two tasks. For example, a negative correlation between reduction in sensitivity on the order task and performance on the visual task under Conditions 2 and 3 of the various experiments would imply some sort of trade-off relationship, with subjects maintaining performance on the order task at the expense of performance on the visual task. In fact, no very clear relationship emerges between performance on the two tasks over the series of experiments. Experiments 2 and 4 do at least agree in one respect. In Experiment 2 a positive correlation is found between the standard deviation of the psychometric function and the number of errors on the visual task, indicating that the steeper the function, the better the subject could cope with the additional decision. Similarly, in Experiment 5 there is a negative correlation between P(A) on the practice session immediately preceding the experimental session and the number of errors made on the visual task, again indicating that the better the person is able to deal with the order task, the better he will perform on the visual task.

The relationship between performance on the order judgement task and performance on the visual task is quite the opposite in Experiment 3, a significant positive correlation between sensitivity on the order task and number of errors being evident. The one certain result to emerge from this consideration of performance on the visual task is that its relation to performance on the order task is obscure, save that, as Experiment 4 showed, manipulation of the level of visual task difficulty does not alter performance on the order judgement.

Experiments 3 and 4 establish the paradigm for the order judgement studies reported in the next chapter, which were conducted with a view to removing doubts about the methodology of the present experiments and the generality of their findings.

CHAPTER 5.

AN EXTENSION OF THE ORDER JUDGEMENT EXPERIMENTS

The intention of this further series of experiments was to determine whether different order judgement situations gave essentially the same results as experiments 3 and 4.

Since the apparatus, procedure and rationale in the series of experiments about to be discussed is similar to that of the experiments in the previous chapter there is no need for further detailed description.

I. ELIMINATING THE POSSIBILITY OF VISUAL DECISIONS BASED ON AFTER-IMAGES

One unsatisfactory aspect of the apparatus used in the previous experiments was the failure to find a background field which would satisfactorily mask the visual signal. Attempts were made to overcome this problem by using a variety of background fields. In the course of the previous series of experiments vertical stripes of various widths and separations, as well as a criss-cross diagonal pattern were used, none with any great success. Consequently, the two vertical lines did tend to persist after the background field returned. This must make us cautious about the validity of the findings of these experiments, for it is possible that in the extra visual decision conditions, subjects simply made the order judgement as before and then made the visual discrimination on the basis of this persisting after-image. Had this been the case, no difference between experimental conditions would have been expected. Although a difference in performance on the order judgement task was evident under different conditions, the effects of the visual decision on the order judgement may be greatly attenuated, and the results may in consequence represent an underestimate of the effect of the additional decision on the order judgements.

The basis of the problem lies in the apparatus; the Cambridge tachistoscope in which the visual signals were presented, being only a two-field tachistoscope, necessitated the changing of stimulus card on every trial. Since the cards are difficult to centre accurately, the pattern appeared in a slightly different position on each trial, rendering effective masking impossible. The only way in which the two lines could have been effectively masked would have been either to have used a three-field tachistoscope with the stimulus card carefully aligned with a background field, or to have used a CRO display, neither of which was a practical proposition in view of the constraints of time and resources within which the present investigation was conducted.

Essentially, the problem is one of ensuring that the subject attends immediately to the visual signal. Instead of bringing this about by limiting the time for which the visual signal is available, it is possible to effect this by forcing the subject to decide immediately which visual signal has been presented. This can be attempted by adopting a choice reaction time procedure, instructing the subject to respond as quickly as possible to the visual signal. It seems reasonable to assume that this procedure should eliminate the possibility of the subject making the length judgement only after he has made the order judgement. Experiment 6 was designed explicitly to test the effects of demanding an immediate response from the subject in this fashion.

Experiment 5

Method and Procedure

The Apparatus was the same as that used in Experiment 4, save that the pulse which triggered the change of the tachistoscope field also triggered a millisecond timer. The timer was stopped by pressing one of two morse keys mounted on either side of the tachistoscope. Three experimental conditions were used, the first two corresponding to Conditions 1 and 2 of Experiment 4. Under Condition 3, in which the line lengths were identical to Condition 2, subjects were instructed to respond as fast as possible by pressing the key on the side corresponding to the position of the longer line in the visual display, while trying not to make more than five mistakes per session. Under this condition, reaction times as well as order judgement data were collected manually by the experimenter. In all other respects, the experimental procedure was identical to that of

Experiment 4, except that practice of 15-20 trials of the condition used in the subsequent experimental session replaced the practice block of fifty order-only trials.

Six fourth-year architecture students volunteered as subjects.

Results

Values of 2 arcsin in $\sqrt{P(A)}$ are given in Table 5.1, and the corresponding Table of ANOVA is given in Table 5.2. Once again the conditions factor emerged as significant ($p < 0.01$), although in this case the groups x conditions interaction was also significant ($p < 0.05$). This is seemingly due to the high performance of Group 2 under Condition 2. Since Group 2 underwent the three conditions in reverse order to that followed by Group 1, starting with the RT condition, it seems that the amount of practice did affect conditions differently in the two groups. For example, the scores on Condition 3 are higher for Group 1 (last session) than for Group 2(first session); under Condition 2, the scores for Group 2 are higher than those for Group 1, the immediately preceding condition for Group 1 having been an easier condition where only the order judgement was required. For Group 2, Condition 2 followed the more difficult RT condition.

Comparison of the mean P(A) values for the different conditions by Duncan's New Multiple Range Test (Edwards, 1960)

Table 5.1 2 Arcsin $\sqrt{P(A)}$ by conditions in Experiment 5.

	Conditions	1	2	3
Subjects	CK	2.159	1.927	1.907
GP 1	JN	2.320	1.697	2.069
	MH	2.120	1.673	1.746
	SE	1.942	1.920	1.707
GP 2	BW	2.212	2.007	1.833
	PK	1.868	2.042	1.722
	$\bar{X}$	2.104	1.878	1.831

Table 5.2 ANOVA of 2 Arcsin $\sqrt{P(A)}$ for Experiment 5.

Source	S.S.	df	M.S.	F	p
Subjects	.10307	4	.02577	2.20	-
Conditions	.25530	2	.12765	10.88	<.01
Groups	.00740	1	.00740	1	-
Groups x Conds.	.15862	2	.07931	6.76	<.05
Error	.09384	8	.0473		

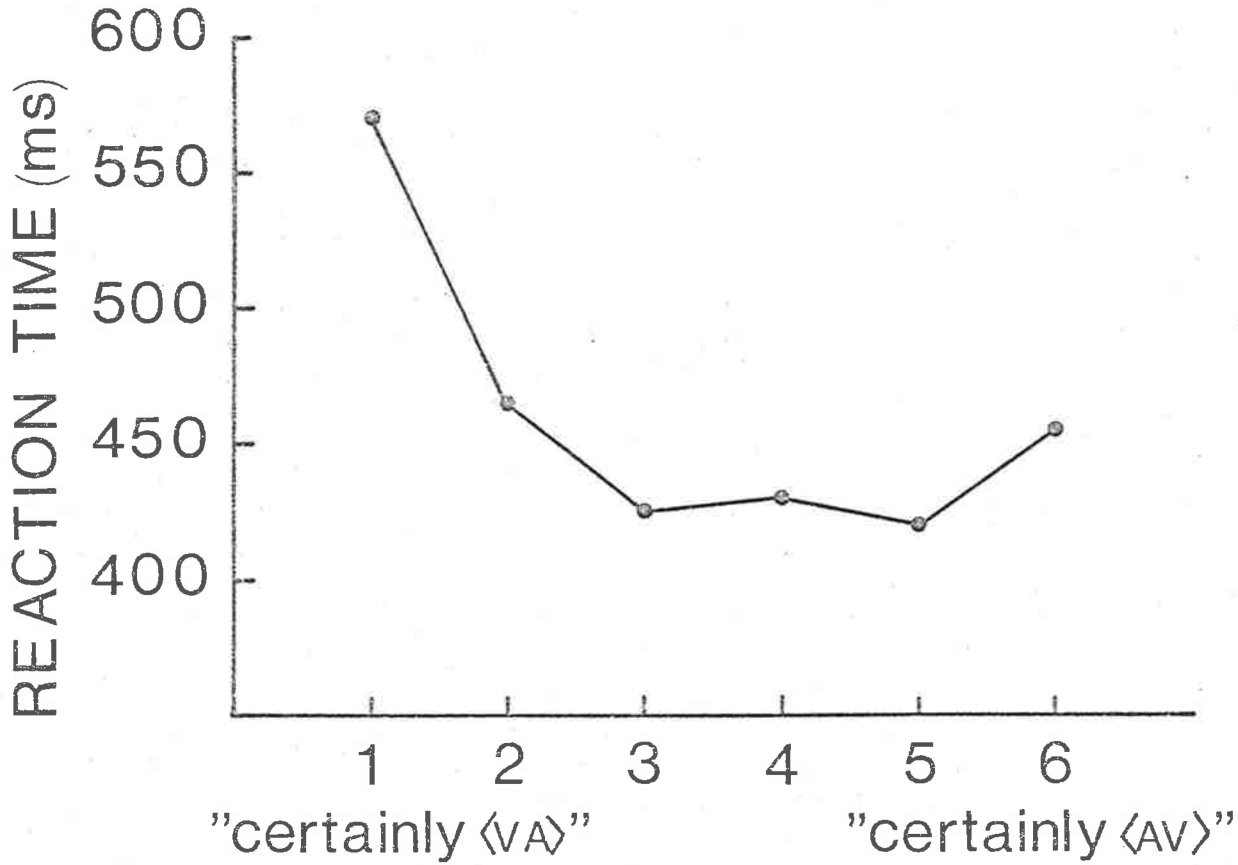

FIG. 5.1, RT to the visual signal in relation to confidence on the order judgement in Exp. 5.

is shown in Table 5.3; means for Conditions 2 and 3 are significantly different from the mean for Condition 1, but not significantly different from one another. With $\alpha = .05$ and three means to compare, the protection level or minimum probability of finding no erroneous significant differences between the three means is .90.

Response bias, B, under different experimental conditions is shown in Table 5.4, and the corresponding ANOVA is given in Table 5.5. The conditions factor is small and fails to reach significant, although the groups factor approaches significance ($p < .10$). Individual differences in bias are quite marked, as can be seen from Table 5.4. Though subjects apparently were less biased towards ⟨VA⟩ responses under Condition 1 than subjects in other experiments, the results do agree with previous investigations in that under the conditions where the additional decision about the visual signal is required there is a shift in bias away from ⟨VA⟩ responses. Mean scores for Conditions 2 and 3 differ little, and inspection of the individual scores indicates that they likewise show a high degree of similarity.

The relationship between RT and confidence category on the order judgement is illustrated in Fig. 5.1. It can be seen that the slowest RTs tended to occur when the subject was most certain about the order judgement. Since subjects did make different numbers of responses in different categories, the means in Fig. 5.1 were necessarily based

Table 5.3 Duncan's New Multiple Range Test for Mean Values of $2\ \mathrm{Arcsin}\sqrt{P(A)}$ under different conditions in Experiment 5.

		1	2	3	
		2.104	1.878	1.831	
1	2.104		.226	.273	R_2 = .1914
2	1.878			.047	R_3 = .2007
3	1.831				p = .05

1 $\underline{2 \qquad 3}$

Means not underscored by the same line are significantly different.

Table 5.4 Response bias 8 under different experimental conditions in Experiment 5.

Conditions		1	2	3
Subjects	CK	2.364	2.273	2.400
GP 1	JN	2.824	3.483	2.870
	MH	1.969	1.861	1.658
	SE	4.445	4.333	4.222
GP 2	BW	3.039	2.895	2.938
	PK	1.889	3.400	4.196
	$\bar{X}$	2.755	3.041	3.047

Table 5.5. Table of ANOVA for B in Experiment 5.

Source	S.S.	df	M.S.	F	p
Subjects	5.5955	4	1.3989	1.14	-
Conditions	.3344	2	.1672	1	-
Groups	5.1788	1	5.1788	4.22	<.10
Groups x Conditions	.41849	2	.2093	1	
Error	9.8092	8	1.2262		

on different numbers of observations and consequently no further statistical analysis was undertaken.

Discussion

The results of this experiment reinforce the validity of the previous findings. In spite of subjects being required to respond immediately to the visual signal, no evidence of a prior entry effect was found in the order-judgement data. Instead, the same pattern of responses emerged as in Experiment 4, with a reduction in sensitivity and a change in bias towards fewer ⟨VA⟩ responses. It seems that any imperfection in the masking patterns cannot account for the failure to find any evidence to support the prior entry hypothesis.

2. THE NATURE OF THE ADDITIONAL TASK

In all experiments so far, the additional task which has been imposed on the subject in order to direct attention to one modality has been a visual discrimination task. It seems at least plausible that the results found may in fact be peculiar to tasks of this sort and that quite different results may be found with other tasks. Although we have called it a discrimination task, it is arguable that the task is more in the nature of a recognition task, since the subject has to choose which of two patterns has appeared in the tachistoscopic field rather than decide which one of a pair of lines is the longer. The generality of the phenomena so far reported was explored further in three experiments. The first of these experiments involved what was explicitly a visual recognition task; the second demanded an auditory discrimination of the subject as the additional task; the third compared performance with attention directed to the visual task with performance when attention was directed to the order task.

Experiment 6

Experiment 6 was conducted with the intention of finding out whether the effects so far reported could be replicated when a different sort of visual decision was demanded of the subject. In this case the subject's task was to report which letter of a designated set was presented in the tachistoscope.

Apparatus was identical to that used in Experiment 4. Visual signals consisted of upper case "Letraset" letters (Letraset No. 364, approx. 2.5 mm high) placed centrally on plain white cards which fitted into the stimulus field of the Cambridge tachistoscope.

There were four experimental conditions, which differed only in the size of the stimulus ensemble. Under Condition 1, the subject had to decide which of two letters was presented and the order in which the letter and the click had occurred; under Conditions 2, 3 and 4 the size of the stimulus set was 4, 8 and 25 letters respectively, the letter "Q" being eliminated from all conditions as it was practically indistinguishable from the letter "O" at the short exposure durations used throughout the experiment with the particular type of lettering used. The same 6-point rating-scale procedure used in Experiment 4 was used on the order-judgement task. Similarly sessions consisted of blocks of 100 trials, following a few practice trials of the condition which was to be used in that session. Subjects were randomly assigned to two groups, one of which underwent the conditions in the order 1-4, the other following the order 4-1.

Eight first-year psychology students served as subjects as part of their course requirement.

Results

2 arcsin $\sqrt{P(A)}$ for order judgements is given for all subjects under all four conditions in Table 5.6, and the corresponding Table of ANOVA is presented in Table 5.7. It is apparent that the effect of different experimental conditions was extremely small, and falls far short of significance. Though the groups factor is significant ($p < 0.005$), the groups x conditions interaction factor is not, indicating once more the lack of any order effect. It can be seen from Table 5.6 that Group 2 performed consistently better than Group 1 throughout, which presumably reflects poor matching of groups.

Response bias, B, is shown in Table 5.8, and the corresponding ANOVA is given in Table 5.9. The groups, subjects and conditions factors fail to reach significance at the .05 level, and once again the lack of a significant interaction factor indicates the absence of any order effect.

The pattern of the difference between conditions is different from the findings of previous experiments; in this case, the larger the size of the ensemble of visual signals, then the less biassed the subject is toward making <VA> responses. The previous series of experiments, it is true, have shown a decrease in bias towards <VA> responses when an additional visual decision has been required of the subject, but none of them has given any indication that the amount by which this bias changes depends on the difficulty of the visual decision.

From the table of error scores (Table 5.10) it can be seen that subjects rarely failed to recognise letters, and the number of errors is too small to determine whether any relationship exists between performance on the visual recognition task and performance on the order judgement task. As might be expected, most errors were made under Condition 4 with the largest number of visual alternatives.

It has been found useful in the past to express number of stimulus alternatives in terms of information theory measures (Garner, 1962). The basic unit of measurement is the bit, or logarithm to the base 2 of the number of alternatives (Log_2N). Provided the physical conditions of stimulus presentation are kept constant over conditions, Log_2N provides a useful estimate of the processing load a task imposes on the subject's central processing mechanisms. Most studies have concentrated on using Log_2N as a means of assessing the number of alternatives along a stimulus dimension that a person can reliably discriminate (e.g. Garner, 1962) or with using it as a measure of the processing load with different sizes of signal ensembles in choice reaction-

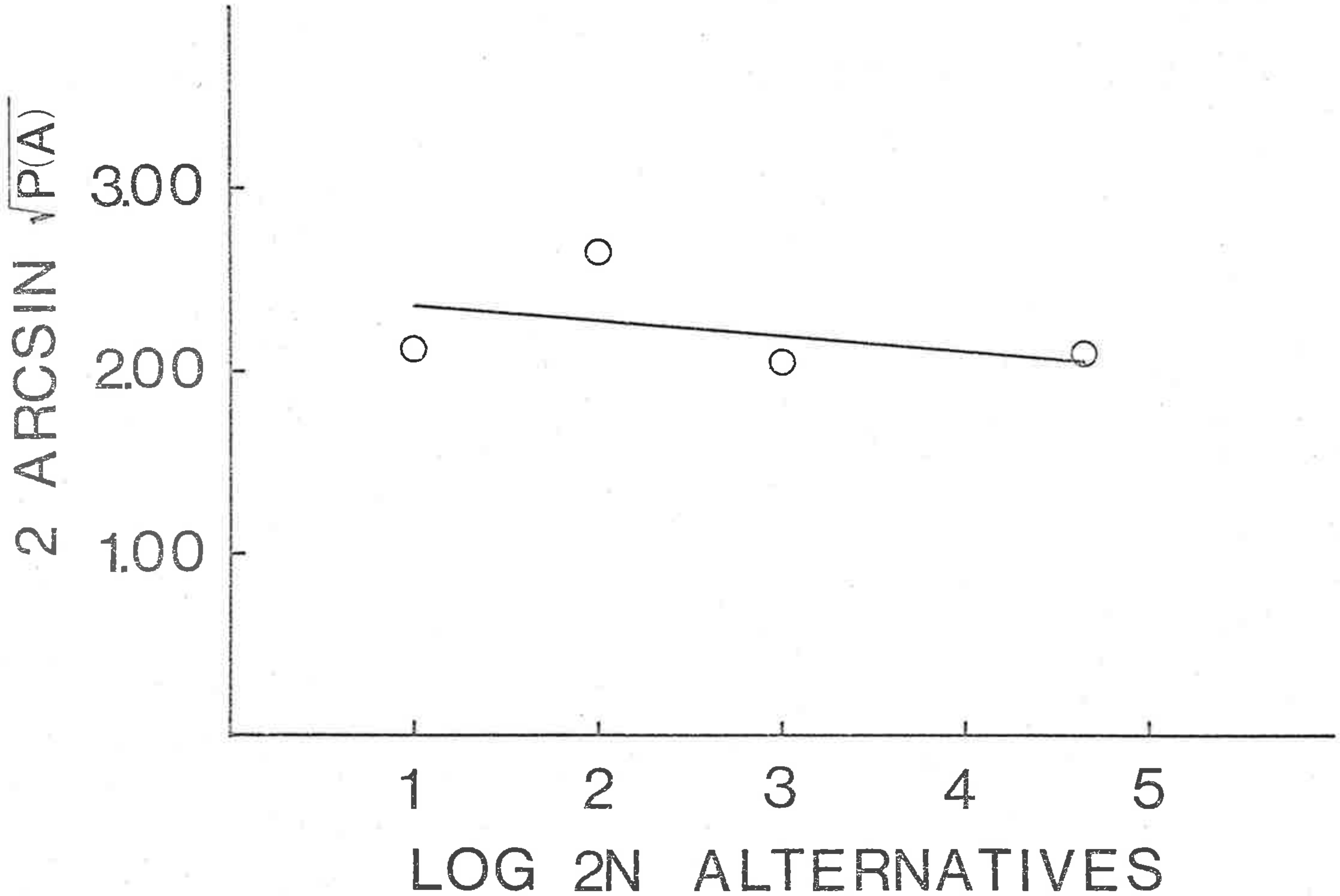

FIG. 5.2, 2 Arcsin $\sqrt{P(A)}$ or the order judgement task as a function of Log_2 N alternatives in Expt. 6.

time situations (Hick, 1952). Log_2N provides a convenient metric for the processing load imposed by the different ensemble sizes in the present experiment. When P(A) for the order judgement is plotted against Log_2N, the data is well-fitted by a straight line with a shallow negative slope (Fig. 5.2). The best fitting line for this data, found by the least squares method has a slope of -.085 and an intercept of 2.433. This serves to emphasise the smallness of the decrease in P(A) for the order judgement as the ensemble size in the visual task increases.

Table 5.6. 2 Arcsin $\sqrt{P(A)}$ for order judgements under different conditions in Experiment 6.

	Conditions	1	2	3	4
Subjects	VB	1.512	1.704	1.671	1.757
	BR	1.729	1.665	1.613	1.635
GP 1	CM	1.842	1.701	1.401	1.848
	TH	1.736	1.727	1.615	1.517
	PB	2.888	2.700	2.663	2.437
	JG	3.057	2.667	2.776	2.666
GP 2	KP	1.718	1.608	1.791	1.555
	PT	2.521	2.686	2.818	2.650
	$\overline{X}$	2.125	2.657	2.044	2.008

Table 5.7. Table of ANOVA for 2 Arcsin$\sqrt{P(A)}$ in Experiment 6.

Source	S.S.	df	M.S.	F	p
Subjects	3.3067	6	.5511	3.06	< .05
Conditions	.0579	3	.0193	11.08	-
Groups	4.9047	1	4.9047	27.25	< .005
Groups x Conds.	.1054	3	.0351	1.95	-
Error	.3284	18	.0180		

Table 5.8 B for different conditions in Expt.6.

	Conditions	1	2	3	4
Subjects	JB	3.200	4.000	1.910	5.057
	BR	2.303	2.483	2.727	2.783
	CM	1.724	1.951	2.397	2.872
	TH	2.263	2.609	2.897	2.679
	$\bar{x}$	2.373	2.761	2.483	3.370
	PB	1.445	3.217	2.386	2.556
	JG	1.900	1.769	2.111	2.263
	KP	2.758	2.743	2.752	2.596
	PT	1.854	1.958	2.347	2.667
	$\bar{x}$	1.989	2.422	2.788	2.541
	$\bar{X}$	2.181	2.592	2.636	2.956

Table 5.9 Table of ANOVA for B in Experiment 6.

Source	S.S.	df	M.S.	F	p
Subjects	4.8363	6	.8061	2.58	-
Conditions	2.3737	3	.7912	2.52	-
Cps	1.3338	1	1.338	4.25	-
Gps	.5726	3	.1909	1	
Error	5.6536	18	.3141		

Table 5.10 Experiment 6. Error scores on visual task.

Conditions		2	4	8	25
Subjects	VB	-	-	-	3
	BR	-	-	-	1
GP 1	CM	-	-	-	-
	TH	1	-	1	2
	PB	-	-	-	-
	JG	-	-	-	-
GP 2	KP	1	1	1	5
	PT	-	-	-	-

Discussion

Although no condition was included which exactly paralleled the order-only conditions of the preceding experiments, the values obtained for 2 arcsin$\sqrt{P(A)}$ are similar to those obtained in conditions where the additional decision was required.

The significant groups factor in the ANOVA of the sensitivity data, which recurs in subsequent experiments, reflects the shortcomings in relying on random assignation of subjects to groups, especially with relatively small group sizes. It may be argued that it would have been preferable to have adopted some matching procedure, but since the only appropriate variable upon which to have matched subjects would have been performance on an order judgement task, this would have introduced a further complicating factor of practice.

In short, the conclusion from this experiment is that the visual recognition task produced an effect on the order judgement comparable to that produced by discrimination tasks in previous experiments, although the heavily overlearned nature of the alternatives used may have minimised the effects of ensemble size. Overlearned patterns such as alphabetic characters may be criticised as unsuitable to test the effect of ensemble size on the performance of the order judgement task. Neisser, Novick and Lazar (1965) have shown, for example, that trained subjects could scan lists of random letters searching for ten different target letters as fast as they could searching for two targets. Perhaps with sufficient practice the small difference observed between conditions would have disappeared.

3. THE EFFECT OF TONE DISCRIMINATION ON BISENSORY ORDER JUDGEMENTS

So far, all the experiments conducted have been concerned with the effect of an additional decision about the visual signal on an audio-visual order judgement task. It seems fairly conclusive that the effect of the extra visual decision is to reduce sensitivity in the order task and to tend to reduce bias towards ⟨VA⟩ responses. What, we may then ask, would be the effect of a comparable auditory discrimination task on bisensory order judgements? Experiment 7 was designed to answer this question.

Experiment 7

Method and Procedure

Instead of being presented with a click through the binaural headphones, the subject was presented with a 50 msec. burst of the output of a sine wave generator. The experimenter set the generator on each trial to give an output of either 1000 or 1200 Hz. according to a predetermined order, which was random within the constraint that series of more than three identical trials were eliminated.

The procedure was similar to that employed in all other experiments. The subject had first to report whether he had been presented with a high tone or a low tone, and then indicate his degree of confidence on a six-point rating scale that the tone or the visual pattern (in this case two lines of equal length presented in the centre of the tachistoscope field) had occurred first. The intervals used were identical to those of

Experiment 5 and subsequent experiments, i.e. the auditory signal preceding by 30 msec. on <av> trials and the visual signal preceding by 70 msec. on <va> trials.

Only two conditions were employed in this experiment. Under Condition 1, only an order-judgement decision was required of the subjects, while under Condition 2 subjects were required to report which of the two tones had occurred before reporting their order-judgement. Subjects were allocated at random into two experimental groups, Group 1 undergoing Condition 1 first and Group 2 undergoing Condition 2 first. Subjects completed one session of 100 trials under each condition. Approximately 15-20 practice trials were given immediately prior to each experimental session, feedback about the order judgement being given only on the first ten of these. No feedback about the order judgement was ever given on any of the experimental trials, though subjects were always told if they made a mistake on the tone judgement.

Eight first-year psychology students served as subjects as part of their course requirement.

Results

The usual measures for the order judgement task, 2 arcsin $\sqrt{P(A)}$ and B, are given in Table 5.11, the corresponding tables of ANOVA being presented in Tables 5.12 and 5.13 respectively. It can be seen from Table 5.12 that the groups factor, the conditions factor and the groups x conditions interaction all reach significance. Again, a significant effect is evident for both the groups factor and the conditions factor. It seems that an additional auditory decision has much the same effect as the additional visual decision.

Table 5.11. Experiment 7. - Results Summary.

		2 Arcsin$\sqrt{P(A)}$		B		Errors on visual task
		Cond. 1	Cond. 2	Cond. 1	Cond. 2	
GP.1	IK	2.668	2.633	2.719	2.731	1
	KH	2.792	2.718	2.438	2.667	6
	CH	2.855	2.879	2.000	3.333	0
	DR	2.813	2.204	3.750	4.238	5
	$\bar{X}_1$	2.7820	2.6085	2.7267	3.2422	
GP.2	JJ	2.767	1.514	3.028	3.417	10
	SR	2.305	1.599	2.750	3.048	0
	RC	3.141	2.237	2.000	2.933	0
	CL	2.280	1.762	2.906	2.790	2
	$\bar{X}_2$	2.6232	1.7780	2.6710	3.0470	
	$\bar{X}$	2.7026	2.1932	2.6988	3.1446	

Table 5.12. ANOVA of 2 Arcsin$\sqrt{P(A)}$ in Experiment 7.

Source	S.S.	df	M.S.	F	p
Conditions	.9787	1	.9787	10.08	< .01
Groups	1.0379	1	1.0379	11.43	< .01
Groups x Conds.	.4512	1	.4512	4.93	< .05
Within cell	1.0893	12	.0908		

Table 5.13. ANOVA of B in Experiment 7.

Source	S.S.	df	M.S.	F	p
Conditions	.0631	1	.0631	1	
Groups	.7948	1	.7948	2.32	N.S.
Groups x Conds.	.0194	1	.0194	1	
Within cell	4.1058	12	.3422		

The lack of any matching procedure again accounts for the significance of the first factor, and the effect of the extra auditory decision on the order of judgement for the second factor; the significance of the groups x conditions interaction suggests a practice effect, and indeed, if we look back to Table 5.11, then we find that the scores of Group 2 under Condition 2, which they underwent first, are considerably lower than the scores of Group 1, who underwent this condition second, there apparently being little difference between the two groups under Condition 1.

None of these factors in the analysis of the bias scores were significant. However, referring to Table 5.13, it is apparent that although the subjects were only very slightly biassed on Condition 1, under Condition 2 the bias did shift in the direction of more ⟨AV⟩ responses.

Error scores for subjects on the auditory discrimination task are given in Table 5.13; no relationship is apparent between error scores and performance under Condition 1, or between error scores and the change in performance between conditions.

Discussion

Substituting the auditory discrimination for a visual task seems to result in substantially the same pattern of findings as regards both sensitivity and bias. Although the similarity of effects of the additional visual and the auditory tasks on sensitivity might have been anticipated in the light of the findings of the previous experiments, the effect on the bias measure was less easily forseeable. In the present experiment, a decrease in bias towards <VA> responses occurred. Although this agrees with the predictions of the prior entry hypothesis in that there is an increased probability of reporting the attended signal as coming first, it is nonetheless consistent with the earlier findings of a reduction in bias to <VA> responses. It must be stressed, however, that these are only tendencies in the data and that in none of the cases has the effect of different conditions on bias been statistically significant.

One other feature worth noting about the present experiment is that the values for 2 arcsin $\sqrt{P(A)}$ (Table 5.11) are generally higher than the corresponding measures in the previous experiments (see Fig. 4.4., Chapter 4) where the auditory signal was a click instead of a tone, while the bias measures appear to be comparable. This reasserts the specificity of the effects of signal combinations on order judgements, a point which emerged from the review of order judgement studies in Chapter 3.

4. ORDER JUDGEMENT WITH AN EXTRA VISUAL DECISION UNDER DIFFERENT ATTENTIONAL INSTRUCTIONS

One final experiment remains to be discussed under the heading of this chapter, and this experiment is concerned with how different attentional instructions to the subject about the importance of the additional task affect performance on the order judgement. If the effects of the additional task are the result of occupying capacity otherwise given over to the order task, it would be expected that the amount by which sensitivity decreases and the extent to which bias changes in the direction of <AV> responses would depend on whether instructions emphasise attention to the additional task or to the order task.

Experiment 8

Method and Procedure

The same apparatus was used as in the previous experiments with the visual signal the same as in the difficult visual decisions condition i.e. a pair of lines 35 mm and 37 mm long alternating from left to right in a pre-determined random sequence. The auditory signal was identical to that used in Experiment 7, namely, a 50 msec. burst of a 1000 Hz. tone signal. Subjects underwent three experimental conditions. Condition 1 corresponded to Condition 1 in Experiment 7; Condition 2 required an extra visual decision of the subject, but instructions under this condition emphasised that subjects should always try to be right about the order decision, and were to report the order decision before they reported the length decision; the stimulus combination in Condition 3 was exactly the same as in Condition 2, but subjects were instructed, as in all previous experiments, to try always to be right about the visual decision, and to report this decision before reporting the order judgement. Subjects were allocated at random to two experimental groups, Group 1 undergoing the conditions in the order 1, 2, 3, and Group 2 in the order 3, 2, 1. Two postgraduate students from the psychology department volunteered as subjects, and four first-year students took part in the experiment as part of their course requirement.

Results and Discussion

2 arcsin $\sqrt{P(A)}$ for all subjects is given in Table 5.14 and the results of the corresponding ANOVA are given in Table 5.15.

Table 5.14. 2 Arcsin$\sqrt{P(A)}$ in Experiment 8.

Conditions		1	2	3
Subjects	JR	2.691	2.319	2.118
GP 1	RM	2.810	2.686	2.322
	RN	2.763	2.781	2.498
	$\bar{x}_1$	2.755	2.595	2.313
	GM	2.647	2.404	1.691
GP 2	JJ	2.933	2.721	2.111
	SP	2.809	2.732	2.192
	$\bar{x}_2$	2.796	2.619	1.998
	$\bar{X}$	2.776	2.607	2.155

Table 5.15. Table of ANOVA of 2 Arcsin P(A) in Experiment 8.

Source	S.S.	df	M.S.	F	p
Groups	0.7529	1	0.7529	2.21	-
Conditions	2.1600	2	1.0800	3.17	$< .05 < .10$
Groups x Conds.	0.5002	2	0.2501	1	
Replications	4.0858	12	0.3405		

Though no effects are significant at the .05 level, it can be seen that the conditions factor just falls short of significance. Looking at the pattern of the mean results, it appears that performance on the order judgement task declined steadily from Condition 1 to Condition 3. This is consistent with the notion that subjects were allocating successively more capacity to the visual task over the three conditions, although the error data in Table 5.16 affords at best equivocal support for this view. While it is true that the total number of errors under Condition 3 is less than under Condition 2, the discrepancy seems to be due mainly to the performance of subject RN, who made a very large number of errors under Condition 2.

The results on the measure of bias contrast with all the previous findings, and a considerable difference in bias is evidence between conditions (Table 5.17), Condition 3 giving rise to greater bias towards ⟨VA⟩ responses than the other two. The results of the ANOVA (Table 5.18) confirm a significant effect for the conditions factor, but for no others. Although this result would seem to conform to the predictions of the prior entry hypothesis, the extent to which previous results (obtained in very similar experimental conditions) are contrary to this notion are sufficient to justify an effort to find an alternative explanation.

For the present, it will do to note that, unlike the other experiments in the current series, the present one included a condition where attention to the order judgement was specifically demanded as well as a condition where being correct on the visual decision was emphasised.

Table 5.16. No.of errors on visual task inConditions 2 & 3 in Experiment 8.

Conditions		2	3
Subjects	JR	0	0
GP 1	RM	0	0
	RN	11	2
	GM	5	6
GP 2	JJ	1	0
	SP	1	5

Table 5.17. Response bias B in Experiment 8.

Conditions		1	2	3
Subjects	JR	3.000	3.1611	2.804
GP 1	RM	4.000	2.833	1.924
	RN	2.833	2.905	2.852
	$\bar{x}_1$	3.278	2.966	2.527
	GM	2.783	3.200	2.408
GP 2	JJ	3.667	3.000	0.948
	SP	4.050	4.000	2.000
	$\bar{x}_2$	3.500	3.400	1.785
	$\bar{X}$	3.388	3.183	2.156

Table 5.18. ANOVA of response bias B in Experiment 8.

Source	S.S.	df	M.S.	F	p
Groups	.0038	1	.0038	1	-
Conditions	5.2347	2	2.6173	7.97	$<.01$
Groups x Conditions	1.1769	2	.5884	1.79	-
Within cell	3.9414	12	.3285		

V. GENERAL DISCUSSION

In general, the experiments discussed in the present chapter support the findings of the TSD experiments in Chapter 4, and confirm their generality. These findings may be summarised as follows.

When an additional decision is required of the subject, whether it is about a signal presented in either the auditory or the visual modality, the sensitivity measure on the order judgement decreases. The extent of this decrease appears not to depend on the difficulty of the decision, although the indication from Experiment 8 is that it does depend on how the person distributes his capacity between the tasks. The failure to find any consistent relationship throughout the series of experiments between the number of errors on the visual task and the initial performance on the order judgement would seem to bear out the first point.

To a lesser extent than the changes in sensitivity, the changes in the bias measures are consistent when the extra decision is required of the subject. The effect of the extra decision in the majority of experiments was to change bias towards more ⟨AV⟩ responses, again regardless of whether the extra decision was about an auditory signal or a visual one. This is in contradiction to the prior entry hypothesis, which we can now regard as gaining little support, at least for this type of order-judgement situation. Experiment 8, however, remains an exception to this pattern.

With the particular signals in these experiments a general tendency towards bias to ⟨VA⟩ responses emerged, and as has already been noted, the general effect of an extra decision task was to reduce this bias. Although the reduction in sensitivity with the additional decision is not surprising, it seems that in this instance, where there is no pressure on the subject to respond as quickly as possible but he has to take in a great deal of information in a very short time, the additional decision also has the effect of breaking down the bias to one of the response alternatives.

CHAPTER 6.

IMPLICATION OF THE ORDER JUDGEMENT DATA FOR INFORMATION PROCESSING IN GENERAL

The indications from the order judgement experiments reported in the last two chapters are that attending to one of the signals in the stimulus pair fails to increase the probability of the subject reporting that signal as occurring first. Under conditions where attention is directed towards one of the signals, a reduction in sensitivity on the order judgement task is evident. This is accompanied by a shift in bias away from reporting the visual signal as coming first, which contradicts the predictions of the prior entry hypothesis.

Now the prior entry hypothesis proceeds from the assumption that temporal specification is an attribute of the signal which is derived from the order in which signals are dealt with by the central processing mechanism. That is, the notion of prior entry implies that because a signal presented in a particular modality in a bisensory array is given priority, then the central processing mechanisms deal with this particular signal first; the perceived order of the signals is assumed to depend on the order in which they are processed, so that the first-processed signals are perceived as the first-happening. However, the failure in most of the experiments reported in Chapters 4 and 5 to find any increase in bias to report an attended signal as coming first argues against this view, while the fact that sensitivity on the order task is reduced under the extra decision conditions implies some information loss under that condition. There seem to be at least three alternative information processing schemes which could account for this.

First, it could be that the impairment is the result of a parallel processing system having to share its limited capacity between both a length decision and an order decision. Second, the impairment could be the result of delay in retrieving the order information from a rapidly-decaying short-term store, since the subject has to report his length judgement first. Finally, the possibility is that the decrement is the result of the order in which different stimulus dimensions are encoded: since length is emphasised in the experimental instructions, this is the dimension encoded first and most efficiently, while the encoding of order information suffers compared with the situation where only the order information has to be encoded.

One feature of the data which would argue against a parallel processing scheme is the failure to find a larger decrement on the order-judgement task with the more difficult visual task in Experiments 4 and 5. Given the instructions to the subject to try to be right about the visual decision, and assuming that the limit to the amount of capacity the subject could give to the visual task is reached only when performance on the order task drops to chance level, we would have expected equivalent performance on the visual task with both the difficult and the easy discriminations, even at the expense of much poorer performance on the order task. Since the opposite was found, i.e. equivalent performance on the order task between conditions but a

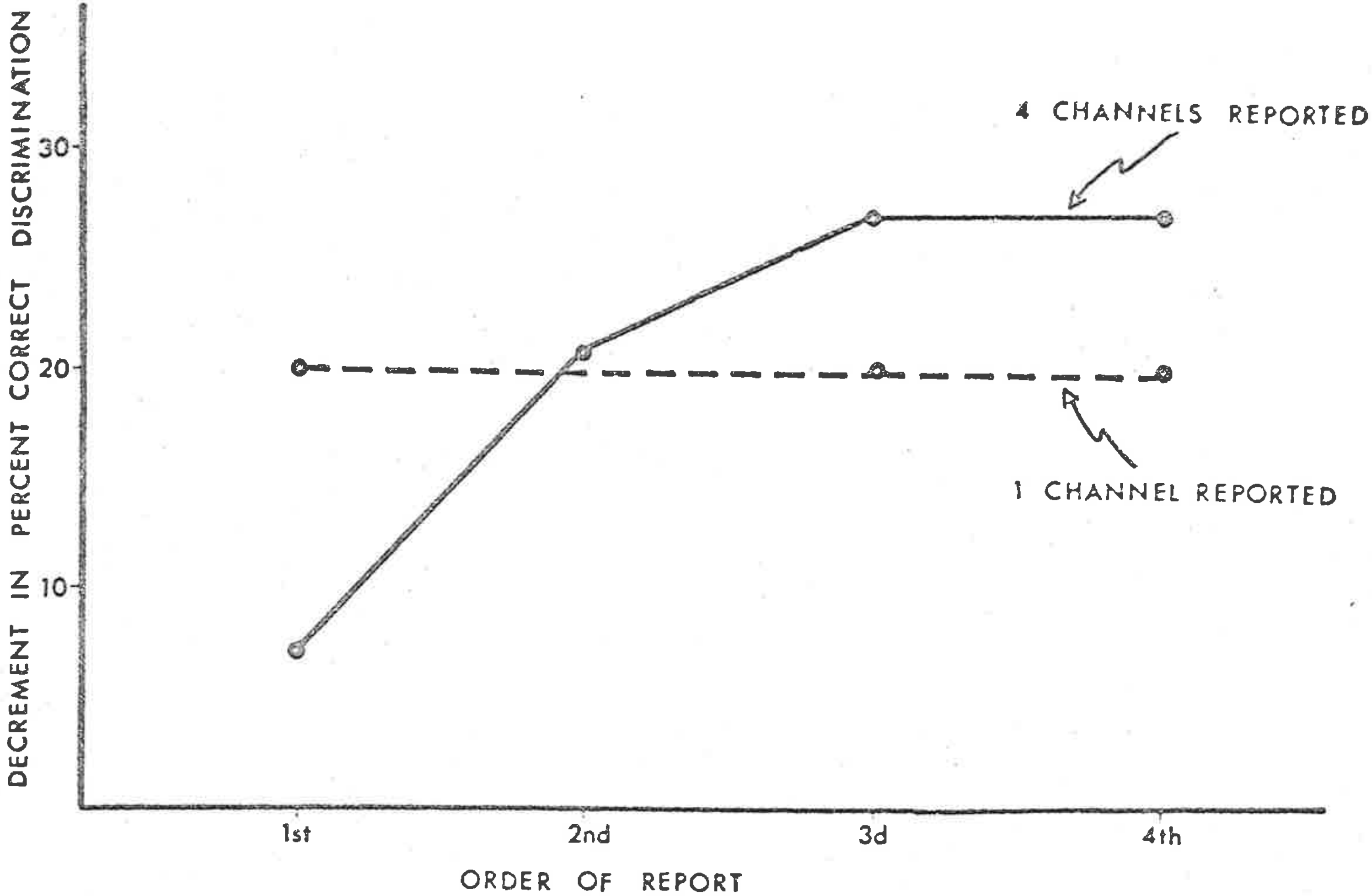

Fig. 6.1 Decrement in percent correct per channel as a function of order of report. (From Lindsay, 1970)

difference on the visual task, a parallel processing scheme seems unable to account for the findings, assuming, of course, that subjects followed the experimental instructions.

Just which of the two remaining alternatives provides the most satisfactory explanation of the data reported above is difficult to decide; it is equally difficult to see what further experiments could be undertaken to decide between them. The source of this difficulty is the similarity of the predictions which the rival schemes generate in order judgement situations like this.

However, pertinent to deciding between these two alternatives are the findings of two experiments conducted by Lindsay and his co-workers which suggest that the impairment of recognition performance on dimensions attended to second, third and fourth on multi-dimensional bisensory arrays are the result of limitations at the encoding stage rather than the result of decay in a transitory storage system. In the first of these experiments (Lindsay, 1970), performance on a one-dimension task was compared to performance under two different conditions where two dimensions of both a visual (vertical and horizontal position) and an auditory (intensity and frequency) had to be attended to. Under the first of these latter two conditions, all four channels had to be reported; under the other, only one channel had to be reported, but the subject did not know which one until after the presentation of the stimulus array. Under the four-channel condition, the decrement compared to the single channel condition increased as a function of the order of report (Fig. 6.1). When only one of the four channels was reported, the decrement was the same for each dimension, no matter what its serial position in the order of report under the four-channel condition, and this decrement was greater than for the first-reported dimension of the four-channel condition. As Lindsay points out, if the impairment under the four-channel report condition were due to the overloading of a rapidly decaying memory system, then performance when only one dimension is to be reported would be expected to be better than where all four are to be reported. Thus it would seem that the impairment comes about during the presentation of the signals, and that the advantage of the first reported dimension is brought about during the process of encoding the stimulus.

In the second experiment (Forbes, Taylor and Lindsay, 1967), pre-cueing of the four dimensions of the bisensory array produced better performance than did post-cueing; this difference between pre- and post-cueing remained constant whether the post-cue followed the signal by 100 ms., 300 ms., 1 sec. or 4 sec., a finding which argues against any decrement being due to information loss in a fast decaying storage system. We may note in passing the similarity between these findings and the results of tachistoscopic studies reviewed by Haber (1964). He concluded that the usual effects of order of report were essentially effects of order of encoding, and that despite the powerful set imposed on us by the way objects or sets of objects are normally expressed in language (e.g. three red stars) we nevertheless retain a deal of flexibility as to the order in which we encode different dimensions of these purely visual displays, as evidenced by his apparent success in training subjects to encode attributes in different orders. With simple bisensory signals varying only in physical parameters or location, there is no such linguistically imposed set and we would expect that the flexibility of coding order would be much greater and require less training to achieve different coding orders.

It may seem that the order judgement tasks reported so far do not constitute an adequate test of the prior entry hypothesis which, it must be admitted, was devised to explain a very different set of experimental circumstances. If this argument is accepted, then it must also be conceded that prior entry is not a general feature of information processing, and is a phenomenon of limited applicability and dubious testability. Certainly, the work of Lindsay and Haber does indicate that features of the stimulus array which are encoded first are reported most accurately, and that we have a degree of choice as to what we encode first. However, this does not mean that because we attend to some feature of a particular signal in a multi-signal array we will tend to perceive that signal as happening sooner in relation to other competing signals than we otherwise would, any more than we will see the signal as brighter or louder or higher-pitched or anything else.

It should be made clear that this view does not deny that different features of a stimulus can interact, e.g. louder signals may be perceived as more highly pitched or as occurring relatively sooner than softer signals. What this view does emphasise is that information about when a signal occurred does not depend on the order in which features of the particular signal array are dealt with by the central processing mechanisms. Nor should it be taken that the view pursued here, with its emphasis on the flexibility of the encoding process, necessarily rules out the possibility that encoding in the order judgement situation can occur in the manner predicted by the prior entry hypothesis. It does leave open the possibility that all the information will be extracted from a particular signal before any of the information from competing signals is encoded into short-term memory, which suggests a means of accounting for the anomalous result in the bias measures in Experiment 8. Experiments 3 to 7, it may be recalled, found a difference in sensitivity but no difference in bias when the subject was instructed to be sure to correctly report a feature of the visual or of the auditory signal as well as his order judgement. Experiment 8, on the other hand, showed only slight effects on sensitivity but significant changes in bias under some instructions. In the additional condition in Experiment 8, unlike Experiments 3 to 7, however, subjects were instructed to be right about the order judgement.

In Experiments 3 to 7, under instructions to be sure to be right about the length judgement, subjects were implicitly instructed to attend to the length judgement as well as to the order judgement. Under the same instruction in Experiment 8, we may think of the subjects as being instructed to attend to the length judgement instead of to the order judgement. If this distinction is crucial for the encoding strategy the subject adopts, then it becomes clear that the implicit instructions generated by the two different procedures might well give rise to different performance, and that the result of Experiment 8, which might be taken as supporting the prior entry hypothesis, is better explained as a special case of the model outlined above.

It may be concluded, then, that the prior entry hypothesis finds little support from the order judgement studies reported here or elsewhere, and what supporting evidence there is can be accommodated by the more general scheme outlined above which also encompasses the rest of the foregoing results. Care should, however, be taken to distinguish between the prior entry hypothesis and what some authors have called the "prior entry effect", i.e. the characteristic type of error in the complication experiment generally attributed to the subject's attending to a particular modality. The findings of Experiment 8 represent what might be termed a "prior entry effect" in the order judgement situation, but the prior entry hypothesis is unable to accommodate all the data.

Returning to the complication experiment, the confusing body of data, theoretical explanations and casual observation takes on a semblance of coherence when this more general explanation is applied. If the order in which information encoded from a stimulus array is flexible, then it is easy to see how different investigators could come up with different results, including the sort of result predicted by the prior entry hypothesis. Unlike the order judgement paradigm, in the complication experiment the visual display consists of a moving pointer, which the subject monitors more or less continuously. If the delivery of the complicating stimulus results in a temporary overload situation, then the possibility is at least open that the subject stops attending to the visual display while he processes the information from the auditory signal. Whether he stops attending before or after the delivery of the auditory stimulus is, of course, something that we would expect to be under the subject's control, and this would determine the direction and magnitude of error. In other words, it seems possible that the error is determined by the coding strategy adopted by the subject. This being the case, it was decided to conduct a series of complication experiments with the dual aims of obtaining a definitive, adequately quantified account of performance in this situation and of exploring the possible strategies adopted by subjects.

CHAPTER 7.

THE COMPLICATION EXPERIMENT UNCOMPLICATED

The failure of the prior entry hypothesis to adequately explain the results of the previously-reported order judgement experiments makes it necessary to seek other possible explanations of the findings of the complication experiments reviewed in Chapter 2. Clearly, it is unsatisfactory to try to explain these phenomena by a theory which has no generality beyond the special circumstances in which the phenomena are observed.

It may be recalled from Chapter 2 that a number of the original investigations of the complication experiment did consider the amount and direction of the error they obtained in relation to the position on the scale at which the complicating stimulus was presented. For example, Wundt, von Tschisch and Pflaum all reported a tendency towards more negative (i.e. anti-clockwise) errors on the left hand side of the dial and towards more positive (clockwise) errors, or at least smaller negative errors in the case of von Tschisch, on the right-hand side of the dial (Boring, 1950; Burrow, 1909). Further experimentation by Geiger using both a uniform-velocity complication clock apparatus and a pendulum apparatus confirmed that this effect was indeed due to spatial factors and not to the varying pointer speed of the pendulum apparatus of the previous experimenters as it accelerated on the upstroke and decelerated on the downstroke (Burrow, 1909). Leatherman (1940) found that different rotation speeds gave rise to errors which were relatively stable when measured in degrees of angular displacement, but which did differ with rotation speed when expressed as temporal errors in milliseconds. Using an adjustment method, Burrow (1909) found that the starting position on the dial of the complicating stimulus did affect the final position to which it was adjusted so that its onset was judged to be coincident with the pointer passing a mark on the dial. Taken together then, these hitherto unconnected findings suggest that the spatial position of the complication stimulus is an important determinant of the amount and direction of error in the complication experiment.

This is not altogether surprising in the light of evidence from purely static displays. There are many instances in the literature in which it has been shown that the perceived position of a stimulus along some dimension is not related in a one-to-one fashion to its objective position along that dimension, and that the magnitude and direction of the discrepancy between perceived and objective location is a function of the position of the stimulus along the particular dimension.

Systematic displacement of this nature for horizontal and vertical locations of dot, line and quadrilateral stimuli have been thoroughly mapped out by Taylor (1961). Using an immediate reproduction technique, she demonstrated that individual dot stimuli on a card tended to be systematically displaced away from the end points and the mid-point of the card in both the horizontal and vertical axes, enabling the displacement tendencies for different points on the card to be represented in two dimensional vector form. These displacements for individual points still apply when the points in question form the ends of

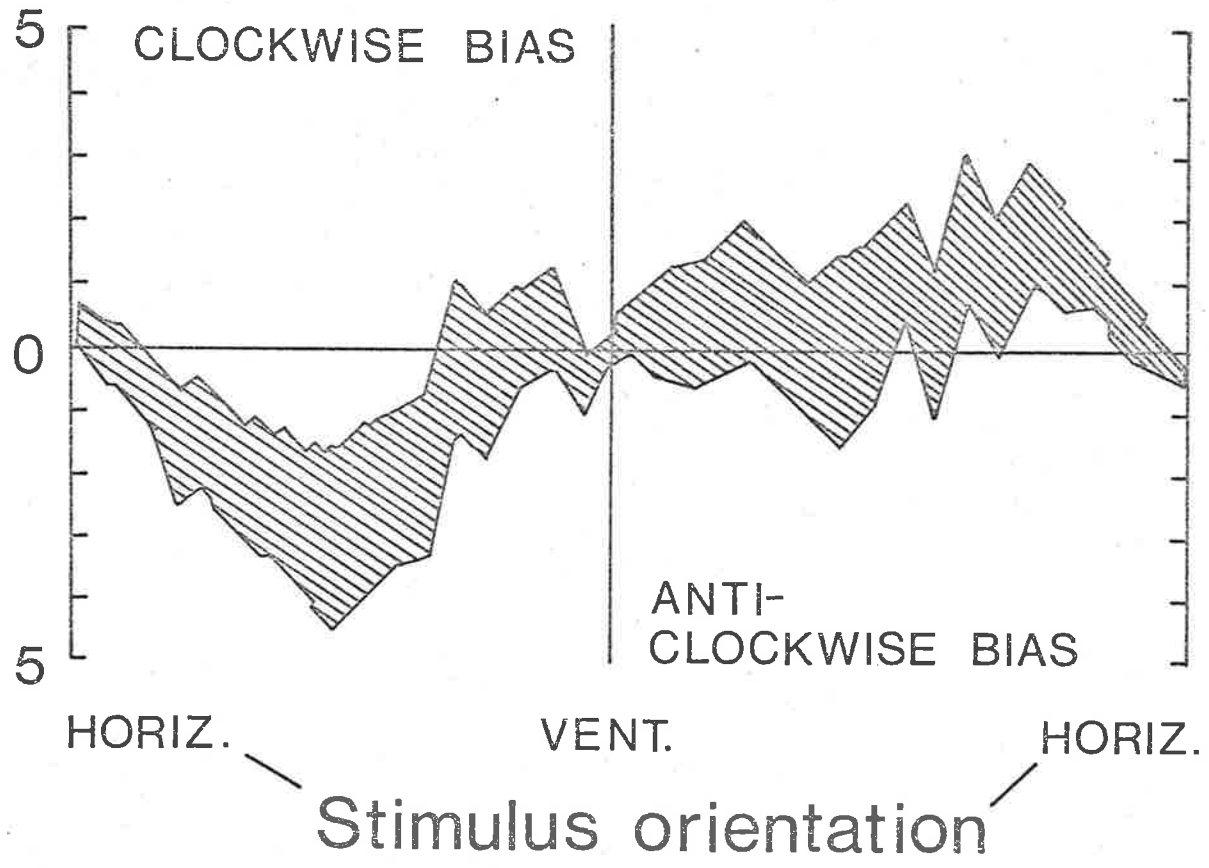

Fig. 7·1 Average Error for seen orientation, adapted from Lederman and Taylor (1969). Shaded area represents region within one standard error of the mean.

lines or the corners of quadrilaterals giving rise to marked distortion of these figures when subjects are required to serially reproduce them over a number of trials.

This kind of systematic distortion would seem to be a fairly general feature of performance where the individual is required to interpolate a stimulus along some continuum. For example, Lederman and Taylor (1969) have demonstrated that a pattern of displacement similar to those found by Taylor (1961) is found when a stimulus dot on a card is located by touch instead of vision, and that a comparable displacement of length judgements occurs when subjects are required to locate by touch a solder dot on a brass rod.

Of more direct relevance in the present context is the finding of systematic displacement as a function of presentation position of stimuli presented in circular or semi-circular displays. Attneave (1955) found that stimuli presented in a circular field tended to be perceived further towards the centre of each quadrant, i.e. away from the horizontal and vertical axes. No data is available from different quadrants in this report, so it is impossible to tell whether errors varied as a function of orientation.

Further data reported by Lederman and Taylor (1969), however, indicate that this is the case. Their subjects had to adjust a moveable arm on a semi-circular display to match the orientation of a radius arm marked on a stimulus card, stimuli being presented either visually or haptically. Their results for visual presentation are presented in Fig. 7.1, from which it can clearly be seen that anti-clockwise errors tended to occur in the left-hand side of the semi-circle and that clockwise errors tended to occur in the right-hand side. If this is the case with static displays, then it seems possible that this tendency can explain the findings of the complication experiment. To test this it would be necessary to show first that the errors obtained with static displays show the same overall tendency as the errors reported from the complication experiment i.e. that negative errors are both larger and more frequent, and secondly to show that the pattern of errors obtained in the complication experiment is similar to that obtained with a static display. To meet the first of these conditions, Experiment 9 was carried out. As the author was not aware of Lederman and Taylor's work at the time when the study was conducted, some differences in procedure that might otherwise have been avoided are evident. In the event, since a verbal estimation technique was chosen instead of a reproduction technique, this experiment constitutes a useful confirmation of Lederman and Taylor's findings.

Experiment 9.

Experiment 9 was intended to explore the pattern of position judgement errors with verbal estimations of the position of a static radius arm on a semi-circular dial.

Method

Apparatus. Stimuli were standard slides showing a white semi-circle with a radius arm in one of ten possible orientations, projected onto a pale green wall. In a dark room, two subjects at a time viewed the slides, one on either side of the slide projector, approximately 2 m. from the wall. As projected, the stimuli had a diameter of approximately 30 cm., with lines 2 mm.

thick. The projector was of the standard Kodak type with a carousel slide feed and a remote control switch. Two blank spaces were left between each slide; when E pressed the remote control switch and held it down, the projector flashed up a blank which served as a warning signal. This was followed immediately by the slide, while E still kept the remote control switch pressed down, so that both the warning signal and the stimulus duration lasted for the minimum possible exposure time on the projector. E then released the control switch so that the stimulus was followed by a blank screen which gave subjects enough light in which to write down their estimates of the angle on a prepared response sheet. When E saw that both subjects had completed their response, he proceeded to the next trial.

Procedure. Subjects were instructed to write down their estimate of the acute angle between the horizontal and the radius arm of the visual display. Four practice trials were given, followed by a series of 40 randomly ordered slides, 4 each in 10 different orientations, viz. 15°, 30°, 45°, 60° or 75° from the horizontal on either the left or the right.

Subjects. Twenty-five first year psychology students volunteered for a short visual perception experiment.

Results

Constant error and the standard error of the mean of judgements are listed in Table 7.1 and depicted in Fig. 7.2. Comparison with Fig. 7.1 shows that the results obtained in the present experiment with a written estimate are almost a mirror image of the results obtained by Lederman and Taylor using an adjustment technique. Paradoxically, this indicates

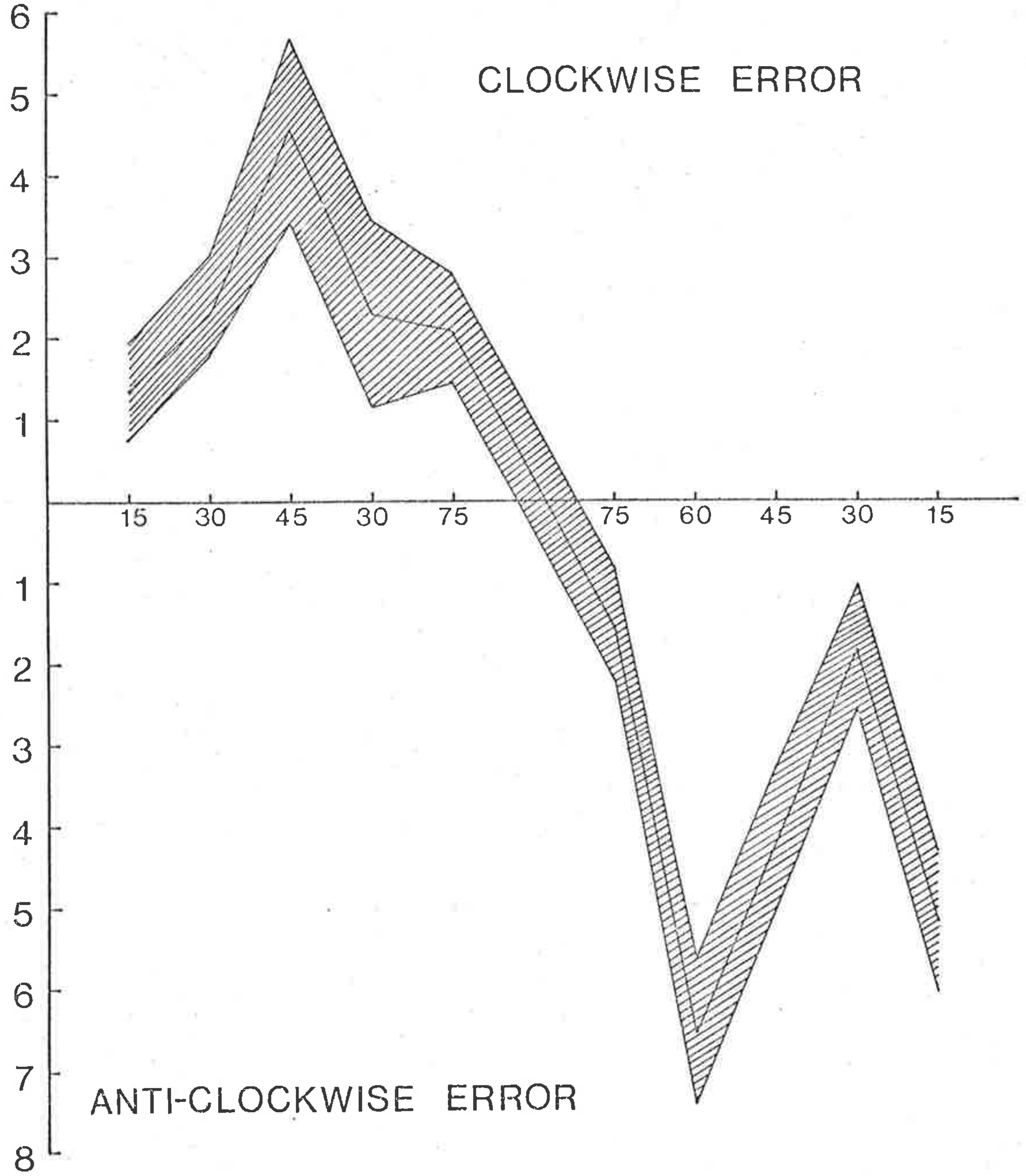

FIG. 7.2, Constant Error in Expt. 9. Shaded Area represents the region within one Standard Error of the Mean.

Table 7.1 Experiment 9. Summary of Angle Estimate Data. + and - sign in front of Constant Error Figures indicates clockwise and anti-clockwise respectively. All data expressed in terms of degrees of arc.

	Left-hand side					Right-hand side				
Position of Radius	15°	30°	45°	60°	75°	75°	60°	45°	30°	15°
Mean estimated position	16.35	32.30	49.55	62.30	77.10	76.55	66.55	49.15	31.85	20.20
Constant error	+1.35	+2.30	+4.55	+2.30	+2.10	-1.55	-6.55	-4.15	-1.85	-5.20
S.D.	6.04	7.09	10.91	11.35	7.15	6.84	9.08	8.66	8.14	8.72
SE of mean constant error	.61	1.71	1.10	1.14	.72	.69	.91	.87	.82	.88

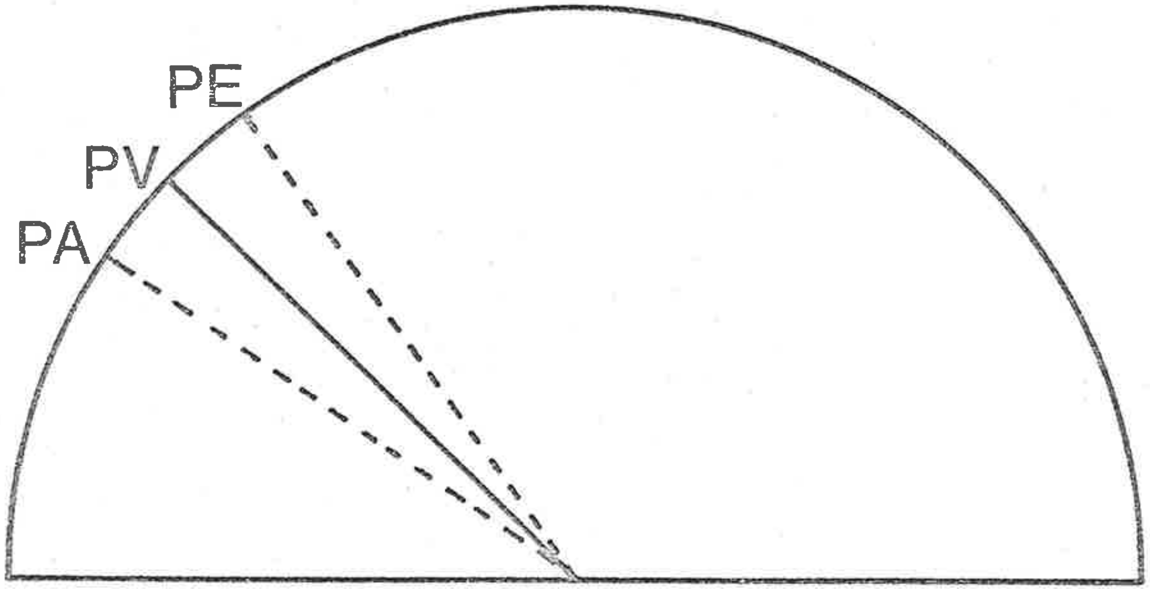

FIG. 7.3 The relationship between Estimated Position, Veridical Position, and Adjusted Position of the Radius.

good agreement between the results. In the present experiment, the subject had to assign an angular value to a briefly presented stimulus. If, for the sake of illustration, we take the case where the estimate is displaced in a clockwise direction as indicated by the position P_E in Fig. 7.3 when P_V is the veridical position of the radius arm, then, when the subject is asked to adjust the position of a radius arm to match the orientation of the stimulus radius arm (which he can see over and over again), he has to displace it in an anti-clockwise direction to the position P_A before his response subjectively matches the veridical position P_V. Thus, it can be seen from Figs. 7.1 and 7.2 that the two sets of findings do correspond closely save for the marked increase in anti-clockwise errors at the right-hand end of the scale in Fig. 7.2.

Analysis of constant errors for different positions by the Friedman Test (Siegel, 1956) indicates significant differences in constant error for different scale positions ($\chi^2{}_r = 55.30$, df = 9, $p < .001$). Individual differences are evident from the data, and this is confirmed by the value of Kendall's W (Siegel, 1956) ($\chi^2 = .027$, df = 9, $p < .70$) which reflects a lack of agreement among judges as to the size of displacements occurring in different positions.

With the estimation technique, clockwise errors predominate in the left-hand quadrant, anti-clockwise errors in the right-hand quadrant. The pattern is generally similar to Lederman and Taylor's, with maximum displacements tending to occur towards the middle of quadrants. The graphs of the constant error in the two studies would seem to differ in that the standard error of the mean is apparently smaller in the present study; this seems attributable to differences in sample size, 100 for each point on the graph in the present study as against 30 in Lederman and Taylor's. Certainly, the standard deviations in the present study (Table 7.1) are large compared to constant error, which might be expected given the short exposure time and the attaching of a numerical estimate of limited precision. Again the same pattern emerges with larger SDs for the stimuli towards the centre of the quadrant, except for the 15° right position.

The probabilities of clockwise and anti-clockwise responses again reflect the pattern of the constant errors; as Fig. 7.4 shows, clockwise responses occur more often in the left-hand quadrant, anti-clockwise in the right-hand quadrant.

Discussion

Both the studies discussed above are in agreement about the general error tendencies when subjects are required to judge the position of a radius in a semi-circle, adjustment procedures yielding the inverse of results obtained with estimation techniques. We may now ask to what extent these results relate to the findings of the complication experiment.

First of all, as Experiment 9 showed, negative errors do tend to be rather more frequent overall (see Table 7.2), a finding which agrees with most of the complication experiments reviewed in Chapter 2. However, when we look at the proportion of clockwise and anti-clockwise errors in different quadrants of the dial, then we find the opposite of such data as can be gleaned from these early reports of the complication experiment. Geiger, for example, agreed with Wundt, von Tschisch and Pflaum

Table 7.2. Experiment 9. Probabilities of Clockwise, Anti-clockwise and exact judgements at different scale positions.

	Left-hand side					Right-hand side					
Position	15°	30°	45°	60°	75°	75°	60°	45°	30°	15°	$\bar{X}$
Type of Judgement											
Clockwise	.48	.39	.46	.46	.62	.24	.11	.23	.28	.14	.341
Anti-clockwise	.33	.20	.22	.28	.23	.61	.73	.46	.38	.60	.404
Exact.	.19	.41	.32	.26	.15	.15	.16	.31	.34	.26	.255

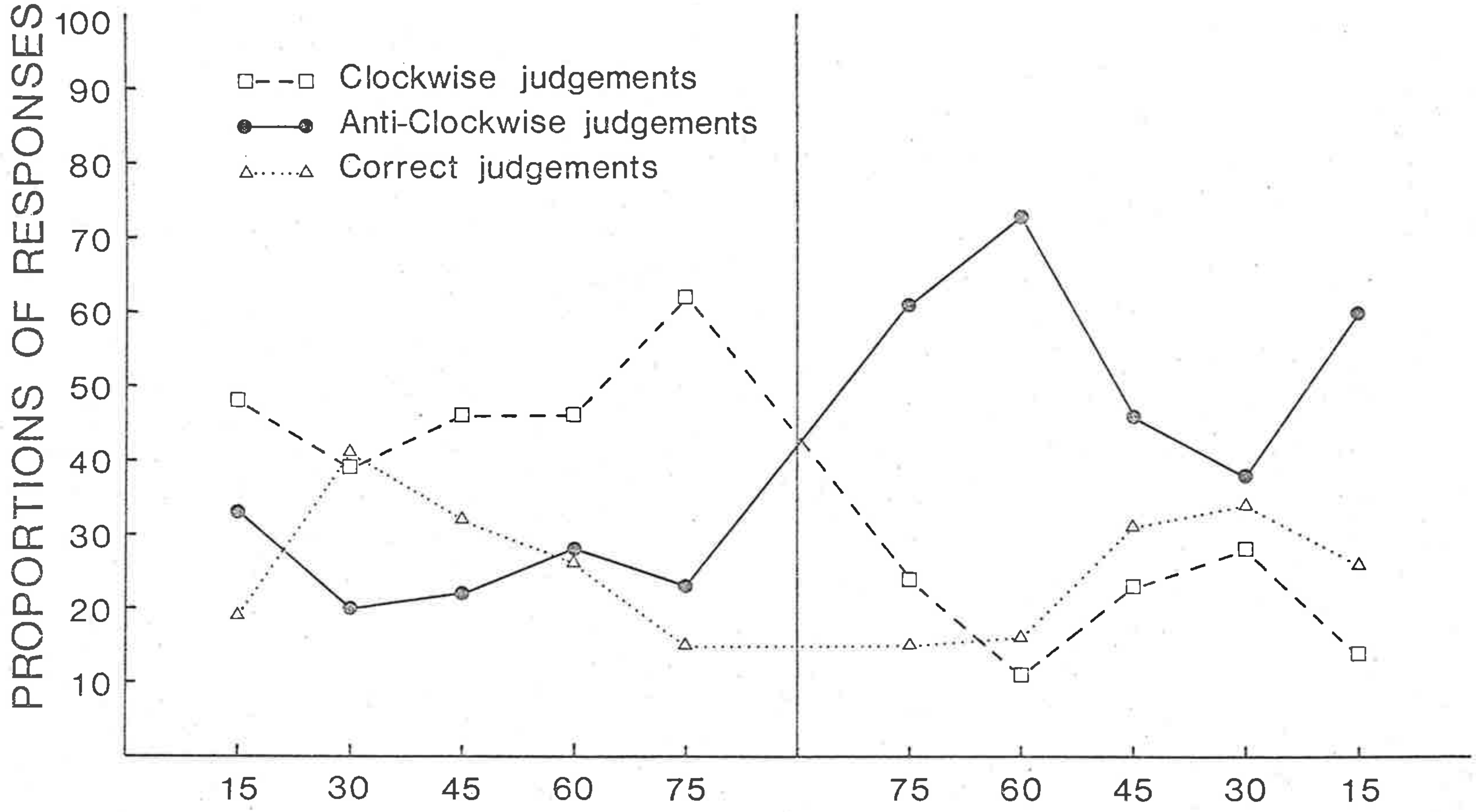

FIG. 7.4, Expt. 9, Proportions of Clockwise, Anti-clockwise and Correct Judgements.

that anti-clockwise errors tend to occur on the left-hand side and that clockwise errors tend to occur on the right-hand side. All these investigators seem to have used an estimation technique, so that the results of these complication experiments conflict with our own constant error data as well as the results from Lederman and Taylor. The only study which used an adjustment technique (Burrow, 1909) required subjects to adjust the onset of an auditory stimulus so that its onset appeared to coincide with the pointer arriving at a centrally placed mark, so that no details about the possible effect of position are available (other than the effect of the starting position of the auditory stimulus mentioned above).

Nevertheless, so inadequate is the data from the complication experiment in this respect, and so consistent is the data from these static displays, that it was felt to be worthwhile pursuing any possible similarity between the pattern of errors in a dynamic display of the complication experiment type and the static type of display used in the above investigations. To this end Experiment 10 was carried out.

Experiment 10

Experiment 10 is essentially a complication experiment of the type discussed in Chapter 2. The only major differences between this experiment and these older experiments are in the use of an increase in white noise as a complicating stimulus rather than a bell-stroke, etc., and in the focus of interest being the error parameters as a function of the scale position at which the complicating stimulus was delivered.

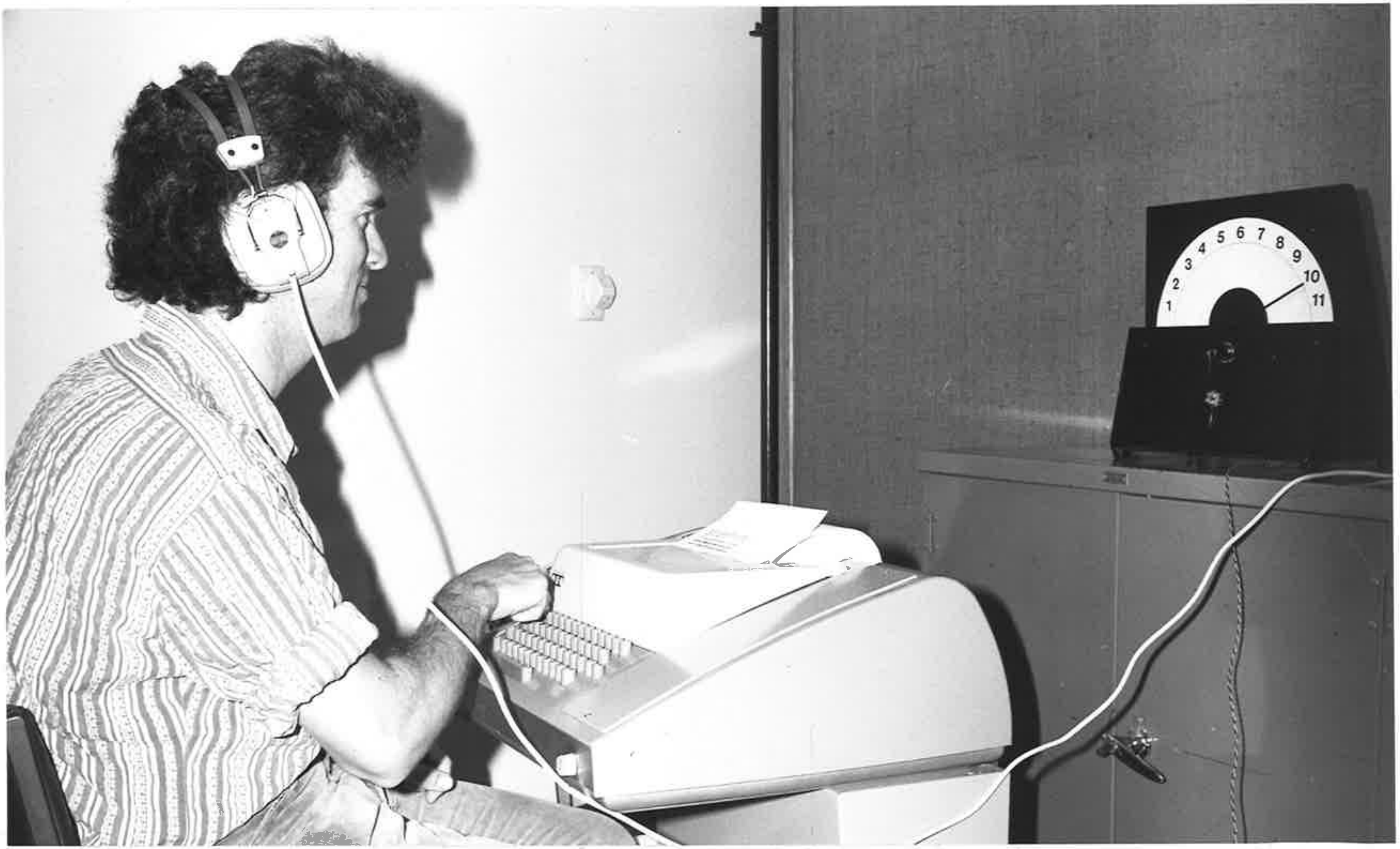

Fig. 7.5. The Complication Apparatus.

Apparatus. Subjects sat facing a semi-circle dial (30 cm diameter) at a distance of approximately 2.5 m (Fig. 7.5). A light aluminium pointer revolved round the dial at a speed of approximately 1 rev. per sec. (1 rev. per 993 msec., with variations of the order of 2 msec.) driven by a constant speed electric motor and a train of gear wheels. The pointer was connected to the final drive by means of a heavy counterbalanced brass boss, to ensure an even speed of rotation. When a hole drilled in this boss passed a beam from a photo-electric cell mounted in the supporting chassis a signal was delivered to a PDP-8L computer which controlled an attenuator connected to a Grason-Stadler white noise generator. After an appropriate interval, the computer switched channels in the attenuator and reduced the level of attenuation by 7 dB for a period of 50 msec., presenting the subject with a brief but easily detectable increase in the level of white noise. Background noise in the earphones worn by the subject was set at a level of 63 dB S.P.L., as determined by a Brüel and Kjaer Sound Level Meter inserted into a piece of thick foam rubber and held up against the earphone, this being the lowest level at which the background noise in the headphones could be easily heard against extraneous noise from the computer, Teletype and associated peripheral equipment.

The onset of the increase in the white noise level was timed to coincide with the arrival of pointer at one of the ten positions on the dial marked by the figures 1-5 and 7-11, these corresponding to the ten positions of the radius arm used in Experiment 9. Subjects were required to judge where the pointer was at the onset of the auditory signal and to record their answers on a Teletype;

the computer both stored these data and overwrote the subject's response on the Teletype, so that subjects were unable to refer back to previous responses. At the completion of each session, the computer provided the subject with feedback by typing out the constant error, absolute error and mean number of revolutions required to reach a decision for each of the ten scale positions. All responses were printed out on paper tape at the conclusion of the session. This allowed any errors on the part of the subject (e.g. typing in too many characters) to be eliminated from further analysis.

Method and Procedure. After familiarisation, subjects underwent ten practice trials, one in each of the ten scale positions. This was followed by ten trials in each of the ten scale positions, these being randomly ordered. Subjects were told that they could have as many revolutions on each trial as they wished before making their decision but that they were to try to arrive at a decision as quickly as possible. Responses were to be expressed to within one decimal place. Typing the first character of the response terminated the auditory signal, and pressing the space bar at the completion of the response initiated a new trial after an intervening revolution on which no auditory signal was delivered.

Subjects. Ten postgraduate and undergraduate students at the University of Adelaide volunteered to take part in the experiment.

Results

Constant error for each subject in each of the ten scale positions is given in Table 7.3, along with the median of these

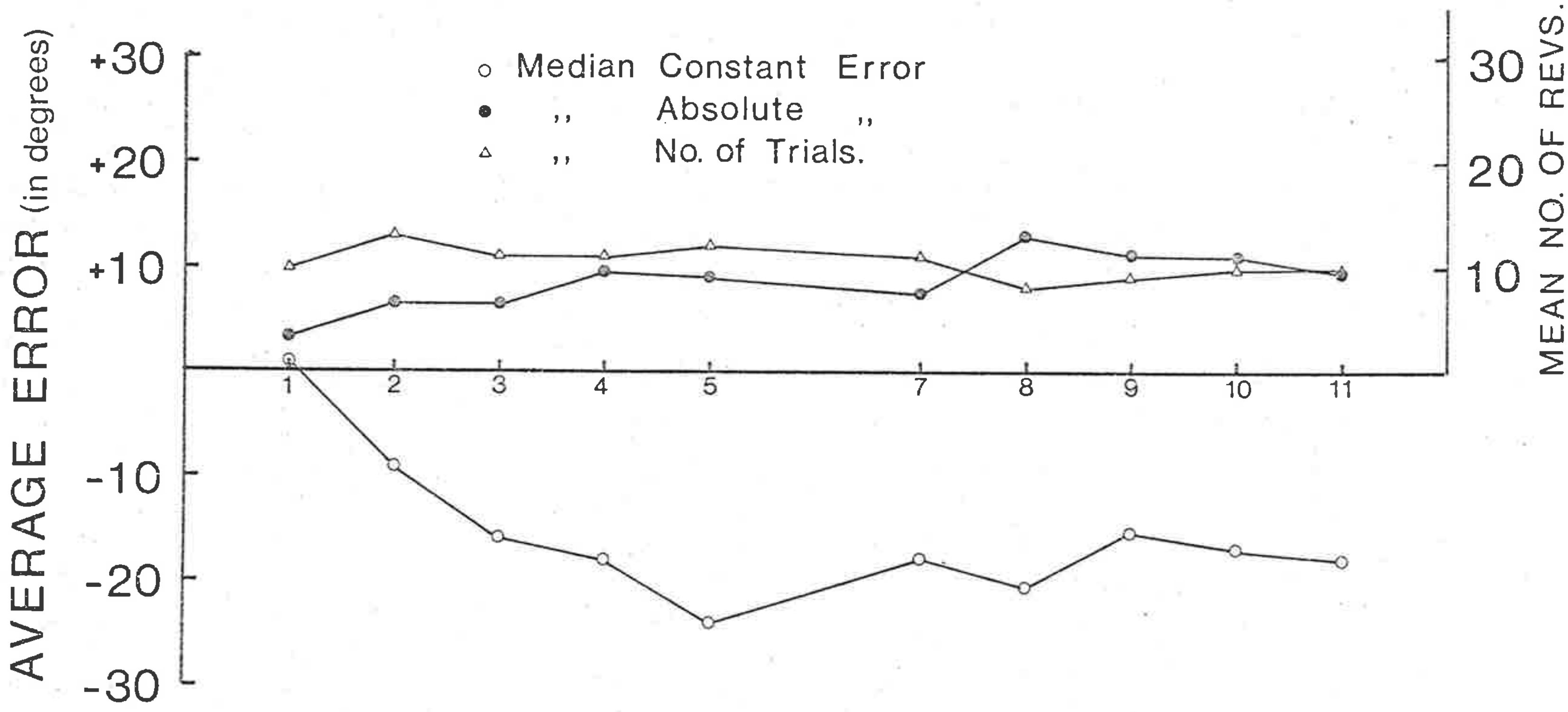

FIG. 7.6, Constant Error, Absolute Error and Revs. to decision in Expt. 10.

constant errors, the median of the absolute errors and the median number of revolutions to. reach a decision. Median constant and absolute error are plotted in Fig. 7.6 in degrees of arc, along with number of revolutions to reach a decision. It can be seen from Fig. 7.6 that the constant error starts off as marginally clockwise at scale position 1, and rapidly becomes anti-clockwise, fluctuating around 17-19 degrees from scale position 3 onwards. Analysis of these data by the Friedman Test reveals a highly significant difference between constant errors for different scale positions ($\chi^2_r = 41.5$, df = 9, $p < .001$). This pattern is reflected in the pattern of absolute errors, which tend to increase in a fashion similar to the constant error throughout ($\chi^2_r = 29.25$, df = 9, $p < .001$). The number of revolutions to reach a decision, however, would seem to have remained relatively stable throughout ($\chi^2_r = 10.87$, df = 9, $p < .05$) and no relationship is evident between the error patterns and the number of trials to reach a decision.

Discussion

Constant error follows a well-defined pattern, becoming increasingly negative over the first few scale divisions, and then levelling off as a fairly steady negative error. No relationship whatsoever is evident between the pattern of constant error in the present experiment and the pattern obtained with the static displays in the previous experiment. Apart from requiring interpolation of an auditory signal rather than a visual one in relation to the semi-circular dial the present experiment involves a different task in that subjects have to judge the position of the auditory signal in relation to a numbered scale

Table 7.3. Summary of Individual and Group Results in Experiment 10.

Scale Position		1	2	3	4	5	7	8	9	10	11
Subject	1	-.81	-1.52	-1.99	-2.7	-2.3	-2.2	-2.0	-0.81	-1.10	-1
	2	+.28	- .18	- .58	-1.22	- .93	-1.25	-1.52	- .75	-1.15	-1.35
	3	+.01	- .56	-1.32	-1.69	-1.69	-1.10	-2.10	-1.31	-.156	-1.77
	4	+.57	+ .24	- .41	- .76	- .62	- .19	+ .21	- .31	- .52	-1.05
	5	+.10	- .69	- .78	- .80	-1.39	-1.31	-1.62	- .51	- .17	- .19
	6	-.71	-1.35	-2.16	-2.08	-1.86	- .43	- .63	- .23	- .25	- .67
	7	+.14	- .65	-1.45	-1.30	-1.86	-2.00	-1.95	-1.35	-1.35	-2.20
	8	-.27	- .78	-1.62	-1.74	-1.20	-2.14	-1.35	-3.32	-1.35	-2.48
	9	0	- .35	- .74	-1.09	-1.50	- .95	- .73	- .54	- .58	- .74
	10	+.95	+ .46	+ .29	+ .10	- .36	- .64	-1.12	-1.31	-1.49	-1.80
Median Constant error (^{o}Arc)		+.9	-9.2	-15.8	-17.9	-23.9	-17.7	-20.6	-15.5	-17	-18
Median Absolute error (^{o}Arc)		3.3	6.6	6.6	9.5	9.0	7.5	12.9	11.3	11.0	9.7
Median No. Revs.		9.9	13.0	11.3	10.9	12.1	11.0	8.2	9.0	9.7	9.7

and are permitted as many trials as they wish before they reach a decision, whereas in the previous experiment they were permitted only one brief exposure of the stimulus to judge, in degrees, the position of a radius arm on an unnumbered arc. In addition, different subjects were used in the two different experiments, and it is possible that individual differences contribute to the conflicting results. Experiment 11 was conducted in an attempt to eliminate both of these possible sources of difference.

Experiment 11

In Experiment 11, subjects had to judge the position of the auditory signal to the nearest 5^{o} as the pointer revolved round an unmarked dial. Following the completion of this part of the experiment, they were shown slides similar to the ones in Experiment 9 and asked to estimate the position of the radius arm in a similar fashion.

Method and Procedure

Apparatus. For the dynamic display, the apparatus was the same in all respects to that used in the previous experiment except that a plain semi-circular dial replaced the numbered dial. The slides were presented by a remotely controlled projector in the same fashion as they were in Experiment 9, but were back-projected against a milk-glass screen some 2.5 m, in front of the subject, with the projector positioned to cast an image of the same diameter as the dial in the dynamic display (approximately 30 cm).

Procedure - Part I. Subjects were instructed to judge the position of the pointer at the onset of the increase in the level of background white noise to the nearest 5^{o} on a scale ranging from 0^{o} on the left-hand side of the dial to 180^{o} on the right-hand side of the dial. As in the previous experiment, subjects completed 100 responses following a practice block of 10 trials.

The static display was presented in an adjacent room. Subjects were similarly instructed for this portion of the experiment. As in Experiment 9, a brief flash of the projector preceded each slide, followed by a brief exposure of the stimulus, and finally a blank screen for as long as the subject required to write down his response on the prepared sheet provided. When the experimenter was satisfied that the subject had completed his response, he proceeded with the next trial. Subjects underwent 50 trials, five in each of the positions corresponding to those used in the dynamic display.

Subjects. 9 undergraduate and graduate psychology students and 2 members of staff volunteered as subjects.

Procedure - Part II. Procedure and apparatus were exactly similar to the dynamic trials in Part I. In Part II, however, all subjects were familiar with the apparatus (some having been subjects in Part I) and were informed that the onset of the auditory signal could only be at the ten specified points on the dial. The subject's task was to recognise at which location the auditory signal had its onset. Four graduate students and one member of technical staff, all familiar with the computer and this particular experiment, served as subjects.

Results

Constant error for each subject and the median for each scale position for the dynamic trials are presented in Table 7.4; corresponding scores on the static trials are listed in Table 7.5. Once again, it appears that the differences between scale positions on the dynamic trials are significant ($\chi^2_r = 29.74$, df = 9, $p < .001$). Likewise, the differences between scale positions on the static task reach statistical significance ($\chi^2_r = 19.46$, df = 9, $p < .02$), though the differences are less marked. The comparison of the patterns of median constant error in Fig. 7.7 shows that the two are quite dissimilar. This is reflected in the values obtained for the correlation coefficients for individual scores on the static display (Table 7.6).

Part II. Constant error for each subject and the median constant error for each scale position is given in Table 7.7, and the pattern of median error is compared with error in Part I and Experiment 10 in Fig. 7.7. Again, the scale positions give rise to significantly different constant error ($\chi^2_r = 21.6$, df = 9, $p < .02$).

Discussion

The similarities in the pattern of constant error for the dynamic display in both parts of Experiment 11 and in Experiment 10 are striking. All three curves follow the same pattern, beginning with a very slight negative error or even a positive error at scale position 1, the error rapidly becoming more and more anti-clockwise on subsequent scale positions until position 4 or 5 is reached, when the error begins to level off at around 20°, at least in Part I of Experiment 11, and Experiment 10. With the experienced subjects performing the recognition task in Part II of Experiment 11, errors do begin to diminish towards the end of the scale, presumably because the experienced subjects in Part II knew that each of the ten stimuli were presented the same number of times.

Table 7.4. Constant Error for the dynamic trials in Part 1 of Expt. 11. All errors are anti-clockwise unless preceded by +. All values are expressed as ^{o}Arc.

	Onset Index	1	2	3	4	5	6	7	8	9	10
Subject	JB	.5	10	19.5	13.5	26.5	28	14.5	14.5	25.5	41
	IJ	3.5	12	19.5	21	26	21.5	9	9.5	7.5	15
	JM	14.5	28	42.5	51	45	34.5	40	51	43	61.5
	M	+6.2	10.5	18.5	14	28	34	36.5	32.5	24.5	48.5
	B	1	12.5	14	+13	+17	11.5	16	18.5	17.5	26
	RF	3.5	13.5	17.5	28	28.5	13	5.5	4.5	+9.5	5
	RC	1	4.5	3.5	+1.5	1	14.5	27.5	21.5	21	24.5
	CN	4.5	15.5	23.5	33.5	34.5	60	60	93	94	91
	AJ	10.5	13	17	25	32.5	33.5	26.5	23	26	20.5
	MY	4	18	10	14	12	9	22.5	10.5	+1.5	+13.5
	BJ	+22	+5	+1	+8	+1.5	5.5	10	0	9	1.5
Median (^{o}Arc)		3.5	13	18.5	14	26.5	21.5	22.5	18.5	21	24.5

Table 7.5. Constant Error (°Arc) for the static trials in Part 1 of Expt. 11.
All errors are anti-clockwise unless preceded by +.

	Arm Position	1	2	3	4	5	6	7	8	9	10
Subject	JB	+1	3	5	3	3	+1	+5	0	0	4
	IJ	4	+2	0	+3	0	6	1	3	0	+3
	JM	1	0	0	0	2	2	0	4	3	+3
	M	+13	+8	3	+6	0	3	+3	+6	3	7
	B	+1	7	8	4	5	13	0	+14	+6	+3
	RF	2	7	9	9	2	10	0	2	+7	+6
	RC	2	7	6	+8	+3	11	9	0	+1	+4
	CN	6	13	20	+2	+7	9	13	6	4	+10
	AJ	+4	2	11	13	3	8	0	+5	0	+3
	MY	5	13	6	+12	+9	12	2	0	+10	+6
	BJ	+3	+6	2	+3	+2	3	1	1	6	5
Median		2	3	6	0	0	8	0	0	3	+3

Table 7.6. Spearman Rho (r_s) for comparisons of dynamic trials with static trials in Part 1 of Expt. 11.

Subject	r_s
JB	.26
IJ	-.08
JM	.47
M	-.21
B	-.26
RF	.62
RC	.38
CN	-.32
AJ	.28
MY	.14
BJ	.78

Table 7.7 Constant Error (^{o}Arc) for Part II of Expt. 11. All errors are anti-clockwise unless preceded by +.

	Onset Index	1	2	3	4	5	6	7	8	9	10
Subject	DP	+1.5	13.5	13.5	12.5	22.5	26	18	18	13.5	18
	GS	+7.5	+7.5	+4.5	1.5	6	0	10.5	9	2.5	7.5
	PC	+6	7.5	6	9	13.5	16.5	10.5	9	0	9
	NB	+1.5	10.5	18	18	19.5	15	15	10.5	9	7.5
	IM	0	12	16.5	15	16.5	6	4.5	9	6	3
Median		+1.5	10.5	13.5	12.5	16.5	15	10.5	9	6	7.5

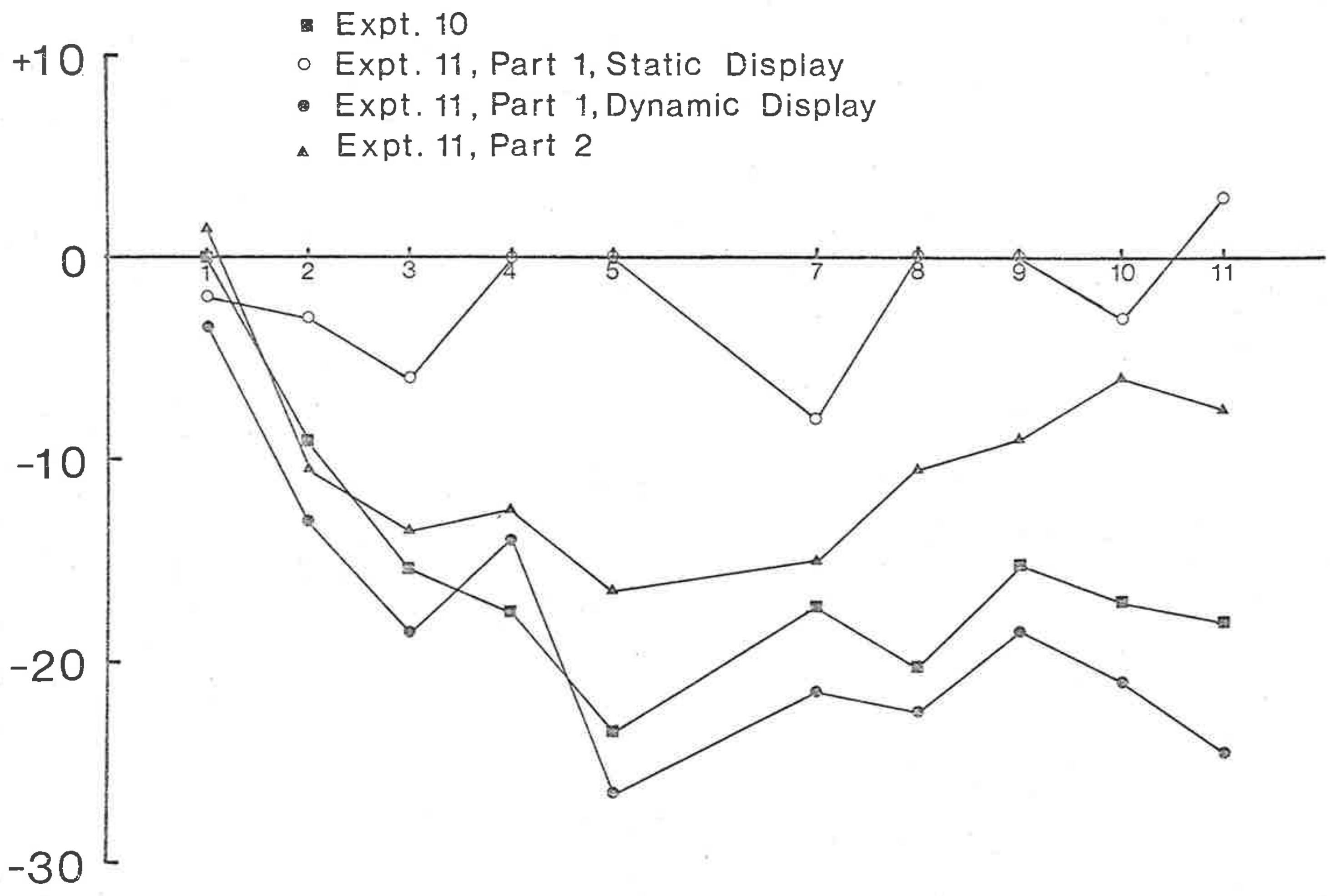

FIG. 7.7, Median Constant Error in degrees of Arc in Expts. 10 and 11.

As mentioned above, the correlation between individual scores on the static and dynamic displays of Part I of Experiment 11 are generaly low and show no systematic pattern. The extent of the non-correspondence of the median scores on the static condition and all the dynamic conditions can clearly be seen from the figure. Referring back to the results of Experiment 9 (Fig.7.2), it can be seen that the pattern of error obtained is rather different from that obtained in the present experiment; it seems that presenting subjects with the dynamic display beforehand does drastically alter the pattern of errors made by subjects on the static display. To what extent this is an artefact of subjects becoming aware of the limited number of scale positions used in the current experiments following exposure to the dynamic display, and to what extent performance on the static display following exposure to the dynamic display would alter if a greater range of stimulus positions were presented, remains uncertain. What is clear is that both patterns of errors on the static displays are completely different from the coherent pattern emerging from the three dynamic conditions, and it would seem a vain hope to look for any explanation of the pattern of errors obtained in the dynamic conditions in terms of the systematic displacements of judgements of the radius arm with static displays.

This is not to say, however, that we cannot seek an explanation of the results in terms of the judgement strategy employed by the subject. Indeed, consideration of judgment strategy seems appropriate in view of the consistency of the findings and the asymmetry of the error pattern and the overwhelming subjective impression experienced by the author and volunteered by some subjects of moving backwards along the scale until a position was encountered where the pointer had definitely passed before the onset of the auditory signal.

John's (1973) discussion of the processes involved in absolute and comparative judgement tasks seems relevant here. His analysis of both types of tasks suggests that absolute judgements are the outcome of three independent operations carried out by subjects on their representation of the stimulus, these being (1) extrapolation from the stimulus representation of the preceding trial ; (2) extrapolation from the stimulus at the nearer end of the stimulus continuum; (3) extrapolation from the opposite end of the stimulus continuum. If the stimulus representation fluctuates randomly over time, then any extrapolation from a relatively fixed point on the subject's representation of the stimulus continuum would tend to result in an underestimation of the distance between the two stimuli, given that the extrapolation ceases as soon as the representation of the stimulus is encountered. Thus, the direction of the error on an absolute judgement task depends on whether the extrapolation to the stimulus representation proceeds from a point above it or a point below it on the stimulus continuum. The representations of the two end-stimuli on the continuum are conceived as being relatively stable while the representation of the immediately preceding stimulus is less so and is liable to decay with the passage of time, so that the relative importance of the first operation is open to manipulation by altering the ISI.

With regard to the present series of experiments, the first operation proposed by John would seem to be of little consequence. A considerable time elapses between the initiation of the subject's response and the presentation of the next stimulus, this being entirely under the subject's own control. Moreover, subjects are allowed as many presentations of the stimulus as they like before making a decision.

Much more applicable, however, would seem to be the processes of extrapolation from the stimuli at the extremes of the continuum, in this case from the two end positions of the semi-circular scale. Intuitively, there would seem to be two influences at work in this situation which could determine the direction of the extrapolation, the first of these being the explicitly numbered scale going from 1 through to 11 (or the scale implicitly imposed by the subject on the unmarked dial, going from 0° through to 180°), and the second being the direction of rotation of the pointer. In the experiments so far, this has always been clockwise. This latter would seem to impose a starting point in a very compelling fashion (namely the location at which the pointer appears), from which any process of extrapolation begins. If this is the case, then the direction of rotation of the pointer is the more powerful determinant of the direction of the extrapolation. As can be seen from Figs. 7.6 and 7.7, the constant error starts off if anything slightly clockwise, a result in accordance with Taylor's (1961) results, and rapidly settles down to a fairly constant anti-clockwise error, i.e. an underestimation from the point where the extrapolation process begins. Only with the experienced subjects in Part II of Experiment 11 is there a tendency for any decrease in this anti-clockwise error towards the end of the scale, and only here is there any evidence for a compensating underestimation arising from extrapolation from the far end of the numberical scale.

Experiment 12 was designed with the aim of assessing the relative contribution of the two determinants of the direction of extrapolation by reversing both the direction of rotation of the pointer and the clockwise ascending orientation of the numbered scale.

Experiment 12

Method

Using the same apparatus as in the immediately preceding experiments, subjects were confronted with the same task as in Part II of Experiment 11, i.e. deciding at which of the ten possible positions the auditory stimulus had been presented. Four presentation conditions differing in the direction of rotation of the pointer and the orientation of the scale were presented as follows:

Condition 1	Pointer clockwise	Scale 1-11
Condition 2	Pointer clockwise	Scale 11-1
Condition 3	Pointer anti-clockwise	Scale 1-11
Condition 4	Pointer anti-clockwise	Scale 11-1

The anti-clockwise direction of rotation was achieved by having subjects observe the apparatus in a large (approximately 1 m x 60 cm) mirror. In these trials (and in the normal presentations in this experiment) the apparatus was raised above the level of the subject's head so that an unimpeded view of the reflection of the apparatus could be obtained. The lower part of the mirror was covered up to prevent distracting reflections. Dial faces were produced for the mirror presentations by taping reversed Letraset digits to a card face so that the correct orientation of the digits was maintained in the mirror image.

As the dial faces had to be changed between conditions, all subjects completed one condition before the next condition was started. Running was spread over two days, subjects attending one session in the morning and one session in the afternoon of both days.

Five first-year psychology students volunteered as subjects. All were unfamiliar with the apparatus before the experiment began.

Results

Constant error at each position for each subject under all conditions is given in Table 7.8. Median constant error under all conditions is plotted in Fig. 7.8. Casting the medians in Table 7.8 in a 4 x 10 table and applying the Friedman Test reveals a significant difference between conditions ($\chi^2_r = 18.21$, df = 3, $p < .001$). From the figure it is apparent that the greatest difference is between the clockwise pointer and the anti-clockwise pointer positions; no clockwise errors occur with the anti-clockwise pointer, and only one slight anti-clockwise error occurs with the clockwise pointer.

An anomaly does appear when comparing the results of Condition 1 with Condition 2, in that the errors are reliably smaller under Condition 2. One possible explanation for this is that under Condition 1, both the points from which the extrapolation process is most likely to begin are at the same end of the scale,

Table 7.8. Constant Error in Expt. 12. Individual scores are converted to degrees of arc. N.B. For Conditions 2 & 4, scale positions are the reverse of the onset indices.

	Onset Index	1	2	3	4	5	6	7	8	9	10
Subject	DB	1.0	1.0	1.4	1.5	3.1	5.2	6.2	7.4	8.1	8.9
	EF	1.1	1.7	2.5	3.3	4.4	5.7	7.2	8.0	9.5	10.1
Condition 1	SP	1.1	1.9	2.7	3.1	3.4	5.9	6.6	7.8	8.6	9.8
	CK	1.0	1.3	1.8	2.3	3.2	6.1	6.7	7.6	9.4	10.2
	DG	1.1	1.6	2.5	4.0	4.5	7.0	7.7	8.8	10.0	11.0
Median (degrees arc)	Median	+1.5	-6	-7.5	-28.5	-39	-16.5	-19.5	-18	-9	-13.5
	DB	11	11	10.6	10.4	9.2	6.4	5.2	4.3	2.5	1.4
	EF	10.7	10.2	9.6	8.7	7.9	5.4	4.5	3.8	2.3	1.5
Condition 2	SP	11	10.1	9.4	8.9	7.8	5.8	4.8	3.5	2.3	1.2
	CK	11	11	10.1	9.8	8.5	5.6	4.6	3.5	2.2	1.3
	DG	11	10.1	8.9	8.0	7.0	5.0	4.0	3.0	2.1	1.0
	Median	0	-3	-9	-13.5	-13.5	-9	-9	-7.5	-4.5	-4.5
	DB	11	11	10.3	10.1	9.3	7.1	5.6	4.3	2.8	2.0
	EF	11	10.2	9.7	8.9	8.1	7.0	5.2	4.6	2.9	1.7
Condition 3	SP	10.9	10.3	9.7	9.4	8.4	6.7	5.0	3.3	2.5	2.1
	CK	11	10.6	10.6	9.5	8.8	7.0	4.9	3.0	2.4	1.2
	DG	11	10.7	9.4	8.4	7.4	5.0	3.9	2.8	1.9	1.0
	Median	0	+9	+10.5	+21	+21	+30	+15	+4.5	+7.5	+10.5
	DB	1.1	1.1	1.4	2.1	3.0	4.9	6.1	8.3	9.4	10.8
	EF	1.0	1.8	2.0	2.7	3.4	5.4	7.1	8.3	9.5	10.3
Condition 4	SP	1.0	1.9	2.0	3.0	4.1	5.5	7.0	8.0	9.2	10.5
	CK	1.0	1.5	1.5	2.2	3.1	4.7	5.6	7.1	8.8	10.8
	DG	1.0	2.4	2.4	3.5	4.4	7.0	8.0	9.0	10.0	11.0
	Median	0	+3	+15	+19.5	+24	+24	+15	+10.5	+9	+3

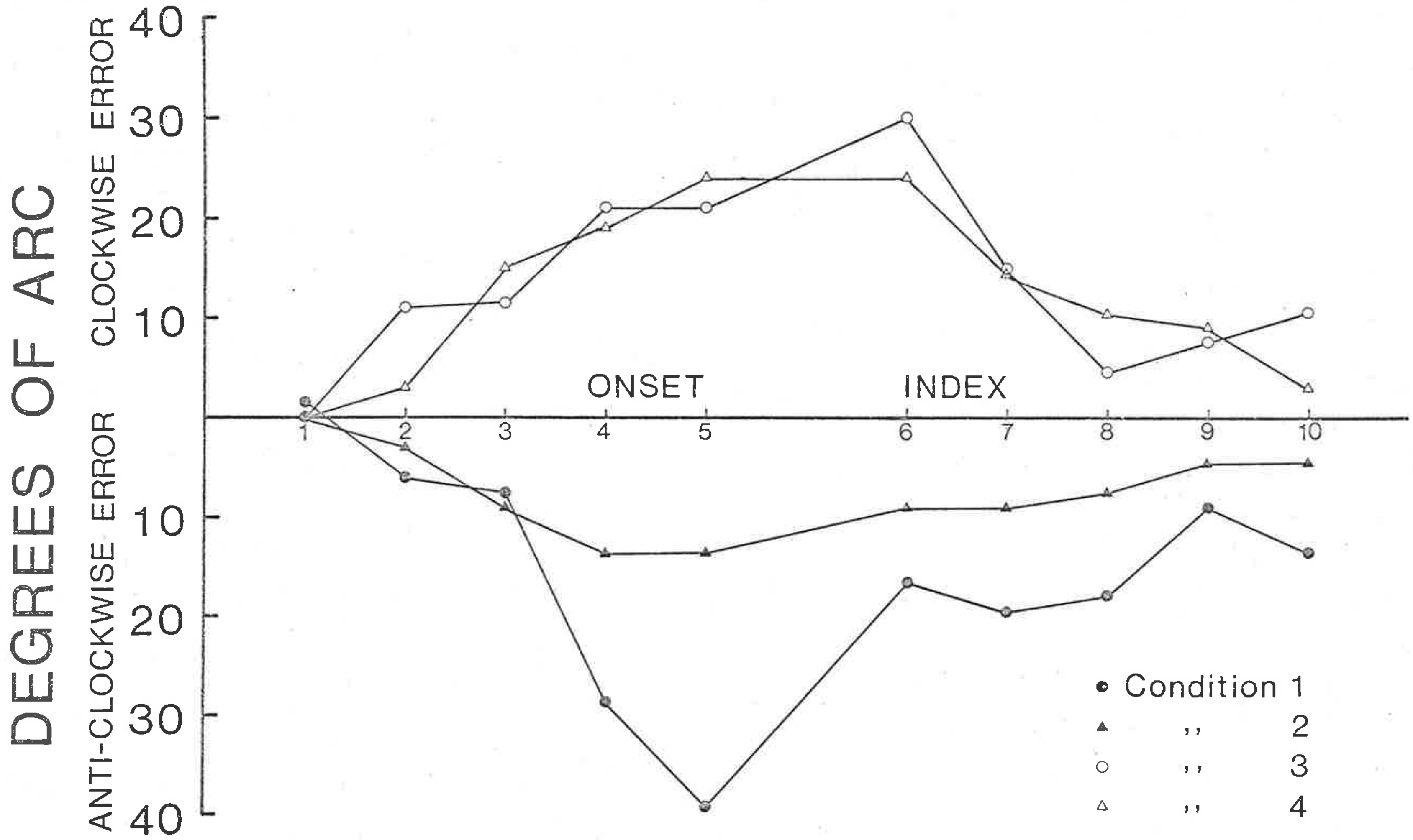

FIG. 7.8, Median Constant Error in Expt. 12.

while under Condition 2 they come at opposite ends of the scale. If the individual's response is the outcome of a combination of these two extrapolation procedures, then it would be expected that under Condition 1 clockwise errors would be enhanced, while under Condition 2 they would diminish. Admittedly, no such tendency is seen with the anti-clockwise positions, the two curves following one another very closely. This may be due to the relatively unfamiliar direction of rotation overriding the effect of the scale positions altogether, a notion which is consistent with the errors for the anti-clockwise conditions being intermediate in magnitude between the clockwise conditions, a feature of the present data.

Discussion

Experiment 12 would seem to confirm the role of rotation direction as the principal determinant of constant error; scale direction would seem to have some slight effect, at least where the direction of rotation is familiar. Taking the results of Experiments 10, 11 and 12 together, two of the findings of the earlier complication experiments are confirmed (see Chapter 2). These comprise:

(1) the predominance of anti-clockwise errors with clockwise pointer rotation,

(2) the effect of presentation position on constant error, although the present results are the complete inverse of the findings of earlier investigators. Since the current investigation is more extensive and better documented on this point than the vague qualitative statements by earlier experimenters, it does not seem altogether unreasonable to give

more credence to the present findings.

The effect of rotation speed of the pointer apart, one final point remains to be settled concerning the complication experiment. It may be recalled from Chapter 2 that Sanford (1971) reported the results of a type of complication experiment, in which a greater tendency to negative error with more intense auditory stimuli was found. It was suggested that this was a result of reduced perceptual lag with the more intense stimuli. When the results were compared with reaction times to the same auditory stimuli, reaction time was found to change much more than did the absolute judgement, louder signals apparently facilitating response as well as decreasing perceptual lag.

Such a view implies that all stimulus positions are equivalent as far as the judgements which result are concerned; at the very least it implies that there are no substantial interactions between intensity of auditory signal and stimulus position. The final experiment in the present investigation, Experiment 13, set out to verify this contention.

Experiment 13

Method

Apparatus. In this experiment, four levels of attenuation were available on the attenuator through which the white noise generator output passed, these being a reduction of the level of attenuation of 2, 3, 7 and 18 dB. These permitted a range of auditory signals entirely comparable to those in Sanford's (1971) experiment. One group of subjects did the experiment in four blocks throughout which all auditory signals were of the same intensity; in this case the attenuation level was altered by the experimenter manually changing the programmed level of attenuation at the start of each session. The other group of subjects completed the experiment in two sessions in which attenuation levels and stimulus positions were arranged in random blocks. For this a new program had to be prepared.

Design and Procedure. Subjects were randomly allocated to the two groups mentioned above. Both groups completed the experiment in two sessions, Group 1 doing two blocks at different intensities in each session, and Group 2 doing half of the trials with all intensity-position combinations in each session. As with previous experiments, ten different scale positions were used; this time in combination with the four possible attenuation levels. Each intensity-position combination was presented 10 times, making 400 trials in all.

The order in which subjects in Group 1 underwent the different conditions was determined by an incomplete Latin Squares design.

The subjects' task was the same as in Experiment 12, namely to identify at which of the ten scale positions the auditory signal occurred. Ten practice trials preceded each block of 200 trials for Group 2 and each block of 100 for Group 1.

Subjects. 12 first-year psychology students volunteered as subjects.

Results

Median constant error is shown in Table 7.9 and Fig. 7.9. It can be seen that all conditions give rise to roughly similar patterns of error over the range of possible conditions, especially in the first half of the range, and that this pattern is consistent with the results of the preceding series of experiments.

Table 7.9. Median Constant Error in Experiment 13. (degrees arc)

	Stimulus Position / Intensity	1	2	3	4	5	6	7	8	9	10
GP 1	2dB	+3.75	-3.00	-12.00	-15.00	-15.75	-16.5	-15.75	-13.5	- 3.75	-12.75
	3dB	+2.25	-4.5	-10.5	-16.5	- 9.75	- 6.75	- 7.5	- 8.25	-12.75	-15.75
	7dB	+1.5	-6.75	-15	-19.5	-17.25	- 4.5	- 9.0	- 8.25	- 7.5	-12.00
	18dB	+1.5	-7.5	-15.75	-21.00	-22.5	-18.00	-15.00	-15.75	-15.75	-15.75
	2dB	+9.0	0.00	- 3.75	- 9.75	-12.75	-10.5	- 8.25	- 9.75	- 9.75	-16.5
	3dB	+7.5	0.00	-10.50	- 8.25	-11.25	- 9.75	- 9.0	-16.5	-16.5	-19.5
	7dB	+3.00	-2.25	- 8.25	-14.25	-14.25	-22.5	-18.00	-18.00	-22.5	-24.00
	18dB	+ .75	-3.75	- 7.5	- 9.75	-17.25	-19.5	-15.75	-15.00	-18.00	-18.75

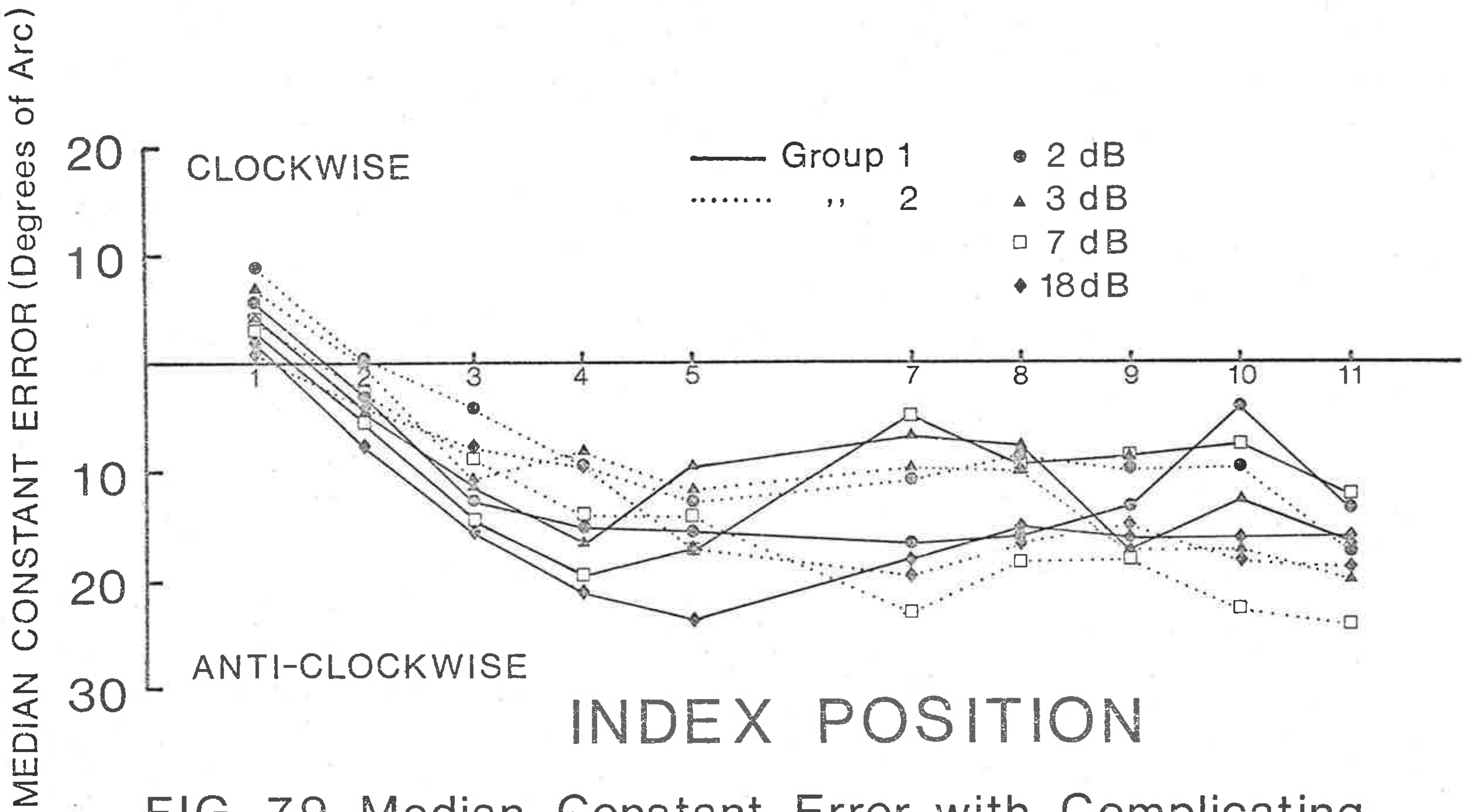

FIG. 7.9, Median Constant Error with Complicating Stimuli of Differing Intensity in Expt. 13.

The effect of intensity of the auditory stimulus is both complicated and slight. Comparison of the four intensity conditions for Group 1 by the Friedman Test revealed no significant differences ($\chi^2_r = 13.8$, df = 9, $p > 0.05$); for Group 2, a significant difference between was found ($\chi^2_r = 17.91$, df = 9, $p < 0.05$), although negative error did not simply increase with increasing intensity as the 7 dB condition had the largest negative errors. However, the important point is that intensity does not seem to interact with scale position in any important way, there being no marked divergence of the curves over any portion of the scale. Analysis of the results using Kendall's W confirms that different intensities gave rise to similar patterns of errors; this was true for both Group 1 (W = .645, df = 9, $p < .01$) and Group 2 (W = .832, df = 9, $p < .001$).

The two groups seem to differ little in constant error. True, there is a slight tendency for Group 1 to make more negative errors over the first few scale positions, but curves for the two groups cross frequently in the latter half of the scale, giving rise to the closely comparable mean median constant errors for each intensity shown in Table 7.10. To some extent, any differences in the conditions are partly obscured by the greater number of revolutions taken by Group 2 to reach a decision. As we might expect in this situation, if the subject is uncertain which of the auditory signals is going to occur, then he will be less able to accurately place that signal when it comes. In consequence, it would be expected that where the subject can sample for as many trials as he wants, he would in fact sample for longer periods. Reference to Table 7.11 shows that this is the case,

Table 7.10. Mean Median Constant Error (degrees of arc) for different intensities in Experiment 13.

	2dB	3dB	7dB	18dB
GP1	11.2	9.0	9.8	14.6
GP2	7.8	9.5	14.1	12.8

Table 7.11. Mean No. Revs. to arrive at a decision for different intensities in Experiment 13.

	2dB	3dB	7dB	18dB
GP1	6.42	5.33	4.82	5.33
GP2	7.74	6.85	6.74	6.69

and that the difference in mean number of revs. between the two groups is of the order of 1.5 revs. One possible explanation of this difference is that Group 2 requires the extra trial to identify the physical parameters of the signal before proceeding with the interpolation judgement. This explanation would account for the similarity of the curves for the two groups. Unfortunately, subjects were not questioned on this point after the experiment so that no experiential confirmation is available.

Discussion

Possible reasons why the present experiment failed to replicate Sanford's (1971) finding of an intensity effect on pointer position judgements are not hard to find. The principal difference in procedure between his experiment and the current one is that in the former, subjects were presented with the stimulus only once before deciding where the pointer was at the onset of the auditory signal, whereas they were allowed as many presentations of the signal as they wished before deciding in the present experiment.

It may be recalled that it was observed from the outset in the present series of experiments that, phenomenologically, the strategy the observer seemed to be using was to first judge the position of the pointer roughly, and then to work back along the scale until a scale position was encountered which the pointer had definitely passed before the onset of the auditory signal, the next clockwise position on the scale then being judged as the onset position. If such a strategy were being followed, this would account for the predominance of anti-clockwise errors in the present experiment compared with the almost exclusively clockwise error reported by Sanford.

The failure to demonstrate any substantial intensity effect remains a rather more puzzling feature of the present experiment. Although a significant effect for intensity was found with random presentation of different intensities, the effect was much less marked than and did not exactly parallel that reported by Sanford. Furthermore, it failed to reach significance for the regular presentation condition (all Sanford's trials having been presented in regular blocks in a similar fashion to this). It seems possible that allowing repeated presentations may have artefactually produced this effect of little or no difference between intensities. Reference to Table 7.12 shows that with the more intense auditory signals subjects required fewer revolutions to reach a decision. The effect of this would be to truncate the process of moving back across the dial revolution by revolution until the scale position which the pointer had definitely passed by the onset of the auditory stimulus, resulting in an under-estimate of any tendency towards more anti-clockwise (or negative) errors arising as a result of louder auditory signals. It may also be noted that Burrow (1909) failed to find any effect of intensity of the auditory signal using an adjustment technique, a procedure which requires repeated presentation of the complication stimulus before the judgement is finalised.

Both these attempts to explain the discrepancies between the present results and Sanford's, depending as they do on an impression (albeit a very convincing one) of what subjects are doing in the task, must be recognised as speculative, at least at present. They would, of course, be open to test by a complication experiment which examines the effects of scale position on judgement of the onset position with the auditory signal being presented on one revolution only.

Despite these disagreements with Sanford's findings, the most useful point from this experiment remains, namely that intensity and scale position do not interact in any important fashion.

CHAPTER 8.

CONCLUSION

Considering the experiments conducted and the theoretical arguments advanced in the course of the present investigation in retrospect, it is plain that they fall into two as yet quite separate groups. The first of these concerns the order judgement studies with which we set out to investigate the prior entry hypothesis, and the second comprises the replications of the complication experiment, and the explanation of their findings. We are now in a position to ask: how do these two theoretical positions relate to one another, and to the original idea of prior entry?

Taking stock of the findings so far, it may be recalled that the first two threshold experiments (Experiments 1 and 2) found, as the prior entry hypothesis predicts, a shift to the left in the psychometric functions for visual first responses under conditions of attention to the visual stimulus. This means that for any given ISI, visual first responses are more probable. This result was not borne out by the main body of experiments in Chapters 4 and 5 (Experiments 3, 4, 5 and 7) where the signal detection measures showed a clear loss in sensitivity with the additional visual decision, but not the shift in bias predicted by the prior entry hypothesis. It was seen that the discrepancy could be explained in terms of the nature of the judgement required in the two different experimental paradigms; under the first, subjects were required to allocate a range of stimulus intervals to one of two possible event classes, under the second the subject was asked to express his degree of confidence that one or other of the two events had occurred.

In view of the consistency of the findings of these experiments and the current more general acceptance of TSD measures, it was proposed in Chapter 6 that the reduction in sensitivity in these experiments came about because of the order in which attributes of signals rather than complete unitary events were encoded into immediate memory. Where temporal specification is one of the attributes to be encoded, and other features of the stimulus array are emphasised by the experimental instructions, then much of the order information is lost before it can be dealt with. This is consistent both with the decrease in sensitivity in the TSD experiments and the decrease in the slope of the psychometric functions reported in Experiments 1 and 2. Moreover, this proposal allows for flexibility in the order in which attributes of multi-dimensional arrays are encoded, depending on the experimental instructions. The anomalous result of the last TSD experiment, Experiment 8, may then be regarded as an extreme case of this encoding flexibility. Here, unlike the other experiments, instructions to attend to the order judgement in one condition were juxtaposed with instructions to attend to the length judgement in the other condition. It was argued that this leads to the subjects attending to the length judgement instead of to the order judgement, rather than attending to the length judgement as well as to the order judgement. Despite the ad hoc nature of the present explanation and its extensions to cover some of the results, it does nevertheless seem preferable to the prior entry explanation because it can encompass more of the data.

In view of this, the question was then raised as to how well the prior entry hypothesis accounted for the data of the complication experiment, in which context it originated. Suggestive findings from earlier investigators led to an examination of the effects of scale position on the magnitude and direction of the error. Experiments 10 and 11 together produced a highly consistent pattern of errors which varied as a function of scale position, this pattern being quite different from the pattern of errors with a static display reported in Experiment 9. The explanation for the pattern of displacements in terms of judgement strategies used by subjects was confirmed in Experiment 12. Finally, Experiment 13 demonstrated the lack of any important interaction between scale position and intensity of the auditory stimulus.

An attempt to explain the phenomena of the complication experiment in terms of the strategies adopted by the subjects is not new and dates back at least to Geiger's (1902) dichotomisation of subjects into 'naive' and 'reflecting' types. What is novel about the present attempt is that it is not specifically concerned with accounting for individual differences, as Geiger was, there being no need since one of the features of the present series of experiments was the consistency in the judgements shown by different individuals. Certaintly, subjects did differ in the magnitude of the displacements they exhibited, but the pattern of errors across the dial is consistent for all.

Despite the absence of individual differences in the present study some features of the earlier work on the complication experiment have been replicated. Most evident of these is the overwhelming overall tendency to negative error, and the explanation in terms of judgement strategies put forward was largely an attempt to account for this finding. To recapitulate, if the subject is unable exactly to locate the pointer at the onset of the auditory signal, he tends to work in an anti-clockwise direction back across the dial (assuming, of course, the pointer is revolving in a clockwise direction) until he finds a scale position which the pointer has definitely cleared before the onset of the auditory signal. This then serves as a basis for his final judgement.

This implies that the more uncertain a subject is about the position of the pointer at the onset of the auditory signal, then the further he will have to move back around the dial before he encounters a position the pointer has definitely cleared before the onset. Given that a subject would be more uncertain about the position of a weak signal than a strong one, errors should be more anti-clockwise for weaker signals. However, this overlooks the fact that weaker signals take longer to detect, so that the pointer moves round further past the onset point before he becomes aware of the auditory signal. The final effect of intensity on the judgement (at least in cases where the subject is allowed to sample for as many revolutions as he wants) is thus the result of two opposing tendencies: a tendency to make anti-clockwise errors arising from uncertainty about the position of the stimulus and a tendency to make clockwise errors arising from a delay in detecting weaker signals. The lack of an intensity effect on the final outcome of the position of judgements found in Experiment 13 thus seems much less surprising.

One final piece of evidence may be adduced in support of this explanatory scheme, and that is Leatherman's (1940) finding that a warning signal which preceded the complicating stimulus by some 139 msec. resulted in more clockwise errors. It seems likely that this warning signal provided a new reference point from which the subject began the process of extrapolation. Much the same effect can be seen in Taylor's (1961) study, where the anchor points on her card stimuli resulted in consistent displacements of the dot stimuli. In the present case, errors at the beginning of the scale tend to be clockwise, so we would anticipate a clockwise shift in judgements if a new end point for the scale were provided in front of and close to the complicating stimulus.

Despite the fact that the prior entry hypothesis was rejected on the basis of the initial series of order-judgement experiments (Chapters 4 and 5), the explanation being put forward here does have some elements in common with it. Like the prior entry hypothesis, it emphasises the fact that there are limitations on our capacity to process information: unlike the prior entry hypothesis it does not suggest that perceptual overload will inevitably lead to the situation where unitary events are either selected out for immediate processing or delayed until events which have been selected are dealt with, and that this will result in non-selected events seeming as though they came later. Instead, it assumes that under such conditions some dimensions of the stimulus array will be attended to and processed first. When some dimensions are not processed until other more important dimensions are dealt with, this results in these less emphasised dimensions being less well discriminated or identified.

Specifically, in the complication experiment, keeping track of the pointer and listening for the auditory signal constitutes an overload situation with the result that there is uncertainty about the position of the pointer at the onset of the auditory signal.

The affinity between this view and the explanation advanced to account for the results of the order-judgement experiments reported earlier will immediately be recognised. In that situation, it was found that the prior entry hypothesis could not account for the changes in order judgement in a bi-sensory situation when an additional judgement was required about one of the signals. Instead of biassing the order judgements so that that particular signal was judged as coming first, order judgements simply became less accurate under the additional judgement condition. It seemed that the information about the order of the two signals was being lost because the subject was making the decision about the specified attribute of one of the signals first. Again, this constitutes a perceptual overload situation in which the processing of some dimensions - in this case the temporal dimension - is delayed. Note, however, that it is information about <u>stimulus dimensions</u> and not representations of whole <u>events</u> which is delayed. This is consistent with the currently popular notion that representations of events are reconstructed from stored, fragmentary, rapidly decaying information about different dimensions, and serves to reinforce the view that perception is the "continuously creative process by which the world of experience is constructed" (Neisser, 1967, p.11).

BIBLIOGRAPHY

ANGELL, J.R., & PIERCE, H. Experimental research on the phenomena of attention. *American Journal of Psychology*, 1892, 4, 528-541.

BABKOFF, H., & SUTTON, S. Perception of temporal order and loudness judgements for dichotic clicks. *Journal of Acoustical Society of America*, 1963, 35, 574-577.

BARON, J. Temporal ROC curves and the psychological moment. *Psychonomic Science*, 1969, 15, 299-300.

BERTELSON, P., & TISSEYRE, F. The time-course of preparation with regular and irregular foreperiods. *Quarterly Journal of Experimental Psychology*, 1968, 20, 297-300.

BORING, E.G. *A history of experimental psychology, (2nd ed.)*, New York: Appleton-Century-Crofts, 1950.

BUCKNER, D.N., & McGRATH, J.J. A comparison of performances on single and dual sensory mode vigilance tasks. (Technical Report No.8). Los Angeles: Human Factors Research Inc., 1961.

BURGESS, S.A. The prior entry effect in the complication experiment. Unpublished Honours thesis, University of Dundee, 1965.

BURROW, N.T. The determination of the position of a momentary impression in the temporal course of a moving impression. *Psychological Monographs*, 1909, 11 (No.47), -163.

CHOCHOLLE, R. Variation des temps de réaction auditifs en fonction de l'intensité a diverses fréquences. *Anneé Psychologique*, 1945, 41-52, 65-124.

DINNERSTEIN, A.J., & ZLOTOGURA, P. Intermodal perception of temporal order and motor skills: effects of age. *Perceptual and Motor Skills*, 1968, 26, 987-1000.

DOUGHERTY, W.G., JONES, G.B., & ENGEL, G.R. Sensory integration of auditory and visual information. *Canadian Journal of Psychology*, 1971, 25, 476-485.

DREW, F. Attention: Experimental and critical. *American Journal of Psychology*, 1896, 7, 533-572.

DUNLAP, K. The complication experiment and related phenomena. *Psychological Review*, 1910, 17, 157-191.

EDWARDS, A. *Experimental design in psychological research.* (Revised edition). New York: Holt, 1960.

EFRON, R. The relationship between the duration of a stimulus and the duration of a perception. *Neuropsychologia*, 1970a, 8, 37-55.

EFRON, R. The minimum duration of a perception. *Neuropsychologia*, 1970b, 8, 57-63.

EFRON, R. Effect of stimulus duration on perceptual onset and offset latencies. *Perception and Psychophysics*, 1970c, 8, 231-234.

EXNER, S. Experimentelle Undersuchung der einfachsten psychischen processe. *Pflüg. Arch. ges. Physiol.*, 1875, 11, 403-432.

FIDELL, S. Sensory function in multimodal signal detection. *Journal of the Acoustical Society of America*, 1970, 47, 1009-1015.

FORBES, S.M., TAYLOR, M.M., & LINDSAY, P.H. Cue timing in a multi-dimensional detection task. *Perceptual and Motor Skills*, 1967, 25, 113-120.

GARNER, W.R. *Uncertainty and structure as psychological concepts*. New York: Wiley, 1962.

GEIGER, M. Neue Complications versuche. *Philos. Stud.*, 1902, 18, 347-436.

GIBBON, J., & RUTSCHMANN, R. Temporal order judgement and reaction time. *Science*, 1969, 165, 413-415.

GORDON, B. The superior colliculus of the brain. *Scientific American*, 1972, 227, 72-82.

GREEN, D.M. Temporal audition acuity. *Psychological Review*, 1971, 78, 540-551.

GREEN, D.M., & SWETS, J.A. *Signal detection theory and psychophysics*. New York: Wiley, 1966.

GREY WALTER, W. The convergence and interaction of visual audition and tactile responses in human non-specific cortex. *Annals of the New York Academic of Sciencies*, 1964, 112, Art.1.

HABER, R.N. The effects of coding strategy on perceptual memory. *Journal of Experimental Psychology*, 1964, 69, 282-286.

HAMLIN, A.J. On the least observable interval between stimuli addressed to disparate senses and to different organs of the same senses. *American Journal of Psychology*, 1895, 6, 564-575.

HERSHENSON, M. Reaction time as a measure of intersensory facilitation. *Journal of Experimental Psychology*, 1962, 63, 289-293.

HICK, W.E. On the rate of gain of information. *Quarterly Journal of Experimental Psychology*, 1952, 4, 11-26.

HIRSH, I.J., & SHERRICK, C.E. Perceived order in different sense modalities. *Journal of Experimental Psychology*, 1961, 62, 423-432.

HIRSH, I.J., & FRAISSE, P. Similtanéité et succession de stimuli hétérogènes. *L'Annêe Psychologique*, 1964, 64, 1-19.

HIRSH, I.J. Auditory perception of temporal orders. *Journal of the Acoustical Society of America*, 1959, 31, 759-767.

HOCHBERG, J. Attention, organisation and consciousness. In: Mostofsky,D.I. *Attention: Contemporary theory and analysis.* New York: Appleton-Century-Crofts, 1970.

HORN, G. The effect of somesthetic and photic stimuli on the activity of units in the striate cortex of unanesthetized, unrestrained cats. *Journal of Physiology (London)*, 1965, 179, pp.263-277.

HOTTA, T., & KAMEDA, K. Interactions between somatic and visual or auditory responses in the thalamus of the cat. *Experimental Neurology*, 1963, 8, 1-13.

JAMES, W. *The principles of psychology.* New York: Dover, 1950.

JOHN, I.D. Information processing in absolute and comparative judgement tasks. *Paper presented at Attention and Performance V.* 1973.

KRISTOFFERSON, A.B. Attention and psychophysical time. *Acta Psychologica*, 1967, 27, 93-100.

LEATHERMAN, C.D. The limits of toleration for similtaneity in the complication experiment. *American Journal of Psychology*, 1940, 21-45.

LEDERMAN, S.J., & TAYLOR, M.M. Perception of interpolated position and orientation by vision and active touch. *Perception and Psychophysics*, 1969, 6, 153-159.

LESHOWITZ, B. The measurement of the two-click threshold. *Journal of the Acoustical Society of America*, 1971, 49, 462-466.

LICHTENSTEIN, M., WHITE, C.T., SIEGFRIED, J.B., & HARTER, M.R. Apparent rate of flicker at various retinal loci and number of perceived flashes per unit time: a paradox. *Perceptual and Motor Skills*, 1963, 17, 523-536.

LINDSAY, P.H. Multichannel processing in perception. In: Mostofsky, D.I. *Attention: Contemporary Theory and Analysis.* New York: Appleton-Century-Crofts, 1970.

LINDSAY, P.H., TAYLOR, M.M., & FORBES, S.M. Attention and multidimensional discrimination. *Perception and Psychophysics*, 1968, 4, 113-118.

LONDON, I.D. Research on sensory interaction in the Soviet Union. *Psychological Bulletin*, 1954, 51, 531-568.

LOVELESS, N.E., BREBNER, J., & HAMILTON, P. Bisensory presentation of information. *Psychological Bulletin*, 1970, 73, 161-199.

McNICOL, D. *A primer of signal detection theory.* London: Allen & Unwin, 1972.

MILLER, G.A., & TAYLOR, W.G. The perception of repeated bursts of noise. *Journal of the Acoustical Society of America*, 1948, 20, 171-182.

MORAY, N. Attention in dichotic listening: affective cues and the influence of instructions. *Quarterly Journal of Experimental Psychology*, 1959, 9, 56-60.

MORRELL, F. Electrical signs of sensory coding. In: *The Neurosciences: A study program.* Rockefeller University Press, 1967, pp.452-469.

MURATA, K., CRAMER, H., & BACH-Y-RITA, P. Neuronal convergence of noxious, acoustic, and visual stimuli in the visual cortex of the cat. *Journal of Neurophysiology*, 1965, 28, pp.1223-1239.

NEEDHAM, J.G. Prior entry within a single sense department. *Journal of Experimental Psychology*, 1934, 17, 400-411.

NEEDHAM, J.G. Some conditions for prior entry. *Journal of General Psychology*, 1936, 14, 226-240.

NEISSER, U., NOVICK, R., & LAZAR, R. Searching for ten targets simultaneously. *Perceptual and Motor Skills*, 1963, 17, 955-961.

NEISSER, U. *Cognitive Psychology.* New York: Appleton-Century-Crofts, 1967.

OATLEY, K., ROBERTSON, A., & SCANLAN, P.M. Judging the order of visual stimuli. *Quarterly Journal of Experimental Psychology*, 1969, 21, 172-179.

PATTERSON, J., & GREEN, D.M. Discrimination of transient signals having identical energy spectra. *Journal of the Acoustical Society of America*, 1970, 48, 894-905.

POFFENBERGER, A.T.

Archives of Psychology, 1912, 3, 1-73.

ROBINSON, D.K. Visual discrimination and temporal order. *Science*, 1967, 156, 1263-1264.

ROBINSON, D.K. Assessments of temporal discrimination in vision. *Psychonomic Science*, 1968, 13, 247.

RONKEN, D. Monaural detection of a phase difference between chicks. *Journal of the Acoustical Society of America*, 1970, 47, 1091-1099.

ROSENTHAL, R. *Experimenter effects in behavioural research.* New York: Appleton-Century-Crofts, 1966.

ROUFS, J.A.J. Perception lag as a function of stimulus luminance. *Vision Research*, 1963, 3, 81-91.

RUTSCHMANN, J., & LINK, R. Perception of temporal order of stimuli differing in sense mode and simple reaction time. *Perception and Motor Skills*, 1964, 18, 345-352.

RUTSCHMANN, R. Perception of temporal order and relative visual latency. *Science*, 1966, 152, 1099-1101.

SANFORD, A.J. Effects of changes in the intensity of white noise on simultaneity judgements and simple reaction time. *Quarterly Journal of Experimental Psychology*, 1971, 23, 296-303.

SANFORD, A.J. A periodic basis for perception and action. In: Colquhoun, W.P. *Biological rhythms and human performance.* London: Academic Press, 1971.

SANFORD, E.C. The personal equation. *American Journal of Psychology*, 1888-1889, 2, 3-38, 271-298, 403-430.

SCHMIDT, R.A. Movement time as a determiner of timing accuracy. *Journal of Experimental Psychology*, 1969, 79, 43-47.

SIEGEL, S. *Non-parametric statistics.* New York: McGraw-Hill, 1956.

SLATER-HAMMEL, A.T. Reliability, accuracy, and refractoriness of a transit reaction. *Research Quarterly American Association of Health and Physical Education Records*, 1960, 31, 217-218.

SMITH, W.F. The relative quickness of auditory and visual perception. *Journal of Experimental Psychology*, 1933, 16, 239-257.

SPERLING, G. A model for visual memory tasks. *Human Factors*, 1963, 5, 19-31.

SPERLING, G. Successive approximations to a model for short-term memory. *Acta Psychologica*, 1967, 27, 285-292.

SPINELLI, D.N., PRIBRAM, K.H., & WEINGARTEN, M. Centrifugal optic nerve responses evoked by auditory and somatic stimulation. *Experimental Neurology*, 1965, 12, 303-319.

STONE, S.A. Prior entry in the auditory-tactual complication. *American Journal of Psychology*, 1926, 37, 284-291.

STERNBERG, S., & KNOLL, R.L. The perception of temporal order: fundamental issues and a general model. In: Kornblum, S. (Ed.), *Attention and Performance IV.* New York: Academic Press, 1973, pp.629-685.

STROUD, J.M. The fine structure of psychological time. In: H. Quastler, (Ed.), *Information Theory and Psychology.* Glencoe, Illinois: Free Press, 1955.

SZAFRAN, J. Changes with age and with exclusion of vision in performance at an aiming task. *Quarterly Journal of Experimental Psychology*, 1951, 3, 111-118.

TAYLOR, M.M. Effect of anchoring and distance perception on the reproduction of forms. *Perceptual and Motor Skills*, 1961, 12, 203-230.

THOR, D.H., & SPITZ, H.H. Temporal discrimination as a function of total presentation time. *Psychonomic Science*, 1968, 13, 291-292.

THOR, D.H. Observer strategies in dichoptic viewing of successive stimuli. *Psychonomic Science*, 1968, 12, 41-42.

THOR, D.H. Dichoptic viewing and temporal discrimination: An attempted replication. *Science*, 1967, 158, 1704-1705.

TITCHENER, E.B. *Lectures on the elementary psychology of feeling and attention.* New York: Macmillan, 1908.

VAUGHAN, G.M., & CORBALLIS, M.C. Beyond tests of significance: estimating strength of effects in selected ANOVA designs. *Psychological Bulletin,* 1969, 72, 204-213.

WALSH, T. Visual onset and offset latencies. *Quarterly Journal of Experimental Psychology*, 1973, 25, 154-162.

WEINGARTEN, M., & SPINELLI, D.N. Retinal receptive field changes produced by auditory and somatic stimulation. *Experimental Neurology*, 1966, 15, 363-376.

WEISS, A.D., & BIRREN, J.E. Age changes in click perception. *American Psychology*, 1957, 12, 385. (Abstract).

WELFORD, N.T. Estimation of the position of a tactile stimulus in a repeated auditory pattern. *Quarterly Journal of Experimental Psychology,* 1948, 1, 180-192.

WHIPPLE, G.M. On nearly simultaneous clicks and flashes. *American Journal of Psychology,* 1898, 10, 280-286.

WILLSON, R. *Cu mulative Gaussian curve fitting.* FOCAL Program, Psychology Department Computing Centre, University of Adelaide.

WOODWORTH, R.S., & SCHLOSBERG, H. *Experimental Psychology*, Revised Edition, New York: Holt, 1954.

WUNDT, W. *Lectures on human and animal psychology* (Translated by J.E. Creighton and E.B. Titchener). London: Swan Sonnenschein, 1894.

ZWISLOCKI, J.J. Theory of temporal auditory summation. *Journal of the Acoustical Society of America*, 1960, 32, 1046-1060.

ADDENDUM

Since the main part of this thesis was written, Sternberg and Knoll (1973) have published a major article setting out a notation for models of the order judgement process and extending this notation to cover six models of order judgement. One of the most evident features of their scheme is that the final shape of the psychometric function depends on two separate, and in principle separable, factors: first, the relative arrival latencies, R_x and R_y, of signals in different channels, x and y, at some central locus; second, the nature of the decision function which converts differences in the arrival latencies to probabilities of 'x first' or 'y first' responses. The psychometric function for order judgement then depends upon some combination of this function with the underlying distribution of differences in arrival latencies in different channels.

When the decision process is conceived in this way, the question then arises as to whether the effects of prior entry are on the arrival latencies in different sensory channels or on the decision function itself. Sternberg and Knoll suggest a means of discovering the locus of prior entry effects by jointly varying the intensities of the two signals. If prior entry affects the decision mechanism only, then the difference in the means of functions under different attentional conditions will be the same for all intensities; if, on the other hand, prior entry affects the 'channels' as well as the decision mechanism, then the effects of prior entry should be less with greater signal intensities.

The data gathered in the earlier part of the present investigation would not seem to be of any help in this type of analysis, since they did set out to tackle the problem of prior entry in a rather different way. Nevertheless, the majority of the signal detection experiments are consistent in showing a change in sensitivity but not in bias under different attentional conditions, which suggests a change in the discriminability of the temporal information in the visual and auditory channels rather than in the decision mechanism.

Before extrapolating this finding to the Sternberg and Knoll model, it would be well to remind ourselves of the very real differences in the sort of information, and consequently in the nature of the decision, entailed in the two procedures. In the course of generating a psychometric function, the experimenter presents the subject with a range of temporal differences between two signals. Since the latencies of these two signals are assumed to fluctuate randomly, this range of intervals is thought of as giving rise to a distribution of differences at some point in the nervous system, and it is on this distribution of differences that the decision mechanism operates to finally generate the psychometric function for order judgement. On the other hand, in the signal detection model, either the visual signal precedes the auditory by some fixed amount or vice versa; as in the other model, the latencies of these signals are assumed to fluctuate randomly, giving rise in this case to two distributions of differences. The subject's task is then to decide to which of the two distributions the interval on any particular trial belongs. Thus it can be seen that the decisions involved in the two procedures are sufficiently different in both cases to warrant caution in regarding the findings from both types of procedure as equivalent. In defence of the signal detection procedure adopted in the present investigation, it seems that this procedure allows much readier separation of channel latency and central decision processes than does the psychometric function procedure.

REFERENCE

STERNBERG, S., & KNOLL, R.L. The perception of temporal order: fundamental issues and a general model. In: Kornblum, S. (Ed.), *Attention and Performance IV*. New York: Academic Press, 1973, pp.629-685.