An Investigation of the Omega Effect

by

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ABSTRACT

A form of apparent visual movement which occurs when spatio-temporally random visual noise is confined in an annular channel has been investigated. The phenomenon, known as the Omega Effect, does not seem to be related to the phi-phenomenon, although there are formal similarities with observations sometimes made in certain stroboscopically illuminated fields.

The period of omega movement was found to be independent of most of the statistics of the visual noise used to evoke it.

Over 100 subjects were tested with a variety of stimulus-annuli. Although large individual differences occurred, the mean period and variance of most Ss did not generally vary, although there was some dependence on performance in the recent past. Significant sex differences were found in estimates of the mean period.

The mode of observation had little effect that could be measured.

Simple, circular annuli evoked the clearest and most consistent reports of apparent movement. The two parameters which conditioned the mean period $\bar{p}$ were found to be the annulus diameter D and the channel thickness T. For large enough groups of Ss, it was shown that

$$\bar{p} = K_1 D \log T + K_2 \log T + K_3 D + K_4$$

fitted the experimental data very closely.

It was demonstrated that both changes in distance and changes in angle of regard affected the mean period, there existing a negative and a positive correlation, respectively. The former finding was in agreement with prediction, but the latter was not. It was postulated that the effect depends to at least some extent on the presence of long-range interactions which possibly exceed the limits normally found in the retina.

Some suggestions are made for possible future work.

PREFACE

A new phenomenon of apparent motion, the Omega Effect, has been studied systematically to determine what relation, if any, it bears to other known aspects of apparent motions of different kinds, and what parameters are involved in its production and modification.

An appendix describes three series of experiments performed in an attempt to find a physiological correlate of the effects of contour interaction in the visual system. Since the results of all three series were negative, the appendix is restricted mainly to a description of the methods used, with possible reasons for their failure.

A reprint of the paper "A test of the hypothesis of bioluminescence in the human eye", written in collaboration with N. de M. Rudolf, is enclosed.

CONTENTS

a) Parameters of the Noise Field

b) Parameters of the Observer

c) Mode of Observation

Introduction

Since about the time of Wertheimer (3), a wide variety of apparent movement phenomena has been the subject of much quantitative study in connection with different contemporaneous theories of visual perception and organization. Some of them are of quite recent origin, having been detected during investigations of previously-known effects; others, in particular that which is now known as the phi-phenomenon, must have been frequently observed during much earlier times. Phi-movement requires very little apparatus for its production; it may be easily evoked, for example, by the simple expedient of alternately opening and closing the contralateral eyes while focussing a point somewhat beyond an object in the near visual field. For a suitable rate of alternation, the disparate images give a convincing illusion of apparent motion of the object. (It is tempting to speculate that Cro-Magnon man was aware of the ability of successive, relatively displaced images to evoke the impression of motion, and, with this knowledge in mind, provided various of the animal subjects of his engravings with multiple legs (1)).

In the nineteenth century, Plateau devised a disc, around the circumference of which were depicted the successive stances of a dancer executing a turn. By rotating the disc and viewing each frame in a mirror positioned to exclude sight of the others, apparent animation of the dancer was obtained. Devices of this type proliferated during the ensuing decade, 1830-1840, and as interest in apparent movement grew, so did the number of reports of its other forms. Thus the after-effect of seen movement (although known by the ancient Greeks and possibly noticed also by Purkinje) was described by Addams in 1834, and eye movements were shown not to be implicated, in this case at least, by Plateau's demonstration of his spiral (1850). Bit by bit the idea grew that movement is a phenomenon <u>sui generis</u>, dependent neither on continuous displacements of retinal images nor on the presence of tracking eye-movements. (For an account of this development, as well as that of the early stroboscopes, see (2)).

After Wertheimer's study of the phi-phenomenon (3) delineated some of those conditions favourable to the perception of apparent movement of that type, and further helped to establish the impression of movement as not inextricably dependent on spatio-temporal factors, Korte (4) attempted to quantify the relations between optimal movement (defined by Wertheimer as that seen to occur when the second stimulus appeared at approximately the same time as the first disappeared) and stimulus intensity I, stimulus duration t, spatial separation d and temporal separation T. That these relations were not as simple as Korte supposed them to be, and that they in fact held only over certain ranges of the variables, was demonstrated by Neuhaus (5). Within these ranges, the laws, as restated by Graham (6), assert that, for a report of optimal movement, 1) for constant t and T, d increases as I increases 2) for constant t and d, I decreases as T increases 3) for constant I and t, d increases as T increases and 4) for constant I and d, t decreases as T increases. Strictly speaking, these laws apply to, or at least their original purpose was to describe, only what Kenkel (7) called beta movement. This is identified by Boring (2) and by Graham (6) with Wertheimer's optimal movement, but the latter than states Korte's laws as applying to "optimal beta movement" (pg. 900), a seemingly redundant terminology, and Vernon (8) refers to it as appearing when there is a difference of size between the two stimuli. For the purposes of the investigation to be reported, the terms "phi-phenomenon" and "phi-movement" are used interchangeably to denote the illusion of movement which occurs when one tachistoscopically presented stimulus follows hard on another, the movement occurring from the spatial position of the first to that of the second. "Pure phi-phenomenon" then refers to that impression of pure movement, not contingent on the presence of an actual object perceived to be moving, which was originally called the phi-phenomenon by Wertheimer. These conventions follow the terminology of many standard textbooks (9, 10, 12 also 11).

Other types of apparent movement may be evoked by successive stimuli whose characteristics fall outside the range of Korte's laws. Summaries of these are to be found in (2), (6) and (8).

Besides the after-effect of seen movement, briefly referred to above, which in its idealized form is evoked by the continuous passage over the retina of the images of stimuli moving in a common direction, so far as a sufficiently small retinal area is concerned, repetitive arrays of

PATTERNS WHICH EVOKE COMPLEMENTARY IMAGES

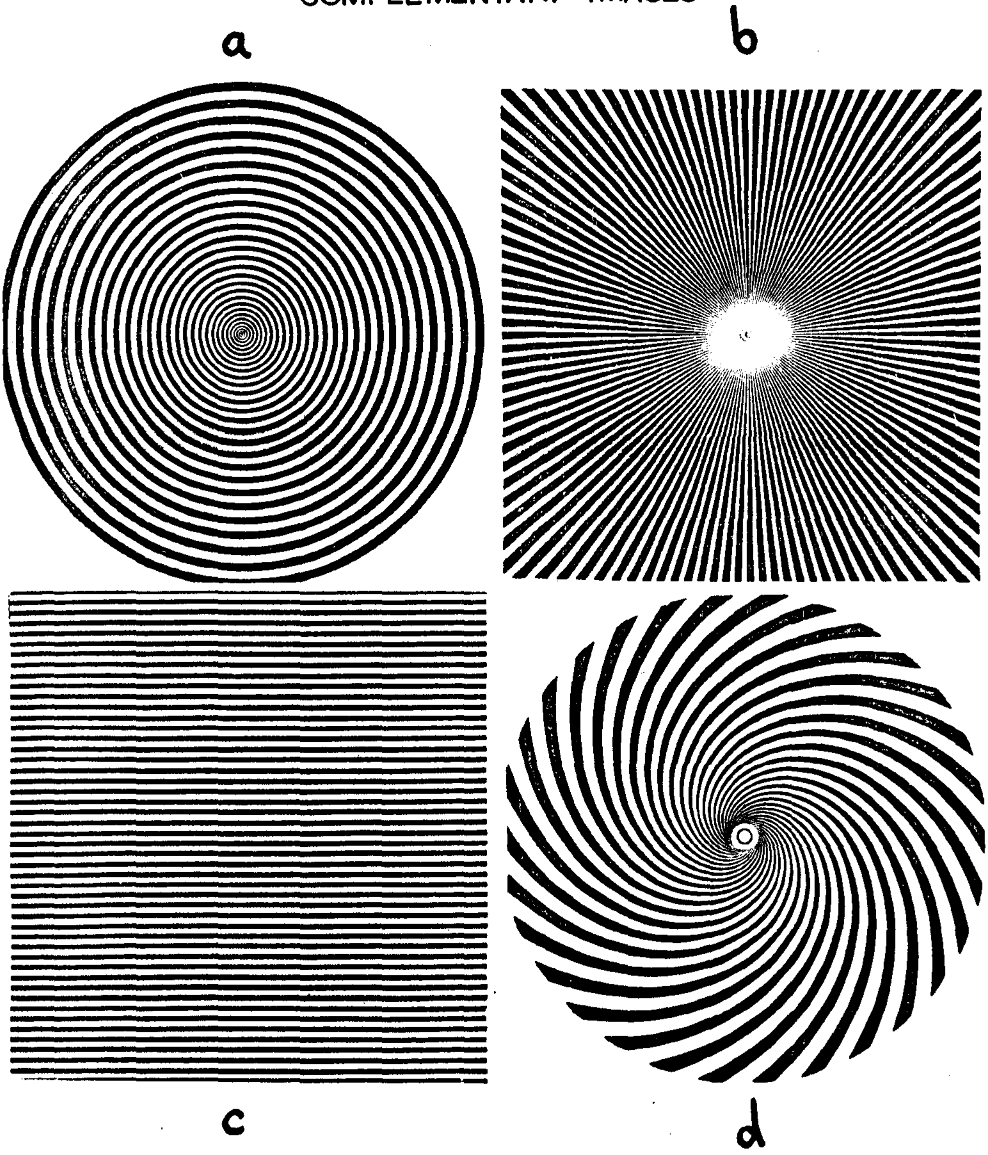


FIGURE 1

contour-stimuli, after being fixated for a period of time, result in after-images that are often seen to be in a state of compelling and sometimes violent motion (13, 15, 14) at right angles to the direction of the repetitive contours. This effect is not to be mistaken for the ordinary, stationary, positive or negative afterimages which may follow such stimulation, nor for the shimmering Moiré-like effects due to imperfect fixation and consequent superposition of retinal images. MacKay (16, 17, 18, 19), who rediscovered these and allied phenomena, has devised several patterns which can be used to evoke them, and has designated them "complementary after-images", because of their geometrical relation to the stimulus. (Fig. 1) That the well-known distortions of regular outline objects when presented against a background of the type illustrated in Figure 1 (Hering's Figure, Wundt's Figure; Orbison's illusions (20)) might be subserved by a mechanism similar to the one which produces complementary after-images, has also been pointed out by MacKay. Wilson, (21, 22) in his intensive studies of complementary after-images, reported that a rudimentary form of the effect could be seen in association with even a single contour, when the presentation of the contour (the border of a black disc) alternated with that of a plain, white field. Besides the usual phenomena evoked by stroboscopic illumination, Wilson noted 1) figure and ground brightness gradients which varied with the relative temporal positions of the two stimuli 2) an impression of slow, continuous expansion or contraction of the disc, again sensitive to the inter-stimulus interval AB and 3) continuous rotation of the disc, of variable speed, and not particularly dependent on AB. The effects were strongest for frequencies of stimulation in the range 15-25 cps. Although Wilson found that stroboscopic flashes interacted with stimuli of constant brightness to give some of the effects produced by his two-flash method, for simple stroboscopic presentation, results were unconvincing.

Zanparoli and Ferradini (23), however, in their investigations of the effects of subfusional stroboscopic stimulation on the perception of various simple patterns, observed anomalous effects even for simple intermittent illumination. They used such figures as circular, elliptical and polygonal annuli, and their dominant finding was that, for suitable flash rates, most of their patterns seemed to be in rotational movement or, if they were at rest, a rapidly moving light "flux" streamed along the channel of the annulus; usually both motions could be seen at once, and their directions were subject to the control of the observer. They also found that any tendency towards non-homogeneity of the stimulus (caused by changing the illumination gradient, for example, or by using annuli of asymmetrical widths) enhanced the impression of both types of apparent movement.

Other investigators have also reported movement evoked by stroboscopic stimulation; this is usually radial expansion or contraction of the stimulus, and has been called "gamma-movement" (7, 24, 25), but the perception of swiftly rotating and well-structured artefacts is sometimes obtained at frequencies above those optimal for gamma-movement (26).

During his investigations of the complementary after-effect (C.A.E.) MacKay found that the use of a background of spatio-temporally random visual "noise" greatly expedited his work. (16, 17, 27). Such a display, which appears as a multitude of randomly appearing and disappearing scintillations of light, such as is obtained by detuning a television receiver, when viewed through a transparency of one of MacKay's patterns, immediately becomes structured: the scintillations are still random, but their chaotic, Brownian-like apparent motion now becomes oriented to directions at right angles to the contours present on the transparency. Thus, a continuous impression of movement very much like that seen during the short duration of the C.A.E. is obtained, and both MacKay and Wilson (22) argue that both are subserved by the same mechanism.

When a transparency of Fig. 1 (a) is viewed against a background of dynamic visual noise, besides the continuous centrifugal or centripetal radial streaming of the complementary after-image, another observation can be made. Wilson (22, pp. 84-5) describes it as "movement of the scintillations ... along the channels between the black lines". The movement was different from the circular streaming evoked by the ray-pattern (Fig. 1 (b)), which exhibits constant angular velocity and instantaneous changes of direction. The movement in the channels of the concentric-circle pattern, on the other hand, varied both with the diameter of the channel being observed, and with time; when it reverses, it slows down to zero and then accelerates in the opposite direction. No corresponding movement was ever seen in the channels of the ray-pattern, i.e. between straight-line contours, but Wilson points out that this is understandable if circular movements have a superior status in the perceptual system. This last conjecture is supported by the evidence he obtained from normal complementary movement: the circular movement produced by the ray figure was invariably described by his subjects as more striking than linear, radial or spiral movements due to appropriate patterns. Another confirmation of this circular bias, this time for real movement, is offered by Brown (28). His subjects adjusted the velocity V_p of a spot moving in a circular path until it was phenomenally equal to the velocity V_a of a similar spot moving through the same distance in a rectangular field of corresponding dimensions. The ratio $^{V}a/V_p$, when V_a=25^{cm}/sec, was 1.19, that is, the circular velocity was phenomenally greater than the linear velocity by about 20%. Difference thresholds of the two movements, according to Brown, would stand in a similar ratio: those for circular movements would be 20% below those for linear movements.

That the perception of apparent movement of the noise "particles" is still possible in a single, annular track (i.e. when all channels of Fig. 1 (b) have been masked off, except for one) is probably not surprising. MacKay, who did some preliminary investigations of this type of movement, describes it as follows:

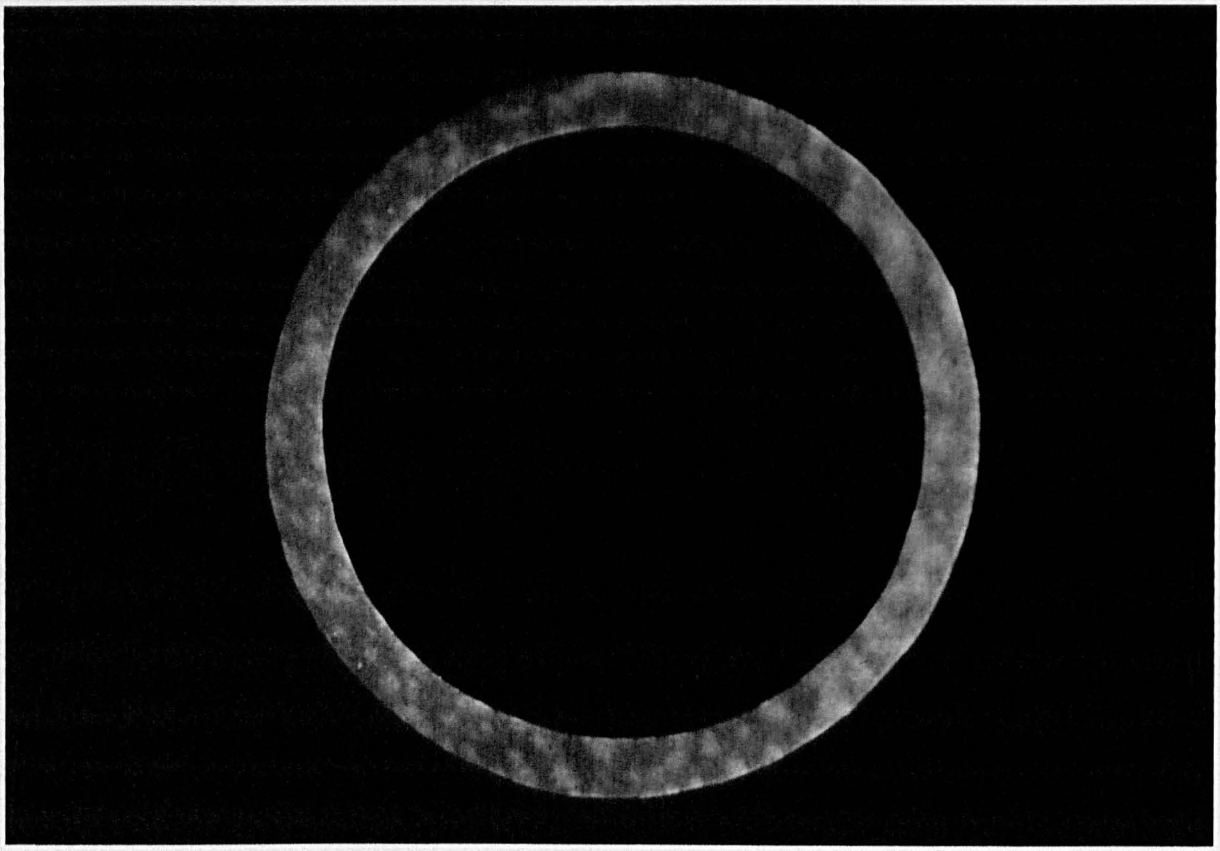
"If you make an annular aperture in an opaque card and hold it before a visual noise source, you see, of course, an annulus of random speckle. The remarkable thing is that this annulus, after a second or two, is seen to be rotating, usually in both directions, rather like a population moving along a pavement in both directions. If now you follow one of the rotations with your eye, you find that you can to some extent influence it. You can 'drive' it round, up to a certain frequency, but then it sticks, and if you try to

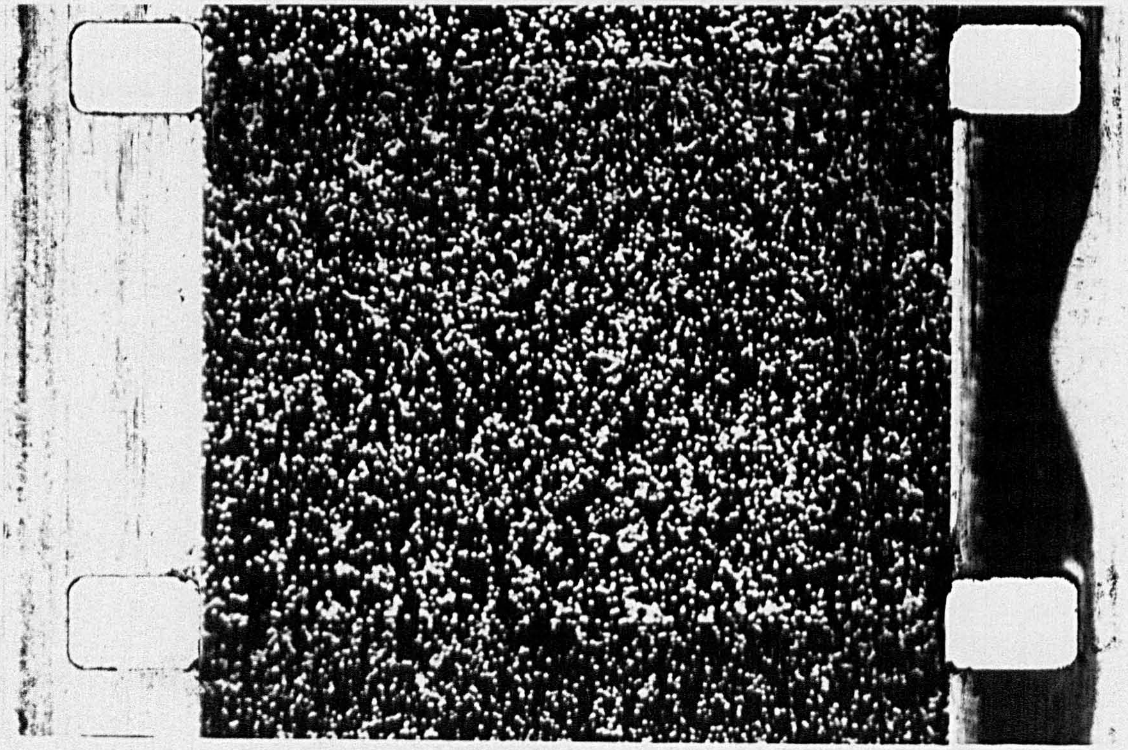
FIGURE 2 (over, top):

Conditions for the Omega Effect. Dynamic noise evokes an illusion of apparent motion.

FIGURE 3 (over, bottom):

Frame of Visual Noise.





drive it faster, you see it lagging behind you". (29) MacKay found that the velocity of the movement was not dependent on the statistics of the noise, nor on the angular subtense of the stimulus, and considered it as a natural rhythm, analogous, perhaps, to the alpha rhythm (although there was little or no correlation with the latter). Wide individual differences appear in the estimates of the movement's period, but a typical figure is about 1.4^{secs}/rev. The stability and manner of evocation of the movement suggested no close relationship with any of the other apparent movement phenomena, and so MacKay tentatively called it the "Omega Effect" (27, 29) (Fig. 2).

Whether the omega effect is a unique apparent movement, and what sort of parameters combine to influence its perception are two of the questions the present study was designed to answer. Does it depend on the presence of contours in the field, as do the complementary after-images, or is it an effect of local flicker on the retina, due to the scintillations of visual noise? It might be argued from Segal's work (26) that the latter is the case, although the observations of Zapparoli and Ferradini (23) imply that the movement due to simple flicker can easily be conditioned by contours. Unfortunately, they give no data concerning the speed of the apparent rotation they saw, nor concerning the flicker frequencies necessary to evoke it, save that they are subfusional. Furthermore, both Segal and Zapparoli used gross flicker, whereby all parts of their stimuli flickered in phase. Concerning "microscopic" flicker - where different, restricted areas of the retina are stimulated independently - the observations of

Johansson are of interest (30). He varied sinusoidally the intensities of configurations of bright lights always present in the visual field, with similar frequencies but with varying phase differences, and produced what he called "W-movement". MacKay, using dynamic visual noise, also reports apparent, Brownian-like, movement (19, 27), but this is completely unstructured in the absence of contours, no intrinsic propensity for circular motion being indicated. Thus it may be concluded that, although massive, in-phase, stroboscopic stimulation may, under suitable conditions, result in the perception of rotatory apparent motion, microscopic stimulation abolishes this effect, or at least cannot sustain it.

If now the conditions for the perception of omega-movement are set up, the formerly random apparent movements of the noise field is constrained between the boundaries of the annulus. Hence one might expect that the impression of "continuous" phi-movement, which no doubt accounts for the Brownian-like motion formerly observed, could be made to "circumnavigate" the annulus, especially if the observer was "set", either by instruction or expectation, to see movement always in a common direction. Furthermore, i) rotational movement, under such circumstances, is frequently seen to oscillate or to change direction, just after the stimulus is first presented ii) it can be "driven" by the observer up to a certain limit, probably, according to this hypothesis, imposed by his individual repetition rate for optimal phi-movement

iii) it takes a longer time to traverse an annulus of large diameter than one of smaller diameter (this follows from Wilson's report (22) that the angular velocity of the movement was much slower for channels near the periphery of his concentric-circle pattern. This finding would be necessary, as there is no reason to believe that phi-movement is dependent on the the curvature of the channel in which it is constrained) iv) the time for one revolution predicted by a phi-phenomenon hypothesis is of the same order of magnitude as that actually observed for omega-movement. These would all seem to indicate that the latter is actually a special case of phi. Evidence to be presented later will, however, suggest that this is not in fact a tenable hypothesis.

Assertion iv) above is based on the data of Corbin (31), whose subjects from a distance of ten feet, estimated the simultaneity-movement threshold at 104 ms, when stimuli separation was two inches. An 8"-annulus has a circumference of about 25", and at a distance of 10' could therefore be traversed by 12½ phi-"jumps" each of two inches. But this would take, assuming the optimal time to be 125ms, about 1.6 seconds. MacKay (29) reported using, as his visual noise source, a movie projector whose speed could be varied between 7 and 20 frames/sec. This optimum rate is thus within his range (and corresponds to 8 frames/sec), and his typical figure of 1.4^{secs}/rev, mentioned earlier, might come as no surprise.

MacKay, however, is of the opinion that an explanation in terms of the phi-phenomenon cannot account for the omega-effect's independence of noise-frame frequency. (private communication). It is indeed difficult to predict the precise behaviour of apparent movement, from a simple phi-hypothesis, for the complicated situation in which the omega-effect is seen. However, a simple qualitative argument may indicate roughly what is to be expected.

By Korte's third law (pg. 2 above) for constant I and t, d increases as T increases, for a report of optimum movement. Hence, as the projector speed is decreased, thereby increasing T, d for optimum movement also goes up. (It should be noted that the ensuing variation in t which would tend to cause the opposite shift in the value of T (Korte's fourth law, pg. 2) is neglected as small in the range 50-200 ms, i.e. 5-20 frames/sec). Thus, instead of the continuous movement seen at higher frame frequencies, discrete jumps of the noise field would be seen, and it could easily be that a few large jumps, each corresponding to a successive noise frame, could complete the transit in the same time as a great many smaller jumps at a higher frame speed. In fact, discrete jumps or jerks of the noise field at low frame speeds is exactly what one sees.

Some criticism of the applicability of Korte's laws to the present circumstances would probably arise from Oldfield (32), who points out that in complex situations, such as an ordinary movie, apparent movement is very tolerant of changes in I and d. Certainly, a random noise field, unlike most laboratory apparent-movement stimuli (33, 34), invariably evokes a response of "movement" from observers. This is spontaneous, and does not need to be elicited by the experimenter, in spite of any "analytical" attitude of the subject. If Oldfield's viewpoint applies, one would expect that omega-movement, also, would be very tolerant of stimulus conditons.

There also remains the discrepancy between the reports of MacKay, who observed that the omega effect was not critically dependent on the angular subtense of the annulus (29), and of Wilson (22) who found that it was.

Neither MacKay nor Wilson states how many subjects were involved in their respective experiments, and Wilson gives no data concerning the parameters of his stimulus or of the magnitude of the velocity of apparent movements.

MacKay favours a different hypothesis to account for the omega effect. As previously mentioned, he considered it to indicate a natural bodily rhythm, and in his more recent paper (27) he expands on this topic. Noting that a constant angular velocity is formally equivalent to a constant proportion between an angle and a time interval, or a velocity and a radius of curvature (35), and the probability of the existence of directionally sensitive elements in the visual system (16, 36, 37, 38, 39, 40), he points out that a neural "standard of angular velocity" could be embodied in the latter. A possible method of accomplishing this would be by coupling elements sensitive to successive incremental changes of direction with time lags roughly proportional to those direction changes. However this simplified example does not account for all the experimental findings, and so MacKay does not hope for its eventual verification.

That the presence of contours does, in fact, condition the perception of velocity in the human observer is known. It is a common observation that an object moving against an inhomogeneous background appears to be moving faster than when its background is unstructured. Brown (41) adduced evidence for this effect when he demonstrated, by systematically varying the inhomogeneity of the field against which his subjects observed a moving black spot. The converse effect also occurs, and indicates that the mechanism for movement detection is more primitive than that for the detection of contours: under suitable conditions, a moving object actually inhibits the perception of stationary contours. This was MacKay's finding for the monocular case (42), and Grindley and Townsend (43), although unable to confirm MacKay's report, owing, they thought, to their less complete stabilisation (they used ordinary fixation), demonstrated that if a moving object were presented to one eye, it invariably resulted in momentary disappearance of a stationary object presented to the other.

This type of finding for real movement leads us to seek parallels in the case of apparent movement, and some work has also been done in this field. Wilson (44) had his subjects estimate in which of two possible directions apparent movement was present or, if movement was seen simultaneously in both (for the two, second flashes were presented at the same time), in which direction it was more striking. His apparatus was so arranged that in one direction, the path of any apparent movement would lie along a contour, while the other it had to cross contours at right angles. His subjects found 1. that the perception of apparent movement was facilitated if contours were present across its path. 2. this effect was almost of the same magnitude when contours and flashes were presented to opposite eyes and 3. the effect of contour orientation was about twice as great for binocular as for monocular viewing.

Wilson's experimental procedure is subject to criticism, however, as it does not exclude the possibility that apparent movement thresholds are shifted up or down if contours present run parallel to the path of movement. If this were the case, and if apparent movement were in fact facilitated (i.e., the simultaneity-movement threshold value for T becoming smaller, with a corresponding downward shift of T_{opt}), optimal movement would no longer be reported along the contours, but, by the conditions of the experiment, would still be reported across them.

A finding of perhaps marginal significance in this connection is that of Jeeves and Bruner (45) who studied the movement-successiveness threshold and reported, under some circumstances, that movement was better and more persistent when it could occur in any one of eight directions (high directional information) than it was if only two directions were possible (low directional information). They consider (Brown, (46)) that 1) on aseending series, Ss have an expectancy for motion 2) this expectancy predisposes S to see motion and 3) the effect of expectancy is increased when directional information is high. Now, if it may be assumed that this directional information need not be inherent in the expectation of the movement, and may be provided by independent stimulation, e.g. by the presence of contours, Jeeves and Bruner would predict Wilson's finding: stronger apparent movement when directional information is high (i.e. across contours) than when it is low (along contours).

MacKay and Wilson's observations on the direction of the complementary after-images are of obvious relevance.

Apparently arrayed against these findings are those of the Gestalt psychologists and the Field-Theory school of Köhler and Wallach (47). There are several studies which bear upon the general problem of interaction of contour and apparent motion. Deatherage and Bitterman (48) found that the path of apparent movement occurring between two flashes presented to different eyes became deflected after a circular inspection figure was present in the path for 1 minute, and that a rectangle intruding even further into the path abolished movement, necessitating an increase in the rate of flash stimulation to re-establish it. Similarly, Shapiro (49) detected a change in the apparent movement between two linesafter a circle, placed between them, was fixated for 3 minutes: succession was reported where before there had been reports of movement. But both these investigators were working around the lower (succession-movement) threshold which is very sensitive to such factors as attitude, suggestion, expectation, set and ascending or descending order of trials (33, 45, 50, 51, 52), and Deatherage (53) also found subjects who, in order to reinstate movement, had to decrease the rate of alternation of the stimuli. Deatherage considered his earlier finding to be due to errors of expectation on the part of his Ss. Brenner (54) established the succession-movement and movement-simultaneity thresholds before and after her Ss fixated a circle of light. She found that the continuous stimulation resulted in a contraction of the temporal range within which apparent motion could be seen, both thresholds being affected.

McEwen (55), in his lucid summary and criticism of these and related experiments, is of the opinion that, by and large, results conform to what the satiation theory of Köhler and Wallach (47) would predict. The perceptual correlate of this theory is that the metric of visual space undergoes an expansion in the region of a contour (56), resulting in, for example, a phenomenal increase of distance d between two alternating test figures on either side of the inspection region. Thus, from Korte's 3rd law, T_{opt} should increase, and this is what is generally observed.

However, none of the investigations cited involved determining the effect on apparent movement of inspection-figures simultaneously visible in the field, and the indications are (33, 41, 44) that, under these circumstances, movement, apparent or real, is enhanced (in the sense of "more striking"). Andrews (private communication) is of the opinion that, in the latter case, one must conclude that the effect of contours on the velocity-sensitive part of the visual system more than compensates for their effect on the spatial metric, and that Korte's laws have, therefore, questionable validity.

If this is so, then it is another aspect of the principle that the mechanism for velocity detection is an entity distinct and more fundamental than that for the processing of contour information.

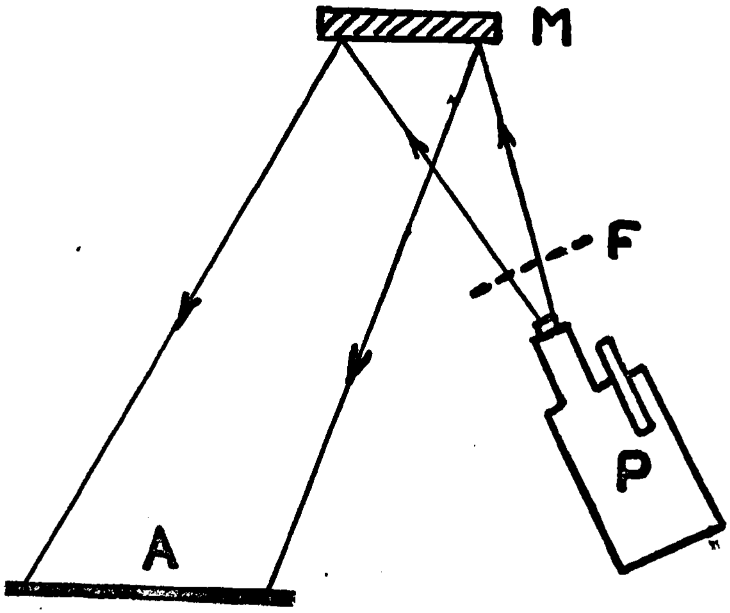
Of the effect, on the perception of apparent movement, of single contours permanently established near its path, nothing has been reported except for MacKay's omega-phenomenon. It is therefore of interest to investigate the determinants of this movement to see what relationship, if any, the effect has with previously studied apparent movement phenomena. There also exists the real possibility that the results will help to clarify the role of short-range interactions in the visual system of man.

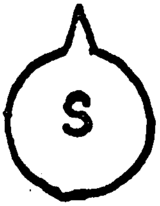
Experimentation . The Omega Effect

The variable to be studied in all the experiments of this section is the period, p, of one complete revolution of the movement between the borders of whatever figure was presented to the subject. These figures were always annuli, sometimes circular, sometimes elliptical and sometimes polygonal, sometimes complete and sometimes incomplete, i.e. partially occluded by opaque segments of variable size and frequency. The figures most often used were circular annuli of three different diameters, D, (3", 5" and 8") and two different thicknesses, T, ($\frac{1}{4}$" and $\frac{1}{2}$"). All figures were prepared from black cardboard and white tissue paper. They were illuminated from the back, so that S, who was seated in front of the figure, saw only that part of the noise field delimited by the boundaries of the annulus.

The actual visual noise source was a movie film, of the type previously found useful by MacKay and Wilson, and was manufactured as follows. On a background of black velvet-paper (a type of paper with velvet-like texture and very low reflectance) was randomly scattered a large number of small (approximately $\frac{1"}{20}$ diameter) discs of thin white paper - the noise. The background and discs were evenly illuminated by two 150-watt reflector-type spotlights, augmented by normal room lighting. A 16 mm. movie camera, mounted on a frame at a distance of about 3 feet above the field, pointed downwards at it, so that a photograph could be taken of that part of the field directly underneath; the time-lapse setting of the camera was used so that frames could be exposed individually. Since the field of view of the

DIAGRAM OF EXPERIMENTAL SETUP





Position of
P : 16mm projector
F : Filter, prism, etc.
M : Plane mirror
A : Opaque screen with annular opening
S : Subject

FIGURE 4:

Mirror is present or not depending on experimental circumstances.

FIGURE 5 (over):

Photograph of experimental setup. The mirror can be seen, partially masked, in the background.

	Average Periods in Seconds		
Subject	Darkened Room	Semi-Darkened Room	Normal Room Lights
1	3.5	3.0	3.0
2	2.0	2.2	2.0
3.	2.5	2.0	3.2
4	4.2	4.0	3.5
5	3.7	4.3	4.0
6	3.3	2.7	2.0
7	3.5	3.7	4.0
8	2.0	2.0	2.5
9	6.0	5.2	5.0
10	2.5	2.7	3.0
Group Averages	3.32	3.18	3.22

<u>TABLE I</u>: Effect of Ambient Light.

Name: .... Eyesight: L: .... R: .....

Age: .... EEG: ....

Date: .... Time .... B.M.R.: ....

Run	Revs/interval	Time interval	Revs/sec.	Angular Subtense	Comments

camera at that distance was about $\frac{1}{6}$ of the total field available, six completely independent regions were available, and since the whole background, lying on the floor, could be rotated, four different orientations, at right angles, of each region were used. One hundred and twenty successive frames were then exposed, the region and/or the orientation being varied randomly before each exposure. The finished film was then developed and a number of positive contact prints were made on more 16 mm film; on the latter the noise appeared as in Figure 3. Loops of noise film could then be made, each sufficiently long to be threaded through a Specto 16 mm movie projector (500 watts) which had a rheostat in series with its driving motor, thus enabling the film speed to be varied without a decrease in light intensity. The projector was then placed about 8 feet behind the pattern (if the room in which the experiment was to be held was too small to do this conveniently, the projector was set roughly opposite the pattern and trained upon a plane mirror, which reflected the projector beam onto the pattern. See Fig. 4) and illuminated it from behind. At this distance, each individual noise "particle" was about $\frac{1''}{10}$ in diameter. A photograph of the experimental setup is shown in Fig. 5.

Depending upon the size of the room and the parameters to be investigated, subjects were seated in front of the pattern either individually or in groups of up to about twenty. They were given a form (Fig. 6) whose purpose, and that of the experiment, was explained to them in the following words:

"This is an experiment designed to investigate some of the factors which influence the perception of motion. Before you, you see an annulus upon which I am about to project a pattern of visual noise (The term "visual noise" was here explained). When you first see it, you will be aware that the noise is in motion around the periphery of the annulus. This motion, however, is not very stable, and will be seen to oscillate, or to change its direction quite frequently. I am about to give you a bit of practice, and I want you to see if you can't overcome this tendency for reversal, and become able to follow the movement all the way around the annulus (Here the room was semi-darkened, and the projector turned on). You will find that if you follow the movement smoothly with your eyes you will be able, not only to abolish the reversals, but actually to force the movement around - up to a limit. It is this critical speed that I want to try and measure, and we shall estimate it as follows".

After each figure was placed in a position, E. after allowing 30 seconds or so inspection time, gave a verbal "ready" signal, followed by "go". E then started a stopwatch, allowing it to run for a randomly chosen, predetermined time. Meanwhile, S counted the number of times the apparent movement of the noise was seen to travel around the annulus. When the predetermined time had elapsed, E instructed S to "stop", and S then wrote down the number of revolutions he had counted, as accurately as he could, in the "Revs/interval" blank on his form corresponding to the appropriate "Run" number. There were generally about 20 "Runs" (i.e. different changes of figure) during an experiment, which took about 45 minutes. If, say, six figures were to be presented, this was done randomly, each figure being used three or four times, generally with a different exposure time for each presentation. For convenience, exposure times were chosen either from the set (5, 8, 11, 14) seconds, or from the set (6, 9, 12, 15) seconds.

When the experiment was completed, S was invited to add any further impressions of the movement he had obtained to any comments he had already made in the "Comments" column during individual runs. He was then requested to leave his completed form in approximately the same place in the room from which he did his observing, so that distances and angles of regard could be measured.

After these measurements were made, and the forms collected, E entered the actual exposure times used in the "Time Interval" column, and from these and S's "Revs/interval" entries, he was able to calculate the average period p for each run. These values then formed the basis for the subsequent data processing.

A total of about 100 different subjects were tested, about half of these participating in two or more experimental sessions. Subjects were drawn, generally, from three sources: 1) undergraduate and graduate volunteers from different university department at Keele, and staff members of the Department of Communication 2) participants in an introductory science conference at Swanwick, Derbyshire in July, 1964. These included individuals of widely varying educational backgrounds. 3) undergraduate "conscripts" obtained through the cooperation of the Department of Psychology at Keele, and tested during their normal laboratory hours.

Since the experimental design enabled several aspects of the omega effect to be tested during a single session, this was done as a rule. However, for convenience, in the account of the experiments which follows, the results pertaining to a single parameter have been presented individually, except where interactions have been found to arise.

Similarly, where details of the experimental procedure used differ from those outlined above, these changes have been recorded under their appropriate section.

a) Parameters of the Noise Field

i) The effect of ambient lighting.

Ten volunteers, tested individually, gave estimates of the period of apparent movement under each of three conditions of ambient lighting of the experimental room: ordinary room lighting (1.38 log. ft-lbts.), subdued room lighting (-0.97 log. ft-lbts.), and no room lighting (-1.93 log. ft-lbts.) except for light scattered from the projector and the stimulus figure. The illumination values given were obtained by using an S.E.I. Exposure Photometer to measure the apparent brightnesses of pieces of white cardboard placed a few feet away from the figure.

Three estimates of the period were obtained for each value of ambient lighting; the average of the three was calculated in each case and is shown in Table 1. For each S it was found that the variation obtained under different lighting conditions was of the same order of magnitude as that obtained under constant conditons. There is no obvious systematic trend associated with ambiant brightness levels, and the t-test for paired

FIGURE 7: Effect of varying noise brightness intensity.

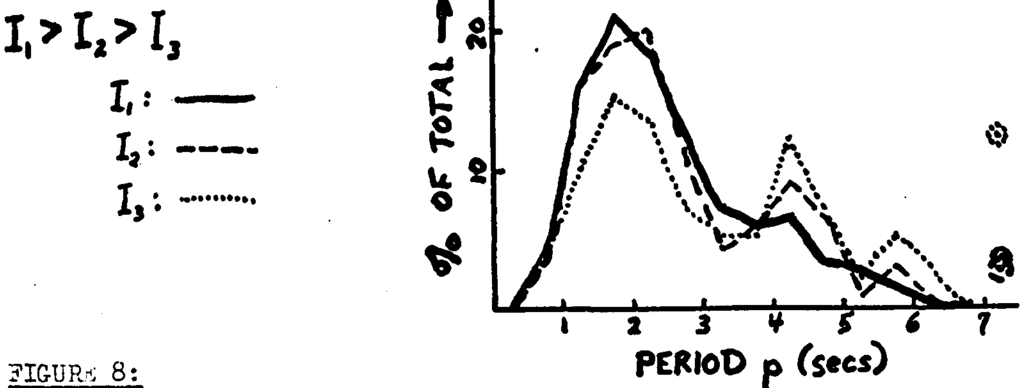


FIGURE 8:
Effect of noise size (distance varied).

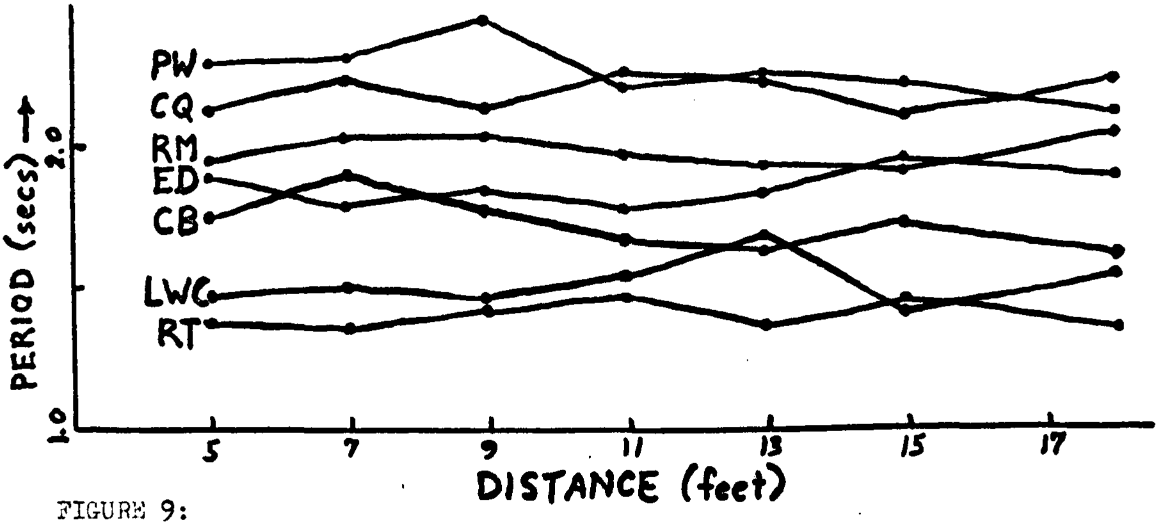
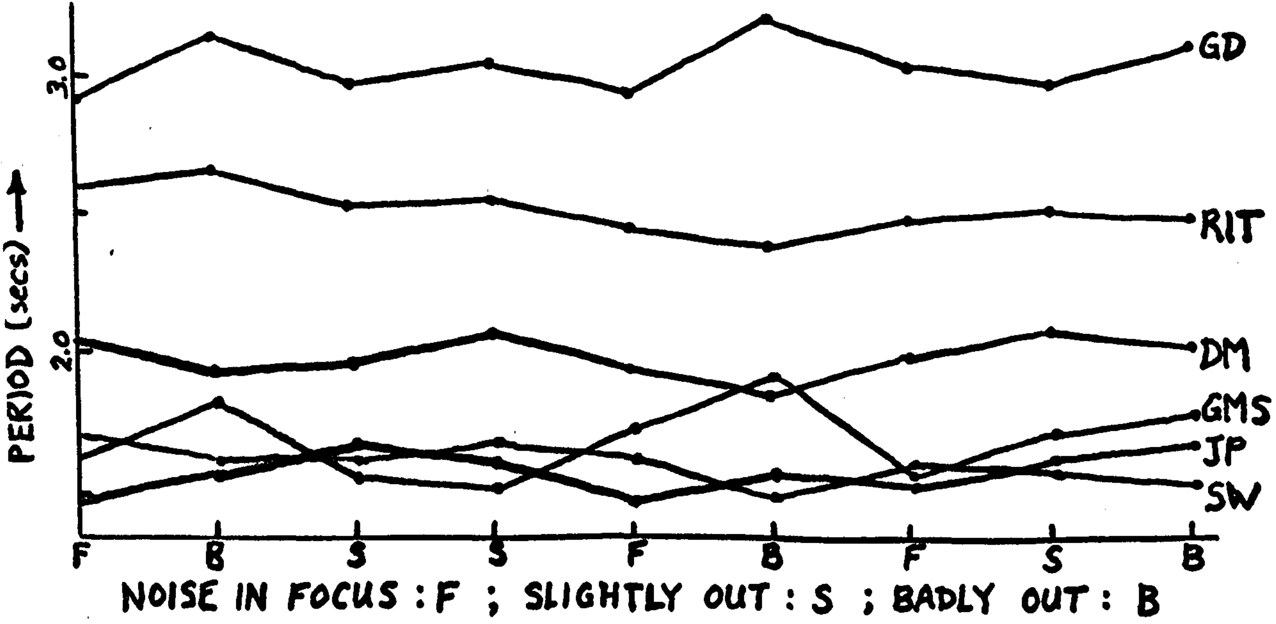


FIGURE 9:
Effect of noise size (focusing varied).



Relative Brightness	1.00	0.50	0.13	0.01	0.001
Average period p (secs)	2.39	2.47	2.55	3.04	3.63
No. of responses	54	55	57	42	30

TABLE II: Effect of Noise Intensity.

variates showed no significant differences between their means.

It may be concluded that ambient lighting, and hence the state of adaptation of the eye, has no effect on the period of omega-movement.

ii) The effect of "noise brightness".

MacKay (27) has reported qualitative differences in dynamic noise fields as the intensity of the noise is changed. It is therefore worthwhile to see if any changes in p are correlated with this factor.

The noise intensity was changed by inserting Ilford Neutral Density filters into the projector beam. Filters (or filter combinations) used corresponded to relative light transmission values of 1.00 (no filter), 0.50, 0.13, 0.01 and 0.001. Sixteen volunteers participated in a group experiment.

Each intensity was presented 4 times, and the mean value of p was calculated for each. Results are shown in Table 2.

At first sight, it would appear that, as noise intensity diminishes, the period of perceived motion increases. It is probable, however, that this effect is illusory, as might be indicated by the number of actual responses on which each mean value is based (Table 2). Remembering that the maximum possible number of responses in each case is 4x16 = 64, it can be seen that at the faintest intensity used, Ss felt confident enough to make a judgment in only 47% of presentations, and that this difficulty is already evident by the time the relative intensity is 0.01. What happens is best illustrated in Figure 7, where results for relative intensities of 1.00, 0.13 and 0.01 are shown presented in a different fashion. Here, all the Ss' estimates are assigned to classes each of width 0.5 seconds, and the number of responses in each class, expressed as a percentage of the total number of responses actually made, is plotted against the class mid-value.

Three dominant features emerge. First, all graphs show a maximum in the vicinity of p=2.0 seconds, irrespective of intensity. Second, as intensity decreases, there arises a secondary maximum near p=4.0 seconds: the plots tend to become bimodal. Third, the number of responses equal to or greater than p=7.0 seconds increases as intensity decreases.

It seems that the increasing average p's of Table 2 is an effect due, not to decreasing intensity, but to the relative importance of the secondary maxima obtained under these conditions. This secondary maximum occurs again in subsequent experiments, and so its discussion will be left until later.

There is no significant difference between the positions of the first maxima, and so it may be tentatively concluded that, over a wide range, p is independent of intensity.

iii) The effect of noise "particle" size.

Subjects were 13 volunteers who were tested individually. Each was seated $4\frac{1}{2}$ feet away from an annulus of D=5", $T=\frac{1}{2}$" and given the usual instructions.

Noise particle size can be conveniently varied within limits imposed by the dimensions of the laboratory by either varying the effective distance of the projector to the stimulus-figure or, with this distance constant, by defocusing the projector. Although both methods suffer from the defect of introducing a diminution of noise intensity as noise size increases, this, in view of the results of the preceding experiment, should have little effect, since noise size could be varied only over a factor of about 3. Thus, it was

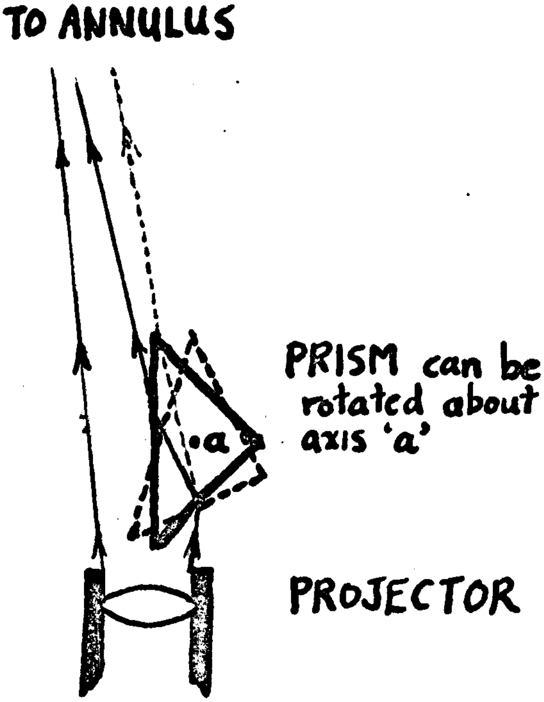


FIGURE 10 (right):

Method of obtaining variable noise density. Prism is adjusted until noise fields coincide.

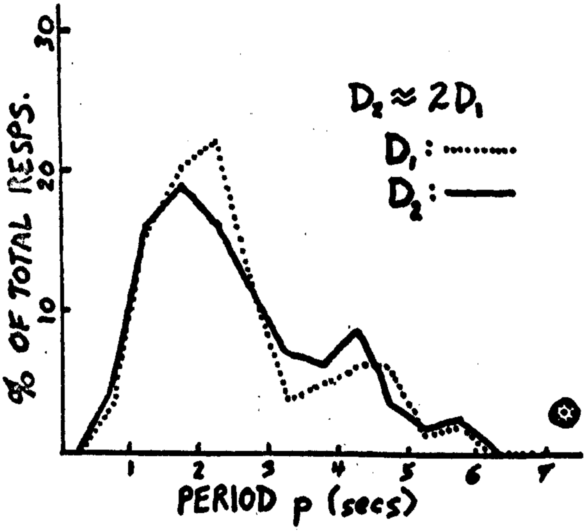


FIGURE 11 (left):

Effect of varying noise density.

not deemed necessary to correct for intensity changes by the use of neutral density filters. Seven Ss were tested by varying the stimulus-projector distance, and 6 by defocusing the projector. Results are shown in Figures 8 and 9. These figures demonstrate that, over the ranges tried, noise size causes no systematic change in Ss' estimates of p.

It was originally hypothesized that defocusing, by causing overlap of the projected images, would tend to cause an increase in p (due to the increased difficulty in following rotations, the greater number of mistakes made and hence the higher proportion of mistaken, overly-large values contributing to the averages). This effect is seen for subjects GD and GMS, when the projector is greatly out of focus, almost abolishing noise structure, but, on the other hand, the reverse is true of DM and SW (Fig. 9). None of the differences is significant for any given observer.

It must be concluded that the perception of omega-movement is consequent on the presence of random inhomogeneities of the stimulus and, over the ranges tested, is independent of the precise form of these inhomogeneities.

iv) Effect of noise density.

In view of the findings of Experiment iii), it was considered unlikely that varying noise density (i.e. number of noise "particles" per unit area of noise field) would have an appreciable effect. However, the only convenient method of doing so, with the apparatus used, provides a check on the effect of any intensity changes on the results of the previous experiment. This method was to place a right prism, with long axis vertical, in the beam of the projector, in such a way that the plane of the base of the prism bisected the beam (Fig. 10). Then, by suitable lateral translations of the prism, and

	GROUP 2			GROUP 1		
No. of Subjects	12	12	12	16	16	16
No. of Responses (to 3" annulus)	42	38	44	54	55	51
Projector speed (frames/sec.)	8	12	16	16	20	24
Average period $\bar{p}$ (seconds)	2.37	2.25	2.10	1.93	2.11	1.62
Group means (seconds)		2.24			1.89	

<u>TABLE III</u>: Effect of Projector Speed.

No. of Ss: 16			
Projector speed (frames/sec)	16	20	24
No. of Responses to 8" annulus	50	57	53
$\bar{p}$ (seconds)	3.22	2.94	3.02
No. of responses to both.	104	112	104
$\bar{p}$ for both stimuli	2.55	2.53	2.33

<u>TABLE IV</u>: Effect of Projector Speed. Group 1.

small rotations about its long axis, two images of the noise field could be partially superposed after being adjusted to equal brightness. In this way, noise density could be effectively doubled at the cost of a reduction of its intensity.

Subjects were 16 volunteers participating in a group experiment. Their results were pooled, each estimate of each subject being placed in its appropriate class, and relative class frequencies plotted against mid-class values, as before. (Fig. 11) Neither means nor variances of these two distributions differ significantly, and it may be concluded that doubling the noise density has no effect on the period of omega-rotation.

v) Effect of projector speed.

The same Ss who participated in Experiment iv) were also required to estimate p as the projector speed (and hence the rate of presentation of successive noise frames) was varied between 16, 20 and 24 frames/sec. Twelve additional Ss were tested at speeds of 8, 12, and 16 frames/sec, since these lower rates could not be obtained with the projector used during the first experiment. The results for both groups are shown in Table 3.

Although a group difference is present (which is to be expected, since the two groups of subjects were tested under different conditions), as indicated by the difference in the two means corresponding to 16 frames/sec, this difference is just not significant ($P \approx 15\%$), nor are the differences between extreme values of film speed within each group. The difference between the two group means calculated by pooling all estimates for that group is, however, very significant ($P < 1\%$). The first group were also

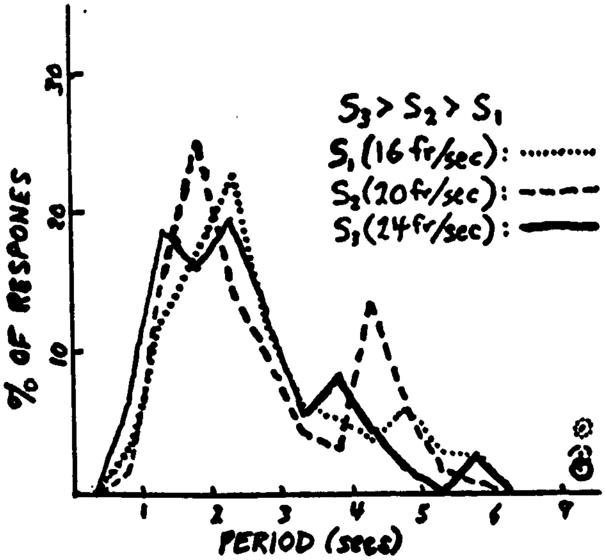


FIGURE 12 (right):

Effect of varying projector frame speed.

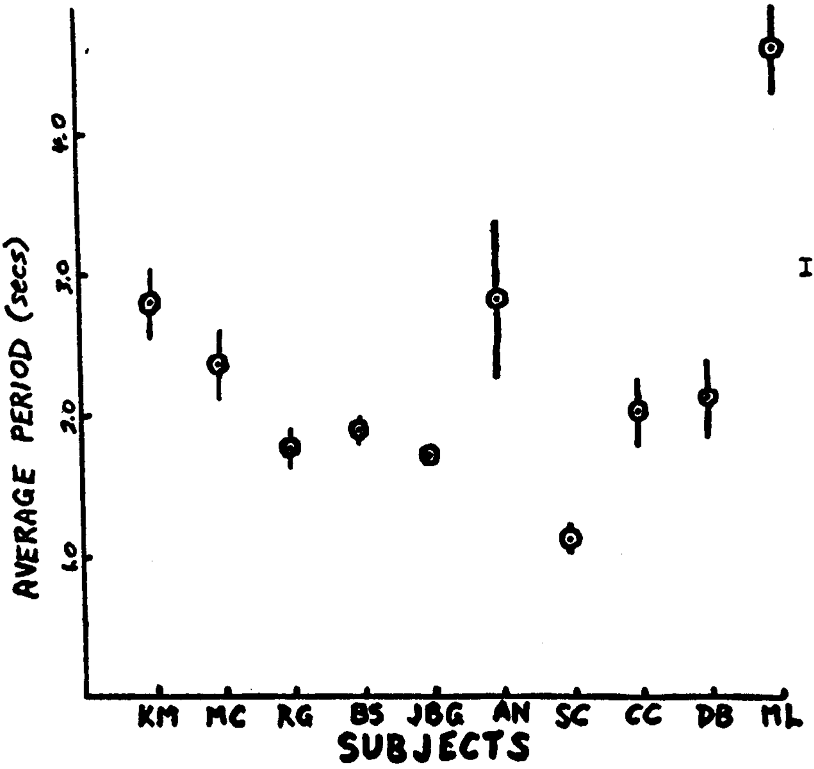


FIGURE 14 (left):

Intersubject differences.

tested with an annulus of different diameter (D=8"); the results of this experiment are shown in Table 4, along with the combined means of both patterns used. Again, none of the differences between means are significant.

A peculiar effect was found to occur in the first group for a film speed of 20 frames/sec. This is shown in the response distribution function (Fig. 12), and consists of a prominent secondary peak in its usual position of about p=4 seconds. The effect of this peak is to increase the average p corresponding to this speed, although the amount by which this happens (estimated by averaging only those values less than or equal to p=3.5) is not enough to affect the significance of any of the differences.

We may conclude that film speed does have a real, but small effect (changing p by no more than 40% when it changes by 300%), and that p tends to decrease as film speed increases. The value of 40%, since the experiment was complicated by intergroup differences, is probably an overestimation.

vi) Effect of auditory distraction

Several Ss participating in the preceding experiment informed E, after the experiment was completed, that they had the impression that the increased noise from the projector at higher speeds might have caused them to over-estimate the speed of apparent rotation. For example, M.L., under "Comments", reports that she tends "to associate loud noise of projector with faster revolution" and P.M.W. records "speed of projector note might influence ideas of speed".

It was therefore thought advisable to check this by presenting Ss with a noise not correlated with the actual projector speed. When this was done, by requiring 6 Ss to wear headphones through which could be played a tape-recording of the noise made by a running projector, it was found that their estimates were independent of both the loudness and the frequency of the recorded noise, even though values in excess of those actually obtaining under normal experimental circumstances were tried.

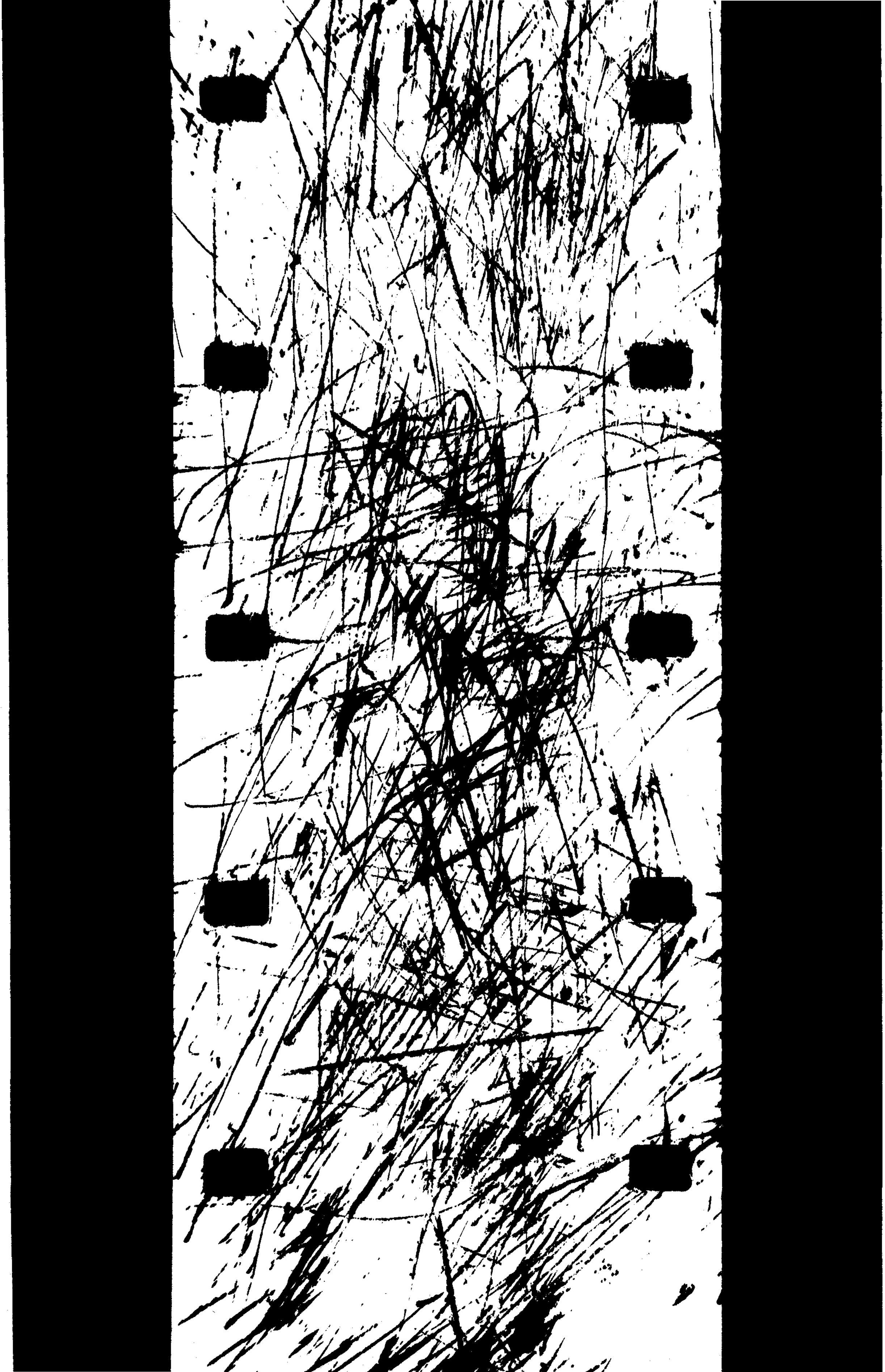
As a further check, 5 Ss, who had not previously been participants in any of the experiments, were seated one at a time in close proximity to the projector, whose beam was reflected onto a piece of thin white cardboard about 3 feet in front of S. At E's signal, and studying the texture of the random noise field in front of him, S then proceeded to estimate the duration of one minute, and his actual time was recorded by E. Six estimates were made for each of three projector speeds. None of the Ss showed significant changes in his time estimates for the three conditions, nor were the pooled value for all Ss significantly different.

That the actual projector noise volume could have had an effect is unlikely. Hirsh <u>et al</u>. (57) found that the effect of noise was to make their Ss overestimate a time interval of the same size used in the present experiment by about 25%, but they used noise levels differing by up to 60 db. Triplett (58) and Cohen <u>et al.</u> (59) found a similar overestimation to be associated with increasing frequencies, but neither used frequencies of the same order of magnitude as those of the present experiment, and again the effect was generally small.

The results would seem to indicate, therefore, that any effect due to the auditory noise of the projector is not a significant determinant of omega-rotation within the ranges tested.

FIGURE 13 (over):

Alternative form of visual noise.



vii) Effect of noise degradation

The negative results obtained by varying different visual noise parameters in the preceding few experiments indicate that the perception of omega-rotation is relatively independent of noise statistics. As a final check, a loop of noise film was prepared, not by photographing confetti, as before, but by taking an exposed and developed length of 16 mm film, of uniform blackness, and scoring it with a piece of coarse sandpaper so that the dynamic noise field consisted, not of randomly appearing points of light, but of straight line segments of various lengths (Fig. 13).

The experiment was then set up as before, and a few Ss who had previously participated in other experiments immediately before were invited to compare their impressions of the movement caused by the new noise field. All reports were unanimous; everyone saw the omega effect and estimated its velocity to be indistinguishable from its previous value. It was not thought necessary to carry the experiment further: the dominant factor involved in the perception of omega movement seems not to reside in the noise parameters.

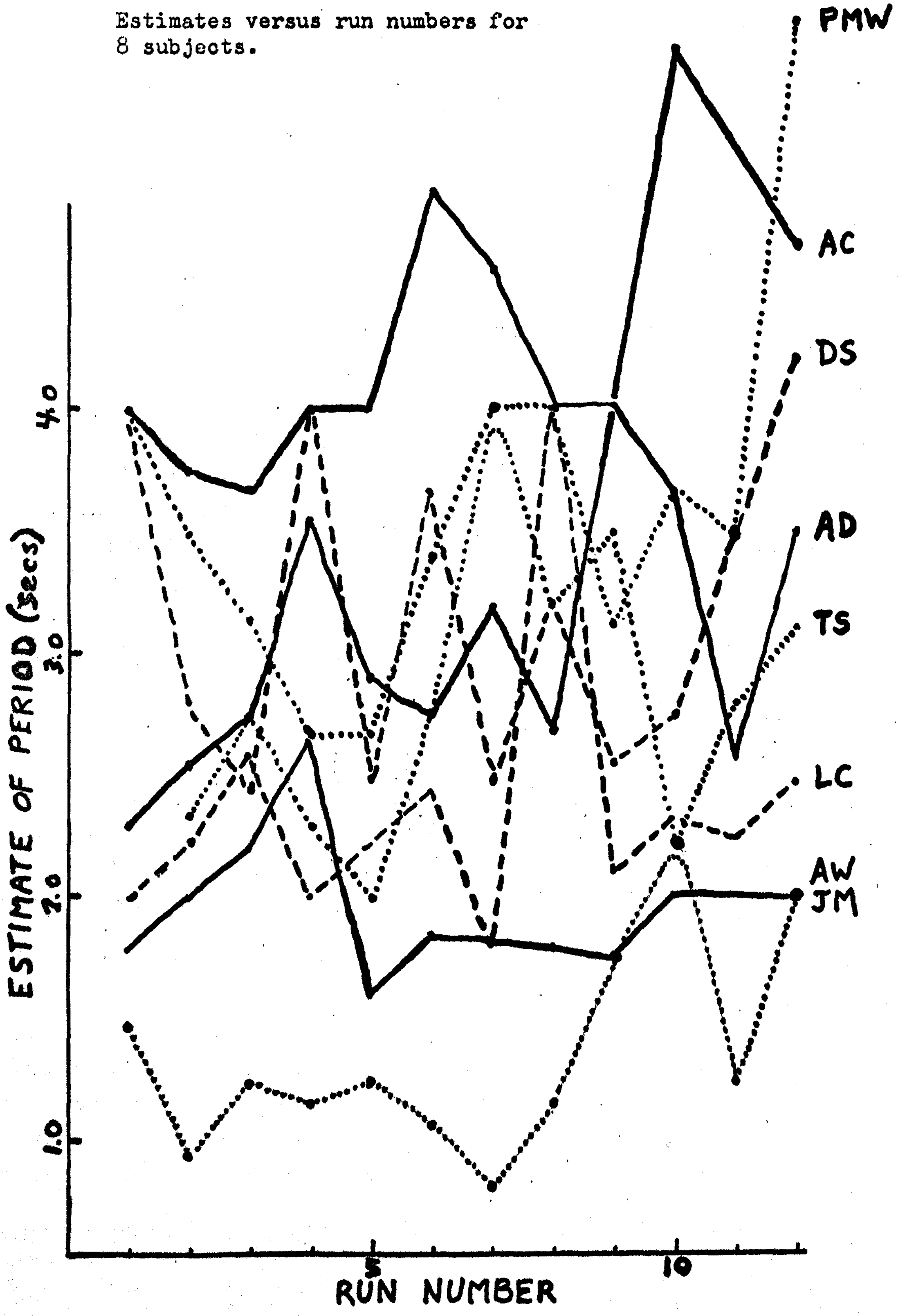
b) Parameters of the Observer.

viii) Inter-subject differences.

At an early stage of investigation, it was found that there exist marked differences between the means and variances of individual Ss. Some idea of the magnitudes of these differences can be obtained from Figure 14, which illustrates the mean and S.E. of the mean for 10 Ss, each seated approximately 10 feet away from an annulus of D=8", T=¼". Bartlett's test for homogeneity of variance indicates that the variance values differ significantly for these 10 Ss; the wide divergence of the values of the means

FIGURE 15:

Estimates versus run numbers for 8 subjects.



Subject:	PMW	AC	DS	AD	TS	LC	AW	JM
r :	0.45	0.69*	0.08	0.50	0.36	0.18	-0.17	0.58

*SIG. AT 10% LEVEL.

TABLE V: Correlation between estimates and run no.

Subject:	PMW	AC	DS	AD	TS	LC	AW	JM
$\bar{p}_1$ (secs)	3.23	4.05	3.23	2.80	2.42	2.25	2.01	1.17
$\bar{p}_2$ (secs)	3.98	4.67	3.11	3.26	3.14	2.49	1.88	1.52
$\bar{p}_2-\bar{p}_1$ (secs)	0.75	0.62	-0.12	0.46	0.72	0.24	-0.13	0.35

TABLE VI: Comparison of 1st and 2nd halves of experiment.

obviates a statistical test of their significance.

There is also to be found a high correlation between means and variances ($r=0.84$ $P<0.01$) which complicates the statistical analysis of the results. (For example, Bartlett's test is as sensitive to non-normality as to differences in variance (60), and correlation between variance and mean is generally an indication of departures from normality). Fortunately, Snedecor's F-test is relatively insensitive to skew, provided that the distributions being tested are skewed in a similar way: it can be used to confirm the inter-subject variance differences claimed above.

ix) Intra-subject differences.

There exist the possibilities that a) the pattern of responses of an individual S during a single experimental session shows a significant trend due to, for example, practice, adaptation or fatigue and b) the average value obtained from an S during one session differs significantly from values found during other sessions (long-term adaptation).

Four men and four women were each given twelve opportunities to estimate p for an 8" annulus; their estimates are plotted against the corresponding run number in Figure 15. About all that is obvious from this form of presentation is that there is wide variation in the estimates of an individual S. Correlation coefficients were calculated for each S, and are shown tabulated (Table 5).

Analysis shows that only one of the coefficients differs significantly from zero. Furthermore, when the 8 values are tested for homogeneity, it was found that they could all be considered as samples from a single population; their values were therefore pooled, giving $\bar{r} = 0.375$. This value is highly significant ($P < 1\%$) and we may conclude that, for this group, as an experiment proceeds, there is a small tendency for apparent rotation to slow down. This effect is demonstrated in Table 6, where, for each S, the mean value of his first 6 estimates is compared with that of his last 6. The net change is generally in the expected direction.

To confirm the above results, data obtained from other groups of Ss were subjected to the same analysis. Thus, another group of 17 Ss, who had the 8" annulus presented to them 4 times during the course of an experiment, showed a correlation of $\bar{r} = -0.15$ (N.S.) between their estimates and their respective run numbers. Yet another group (20Ss) showed the completely insignificant value of $\bar{r} = 0.07$.

It would seem, therefore, that whatever effect was causing the significant correlation obtained with the first group (where each S was required to give twelve estimates during the course of the experiment) has not yet had time to become established when S has only four estimates to make. It was decided to look at the distribution of correlation coefficients calculated from the estimates of Ss in the latter category, in the expectation of obtaining a mode at some small positive value of r. Accordingly, coefficients were found for 60 Ss participating in an experiment for the first time; these values were grouped in classes of width 0.25 and are shown plotted in Figure 16.

It can be seen that the results are the complete reverse of expectation. The curve obtained is clearly bimodal with a minimum in the vicinity of $r = 0$, and maxima at both large negative and large positive values of r.

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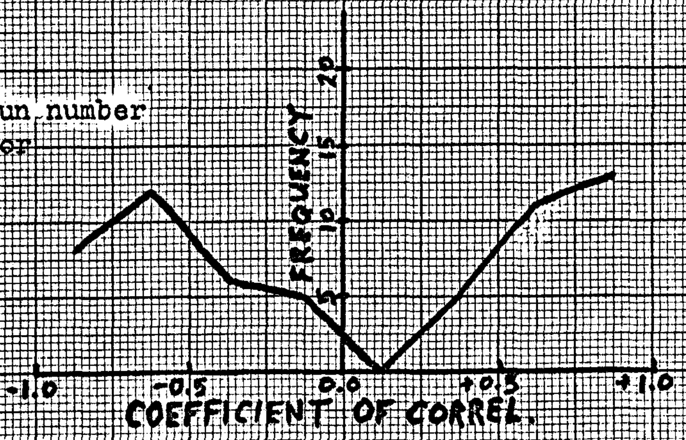


FIGURE 16 (right):

Distribution of estimate/run number correlation coefficients for 60 subjects.

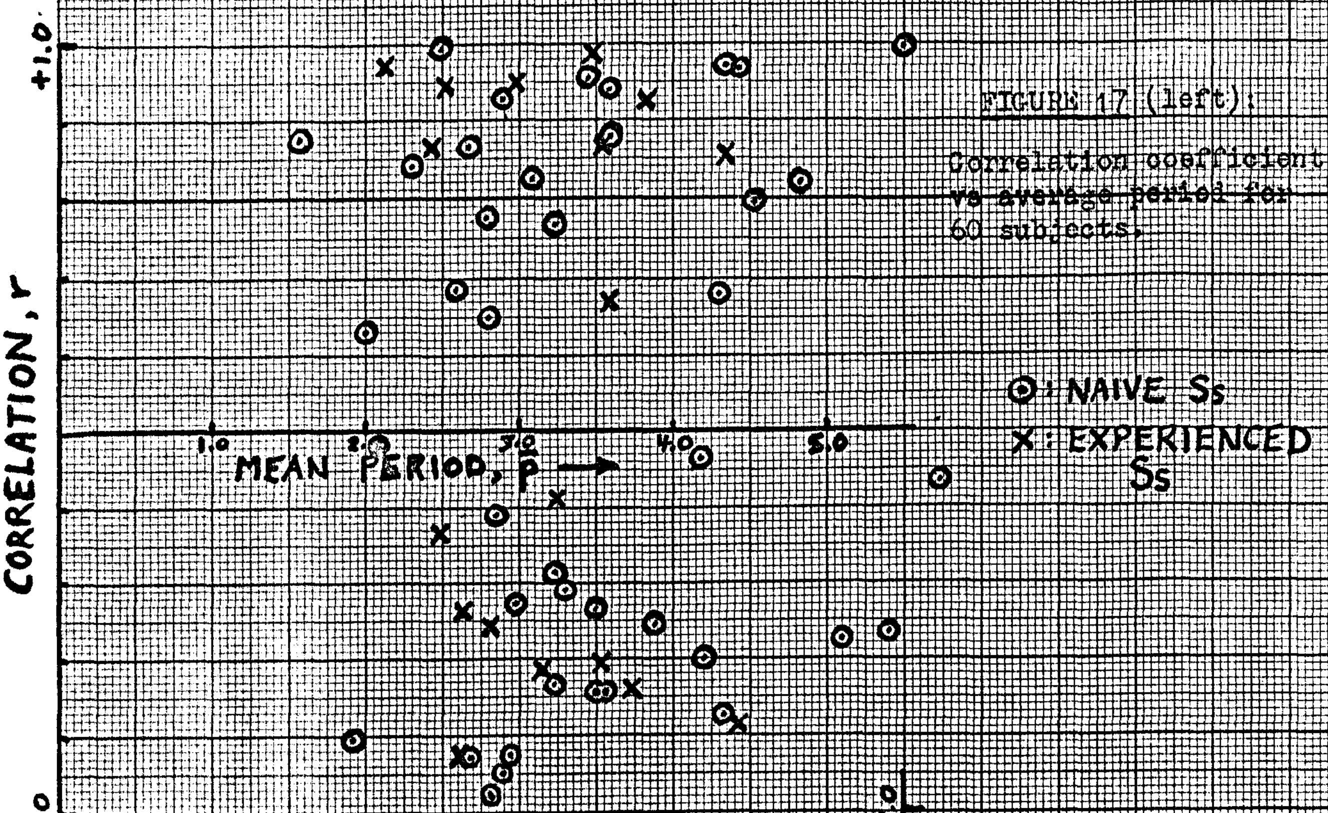


FIGURE 17 (left):

Correlation coefficient vs average period for 60 subjects.

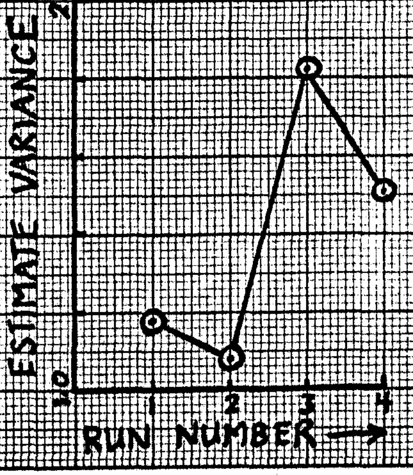


FIGURE 18 (right):

Variance vs Run Number.

Subjects divide themselves fairly evenly into two groups: those who give, on the average, progressively larger estimates of p as the experiment proceeds, and those who give progressively smaller estimates. There is no relationship between a subject's mean estimate of p, $\bar{p}$, and his correlation coefficient r (Fig. 17), as might be expected were group influences at work causing, for example, a S whose p-estimates were much higher than the group mean to regress towards that mean. As a further check of this hypothesis a test suggested by the following argument was carried out. If there exist either practice effects causing progressive convergence to a value of perceived velocity common to all observers or a general tendency for subjects to regress towards a group mean (because of, for example, group interactions) then the variance of all estimates made by all subjects should decrease as the experiment proceeds, reflecting the increasing unanimity of those estimates. Thus a comparison of the run variances of the estimates is well worth making. This has been done for the same group of 60 Ss in Figure 18. It can be seen that the trend is in a direction opposite to that predicted which again indicates that the factors mentioned play no large part in the determination of the rate of apparent rotation.

It might be noted that the large variance value obtained for run number 3 is significantly different ($P = 5\%$) from the estimate of variance obtained by pooling the other three values. This is a feature that was found in several of the groups tested, and could easily be due to boredom and consequent drifts of attention. The variance recovers somewhat at run number 4, perhaps because the end of the experiment is in sight!

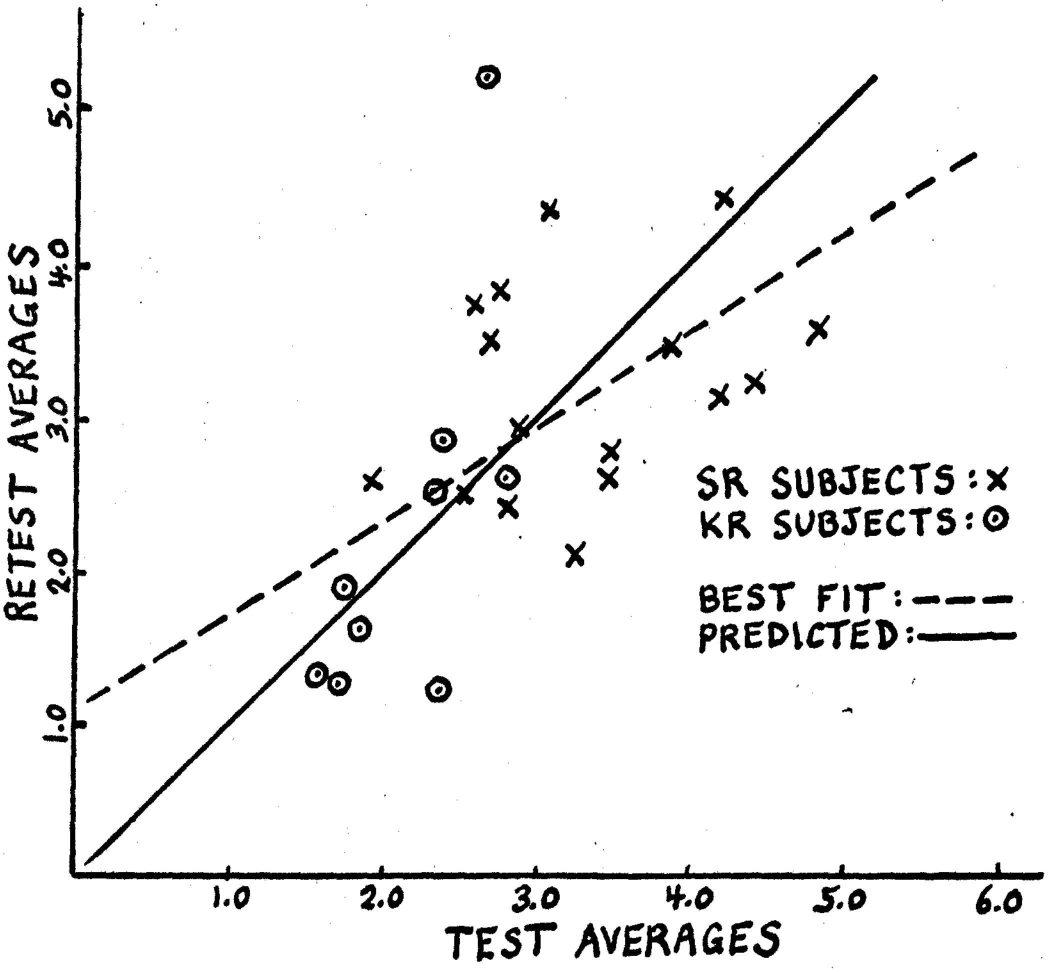


FIGURE 19:

Test/retest perceived periods for 8N Annulus and for two groups of subjects.

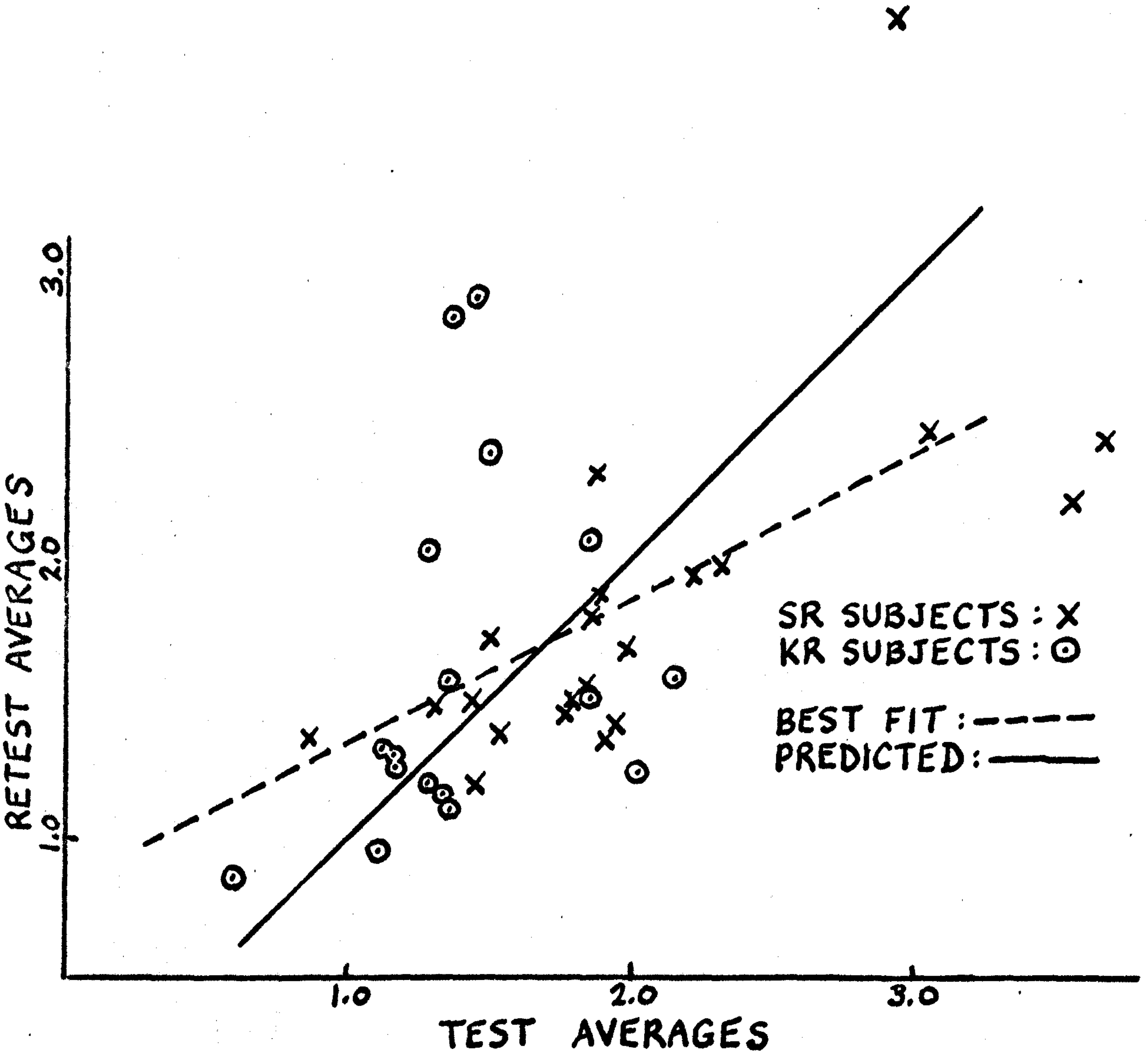


FIGURE 20:

Test/retest perceived periods for 3W Annulus and for two groups of subjects.

Note scale change from previous figure.

x) Long-term changes.

When subjects are given an opportunity to re-estimate the period of apparent rotation of an 8" annulus days or weeks after making their first estimate, it was found that, as a general rule, there was only a small correlation between test and re-test values, but that this correlation was not significantly dependent on the time elapsed between experiments. Figure 19 shows plotted values for 25 Ss, 16 of whom were retested only a day or two afterwards and 9 of whom were retested after a month or more. A least squares fit was made to these values and compared with the fit that would be expected were the results perfectly reproducible; both these lines are indicated in Figure 19, and it can be shown that the slope of the regression line is significantly different (P=1%) from that of the expected value.

It must be concluded that, although test-retest reproducibility is significantly greater than zero (for these 25 Ss, r=0.54), this reproducibility is modified by other factors in such a way as to cause regression towards a common mean value.

No significant difference exists between either the test-retest means, or their respective variances, indicating that no long-term practice or adaptation effects complicate the measurements for the number of presentations most commonly used.

Figure 20 demonstrates the same effect for a group of 39 Ss, 22 of whom were retested within two days after the first test and 17 of whom were not retested until a month later. The difference is that in this case the Ss' estimates were for a 3" annulus; data will be presented later to show that estimates for this size annulus and for a given S are much more consistent than for the larger annuli, that is, a S's variance is smaller in the former case. The test-retest correlation for the first group (retested 2 days later) was found to be r=0.71 (P=1%). This value is to be contrasted with the value r=0.29 (N.S.) obtained from the group retested after one month. The difference between these two values is just significant at the 10% level and so, since the groups are comparable in other respects, it may be concluded that, as time elapses, test-retest correlations become smaller until, after a month or so, Ss behave essentially as if they had not participated in previous experiments.

The exact process of this "regression to independence" has not been investigated, as a number of Ss sufficient for comparison purposes has not been retested after appropriate time periods. Indications are, however, that there always exist positive test-retest correlations even for periods of time up to 18 months and that these final values are reached within a few days of the first test, provided that each experiment is restricted to only a few (3 or 4) presentations of the stimulus. If more intensive training is given, correlations are, of course, higher, but any changes they might undergo with time is unknown.

It should perhaps be emphasized that the r-values calculated above are essentially measures of the amount of group "structure", a high value of r indicating that subjects tend to preserve their ranked positions within the group. As such, they would ordinarily be measures of both subject self-consistency and group stratification, and although these are to some extent interrelated, especially if the former is great, a high value of r would be obtained even if all Ss were biassed in the same direction, tending, for

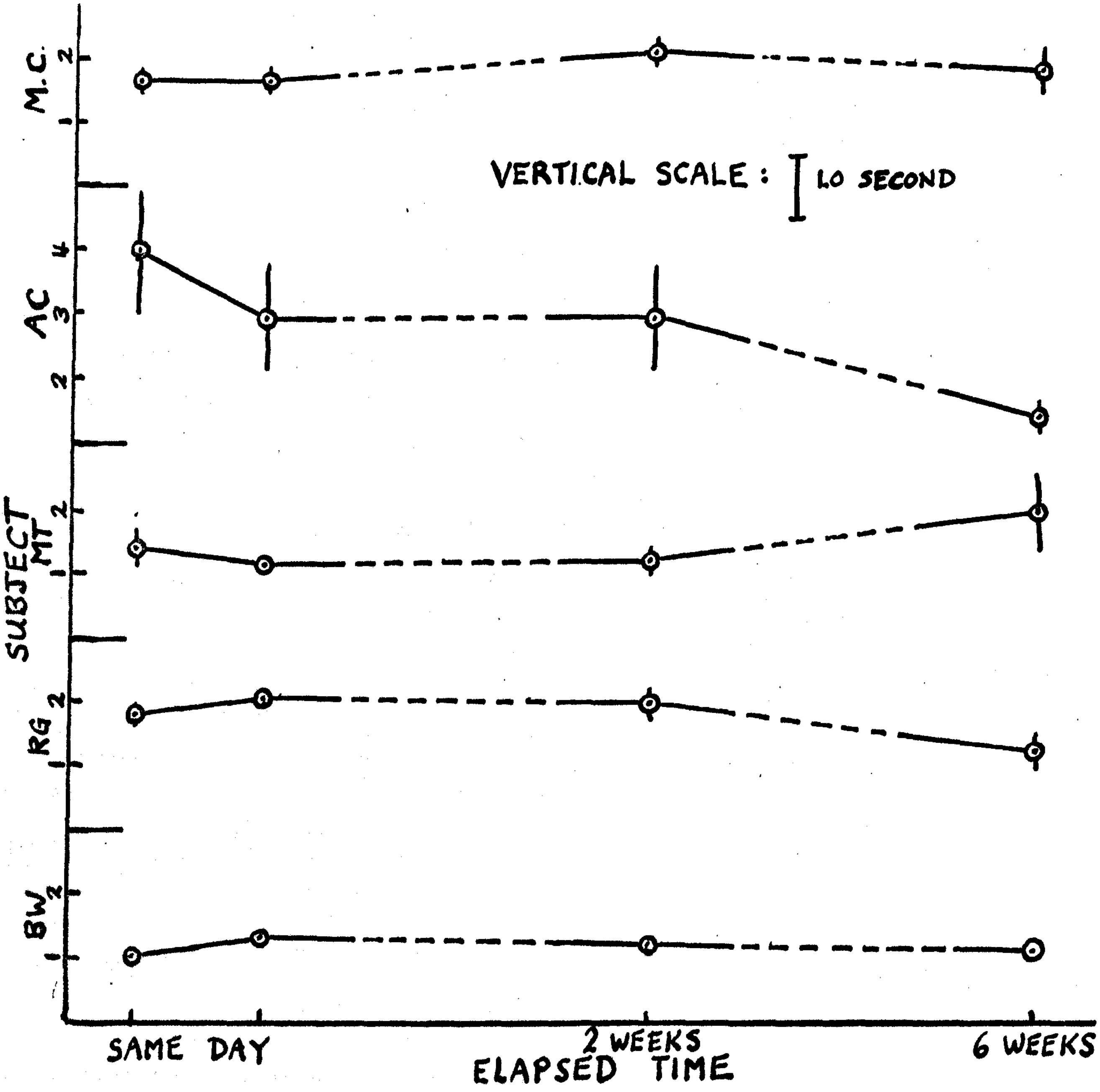


FIGURE 21:

Consistency of estimates. Estimates and mean deviations are plotted against time for 10 subjects.

example, to give progressively bigger estimates as time went on (provided that the biases were in the same direction and of about the same size). However, if we impose the restrictions that both means and variances of the groups are equal for the first (test) and second (retest) presentations, (a condition normally found in practice), then it can be shown that r is given by $r = 1 - \frac{1}{2} \sum (R_i - T_i)^2 / \sum (R_i - \bar{R})^2$.
where R_i and T_i are the retest and test estimates, respectively, of the ith subject and $\bar{R} = \bar{T}$ is the common mean value for all subjects. Thus r becomes a measure of the general consistency of the subjects under these circumstances, even though any given subject's results are equivocal due to his personal variance and the small numbers of estimates made during each experiment.

Figure 21 shows, for example, the means of estimates made on 4 observations of a 3" annulus by each of 10 Ss on each of 4 separate occasions during a six-week interval. It can be seen that both means and average deviations differ from time to time for a given S; however there is generally no reason to think that these values reflect significant changes.

xi) Short-term effects.

As has already been pointed out, stimulus presentations were randomized with respect to exposure time, that is, during the course of an experiment which involved the presentation of stimulus A six times, S would perhaps follow the apparent movement in A for 12 seconds during its first appearance, for 9 during its second, for 15 during its third, for 6 during its fourth, and so on. The question to be investigated in this section is that of the possibility of differences between estimates given for the various presentation durations.

Time Interval (Secs):	6	8	9	11	12	14	15
KJ30 (11 Ss)(A)	2.66		2.47		2.38		
KF10 (20 Ss)(B)		[illegible]	2.04		2.05		2.04
SJ9 (22 Ss)(C)		2.58		2.44		2.58	
Variances							
KJ30(A)	1.78		1.27		0.86		
RF10(B)			1.45		1.21		1.29
SJ9(C)		0.86		0.88		0.92	

<u>TABLE VII:</u> Comparison of Time Intervals

Three different groups of Ss were used, two of which, A and B, were composed of naive individuals, while the members of the third, C, had already participated in a previous experiment. Although four different presentation times were used in each experiment, only three of these could be matched on the basis of frequency of occurrence and stimulus homogeneity. The average estimate and variance for all stimuli and for all Ss, were then calculated for each of the three time intervals (Table 7). No significant difference was found between any of the mean values within a given group, and only one of the groups, A, showed any systematic trend at all.

It must be concluded that, for the purposes of this investigation, short-term adaptation or practice effects do not exist.

The variance differences between groups A and B, and group C is not an effect of convergence of the more experienced Ss; in agreement with previous findings, their group variance remained unaltered with practice. The difference most probably reflects the fact that a less varied set of stimulus-annuli was used with these latter subjects.

The extreme variance values found for group A are, however, significantly different ($P < 1\%$), even though their corresponding means are not, and the values obtained from group B, although not significantly different, show a tendency to decrease as the time interval increases. A possible reason for this change will be discussed in the next section.

xii) Distribution of errors.

It was usual to find that a subject occasionally found himself unable to make an accurate estimation of the number of apparent rotations he saw, because of shifts of attention, reversals of the movement, miscounting and

Group	H_1	p_1	H_2	p_2	Totals	H_{1p}	H_{2p}	Σ_p
A (11)	25	0.66	13	0.34	38	22.4	16.8	39.2
B (20)	51	0.63	30	0.37	81	40.6	30.7	71.3
C (22)	22	0.47	25	0.53	47	44.8	33.7	78.5
D (16)	42	0.53	38	0.47	80	32.5	24.5	57.0
Totals:(69)	140	0.57	106	0.43	246	140.3	105.7	245.0

TABLE VIII: Errors made during first and second halves of experiment.

H_1: first half p_1: proportion of errors made in first half
H_2: second half p_2: " " " " " second half
H_{1p}: predicted errors in first half } based on $\frac{246}{69} = 3.56$ errors/subject
H_{2p}: " " " second half

so forth. Some estimates, as indicated by Ss' comments, were based on extrapolations from those complete revolutions actually seen, and it is to be assumed that sometimes suspect reports were made without an indication of their unreliability being made in the "Comments" section. It is of interest to check the distribution of the suspected errors actually reported, to see if there is any systematic trend which might indicate the effects of, for example, practice or boredom. A response was considered "suspect" if 1. S reported his own suspicion in his "Comments" 2. an estimate was not made at all, the corresponding space in "Revs/interval" being left blank or 3. an estimate made was of such a size that it resulted in the calculated value of p being equal or greater than 7.0 seconds. (This last criterion is perhaps overly generous; by Chauvinet's Criterion of Rejection, a value p may be omitted if $|p-\bar{p}|/\sigma \geqslant 2.8$ (for $\bar{p}$ based on 100 estimates). Since typically $\bar{p} \sim 2.5$ seconds and $\sigma \sim 1.0$ seconds we may ordinarily reject a value p if $p \geqslant 5.3$. The extra allowance was made to decrease the danger of rejecting a p belonging to, perhaps, a secondary maximum occurring at a larger value of p.)

When all errors from these three sources were counted for a given group, it was found that, for the case of single stimuli, there were not enough errors to make differences significant, particularly for the more regular, simple circular annuli. Therefore the results for all stimuli were pooled, and the number of errors made during the first half of the experiment compared with the number made during the second half (Table 8). The null hypothesis of no difference between the first and second halves of the experiment was tested for four groups, the first three of which, A, B & C, participated in Experiment xi) and the fourth, D, being composed of 16 additional naive subjects. This hypothesis was confirmed for groups C and D, but A and B showed significant differences ($P < 10\%$) between the two half-experiments. A test was also made of group differences, basing the null hypothesis on a figure of $^{246}/_{69} = 3.56$, the average number of errors per subject. It was found that the groups differed significantly, mainly because group C was responsible for many fewer errors than expected and group D for many more. C, it should be remembered, was composed of experienced Ss, while the other groups were not.

As a general conclusion, therefore, we may say that naive Ss tend to make fewer errors as the experiment proceeds and that experienced Ss, while not showing this tendency, do make fewer errors during an experiment. The mean number of errors per naive S is almost twice as great as that per experienced S.

Knowing this tendency for naive Ss, we can attempt to explain the large variance value found for the six-second interval of group A in Experiment xi). Checking the sequence of time-intervals used for this group, it was found that, by chance, and in contrast to the other groups, 4 of the 6 times the six-second interval was used fell in the first half of the experiment, and that a fifth fell just at the beginning of the second half. On the other hand, 4 of the six times the twelve-second interval was used fell towards the end of the second half. Thus, if a higher number of errors (presumably indicating a higher level of difficulty) is associated with a greater variance, we would expect to find what was actually observed.

A difficulty with this explanation is that, if the general tendency is the only factor operative, we would expect to find significantly more errors made during the six-second interval, for this group, than for the twelve-

	Time Interval (secs)			
Group	6	8-9	11-12	14-15
A	11	12	10	
B		18	24	22
C		9	20	18

TABLE IX: Errors by Time Interval

second interval. In fact, this is not found; to the contrary, the number of errors made during a given exposure-time increases with that exposure time, although not to the same extent in A as in B and C. (Table 9).

xiii) Effect of E's suggestion on w-movement.

It has been shown in previous experiments that there exists a fairly wide range within which an individual S place his estimates of the rate of apparent rotation. Within this range, an experience S tends to base his estimates on those he has made in the recent past, indicating that expectation or "set" is exercising some influence on his judgements. The question to be answered in this experiment is whether E can influence the estimates of his subjects by making overt suggestions as to the velocity of the apparent movement he is about to show them.

Two groups of naive Ss were used; each was composed of 10 Introductory Psychology students who had never before seen the phenomenon to be investigated. Six different stimulus-annuli were chosen and their presentation randomized in the usual way. The ordinary instructions were given and, in addition, group F was informed that the period of the motion about to be seen was, for most Ss, about 2 seconds (i.e. the approximate mode for uninfluenced Ss). E emphazied this point by tracing his finger around the annulus for a few revolutions: "About this speed". Group S was given similar instructions and demonstrations, but the period they were told to expect was of the order of 4 seconds. It was not thought advisable to use a wider range for fear of making the discrepancy between expectation and observation so large as to arouse Ss' suspicions. Since estimates as low as 2 seconds or as high as 4 are not uncommon, even for the same S at different times, this complication should not be involved.

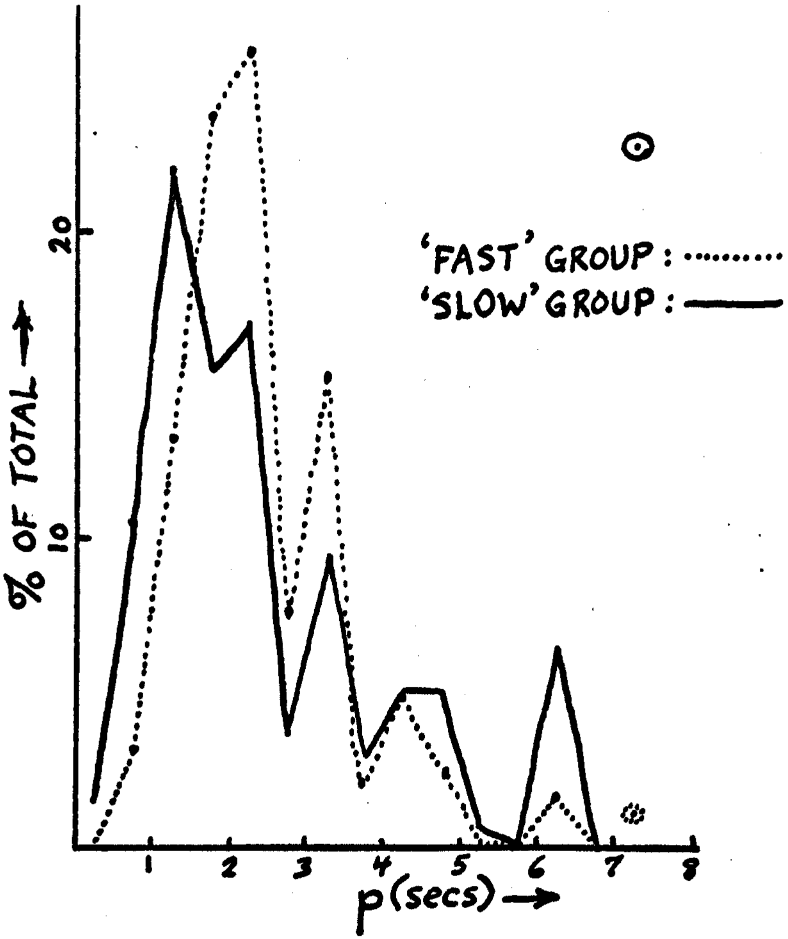


FIGURE 22 (right):

Effect of instructions. Distributions of 'Slow' and 'Fast' groups are compared.

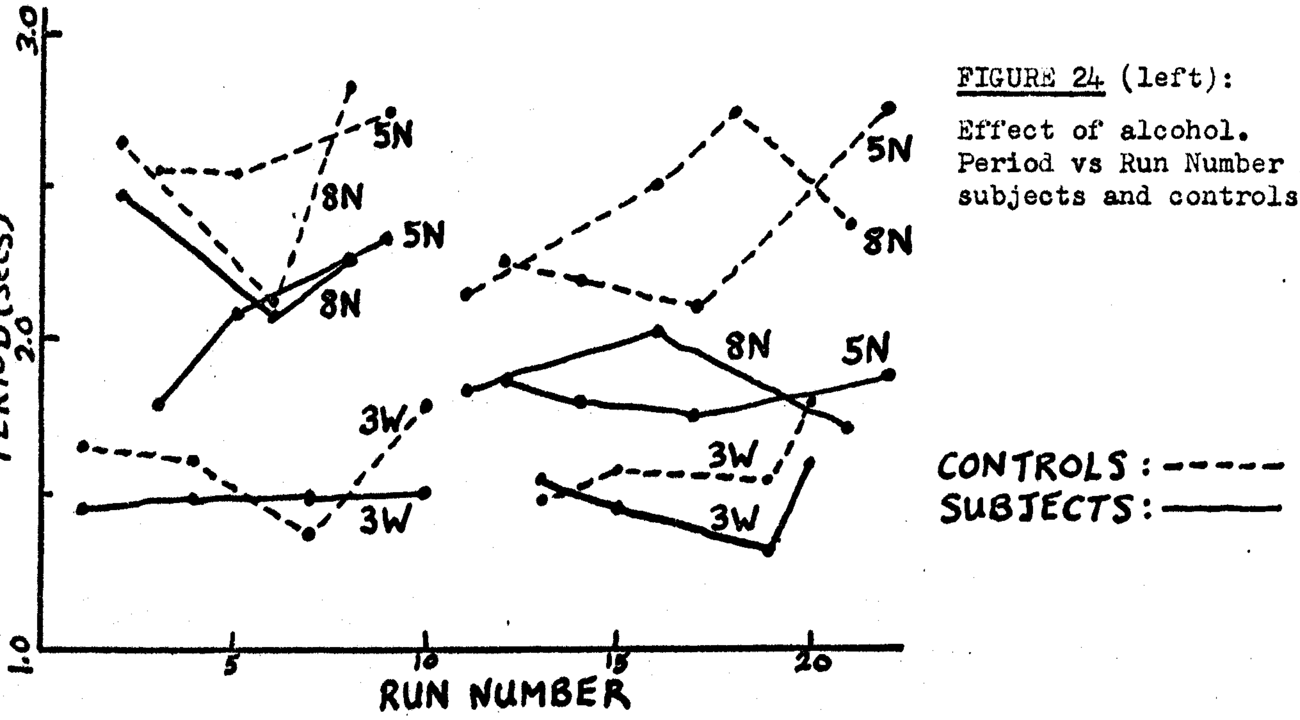


FIGURE 24 (left):

Effect of alcohol. Period vs Run Number for subjects and controls.

STIMULUS:	8N		8NB		5N		3W		OCT		Sq	
GROUP:	m	s^2	m	s^2	m	s^2	m	s^2	m	s^2	m	s^2
S	2.52	1.42	1.70	1.21	2.56	2.24	1.72	0.95	3.39	3.59	2.75	3.06
F	2.56	1.24	2.80*	1.16	2.04	0.32*	1.53	0.31*	2.96	0.91*	2.77	0.93*

GROUP	TOTAL		
	m	s^2	n
S	2.445	2.34	136
F	2.398	1.07*	189

*SIG ($P < 1\%$) wrt corresponding S value

TABLE X: S vs F Groups.

m : mean (seconds)
s^2 : variance
n : no. of responses

The distribution of responses for all stimuli is shown in Figure 22. Contrary to expectation, it appears that, on the whole and except for concentrations of responses at larger periods, group S tends to see faster rates of apparent movement than group F. There are two possible signs of the effects of group S's instructions: a significantly larger distribution variance, and a very much larger proportion of "errors" (according to criteria already mentioned). The latter proportions, for comparison, are plotted against p=7.25 in Figure 22.

When the means and variances of the p-distributions for the two groups and for the six different stimuli are compared it is found i) that differences in mean values are not significant (with the exception of stimulus 8NB) but ii) that differences in variances generally are. (Table 10). Furthermore, variances of the S group are always larger than their corresponding F-group values, while mean values are sometimes larger and sometimes smaller. If the results for all stimuli are combined for each group, there is no significant difference in mean values, but the s-group is subject to a larger variance.

We may conclude that expectation has a negligible effect on the group mean; its effect does, however, induce Ss to make a larger number of errors, with an associated increased variance of the estimates actually given. If these two measures are connected, as seems most likely, and if their size is an estimate of the difficulty of the task to be performed, the results agree with the hypothesis that Ss find it more difficult to make an estimate if their expectation is not in accord with what they would normally report without being influenced by E.

xiv) Effect of the group situation.

Since the large majority of the experiments performed was with groups of Ss, some of whom presumably know each other well, it is necessary to know the extent to which one S is able to influence his neighbour. In experiments of this type individuals are often influenced by the judgments of others (61, 62, 63), and although the experimental conditions were such as to preclude gross interactions (semi-darkened room; estimates made in silence), still some Ss indicated the rate of the movement they saw by following it with visible hand or head motions. Furthermore, when the experimental room was small and the number of Ss large, they inevitably were positioned closely enough to each other to make interactions a real possibility (not to mention conscious cheating!)

To see if any such effects were present, the members of a group were listed, along with each's average estimate $\bar{p}$ of the period of one of the annuli used. Each subject's neighbour was then determined from the records, and the neighbour's average estimate of the period of the same annulus was then paired with the subject's. For the purposes of the investigation, each subject's neighbour was taken to be the subject on his immediate left; if there was no subject here, "neighbourship" reverted to either the subject on his right, or to the nearest subject in front, whichever was the closest. Thus two lists of p-estimates were obtained, the second consisting essentially of a re-distribution of the first.

If the latter were a completely random re-distribution, we would expect the coefficient of correlation r_{SN} between the two sets of estimates to be zero, and any deviation from this value must be taken as evidence of

Group	No of Ss.	Ss' Average & Variation		Neighbours' Average & Variation		Correlation (neighbours)	Correlation (non-neighbours)
		m_S	s_S^2	m_N	s_N^2	r_{SN}	r_{SNN}
A	16	3.04	0.74	2.97	0.63	0.210	-0.004
B	14	2.25	1.06	2.51	1.62	0.215	-0.098
C	20	1.85	0.70	2.02	0.91	0.222	0.063

TABLE XI: Proximity Effect.

non-randomness of the pairings, that is, of subjects influencing one another. The correlations calculated for three groups of subjects, along with other data, are shown in Table 11.

Although the analysis was performed on the results of a different stimulus-annulus for each group (in the hope of finding a level of susceptibility to influence which was sensitive to task difficulty), all three r_{SN} are very close to the same value. None are significant, however, because of the low number of Ss in each group. The values r_{SNN} were computed for subjects and randomly chosen non-neighbours; they tend to be smaller than the r_{SN}, as is to be expected.

If the three r_{SN} are combined, they result in $\bar{r}_{SN}$=0.216 which is just not significant at the 10% level (P=13%). It is probable, however, that the significance of this result should be amended by the reports made by Ss when questioned after the experiment: several admitted that they were in fact influenced by others, particularly when the found difficulty in making their own estimate. All things considered, it seems likely that the group situation does slightly modify the responses of individual Ss.

xv) Dependence of estimates on preceding estimates.

It has been shown that various external influences can affect S's estimates of the omega effect to a small degree and that S also carries over a certain degree of similarity from day to day. The latter effect can be interpreted in two ways: either it is a straightforward reflection of a tendency to base estimates on a more or less invariant, and probably innate standard (MacKay's "standard of angular velocity"), or the similarity is due to the fact that S bases his estimates on his memory of estimates he had made

FIGURE 23:

Name: John. W. SALT [illegible]
Age: 22
Date: 8th July 1964 Time: 5:45 pm.

Eyesight: L: R:
EEG:
B.M.R:

Run	Revs/interval	Time interval	secs/rev	Angular Subtense	Comments STIM.
1	4½	8	1.78	8°30′ ⑥	⑧ 1.78 ±0.21 (3)
2	9½	11	1.16	3°10′ ⑦	
3	8	14	1.75	5°20′ ①	
4	9	14	1.55	3°10′ ④	3N
5	2	5	2.50	8°30′ ⑪	8W
6	4	5	1.25		
7	4	8	2.00	5°20′ ⑧	
8	3¾	11 × 4/15	2.94		
9	5	11	2.20		5N
10	7	14	2.00		8W
11	4	8	2.00		
12	7½	11	1.47		5W
13	5½	11	2.00		8W
14	6½	8	1.23		
15	4½	14	3.11		
16	3	5	1.67		3N
17	2½	8	3.20		8W
18	7½	14	1.87		
19	7	11	1.57		
20	1¾	5 × 4/7	2.86		
21	10	14	1.40		
22	4½	8	1.78		

previously. These interpretations are not mutually exclusive; it could well be that S's estimates are indeed based on an innate standard (with presumably a certain associated range of selective sensitivity, analogous to those found for directional and velocity-sensitive receptive fields in the rabbit (38, 39) and frog (36, 64)) but that the exact position in the range is to some extent adjustable by influences of the second type.

The effect of immediate memory is to be tested in this experiment. The results of 48 Ss, who, as a whole,,showed no significant tendency to either increase or decrease their estimates during the course of the experiment, were analysed in the following way. Each S had been required to make 4 estimates of the period of stimulus 8W; each presentation of 8W was, of course, preceded by the presentation of another stimulus-annulus, generally each time of different dimensions. A typical series of responses is shown in Figure 23; E's calculations are also indicated, as are the positions of the estimates here of interest.

The estimated periods of those stimuli immediately preceding 8W are, successively, 1.55, 2.20, 1.47 and 1.67 seconds. Of these the second and fourth are larger than the first and third. The responses to the 8W stimulus were now divided into two groups - the S group, preceded by small estimates, and the L group, preceded by relatively larger ones. In the present example, 2.50 and 2.00 seconds would be assigned to the S group, and 2.00 and 3.20 seconds to the L group. This procedure was carried out for all 48 Ss; each of their estimates was assigned to one or the other group according to the magnitude of the immediately preceding estimate.

(a) Group	n	$\bar{p}$(secs)	s^2	(b) n	$\bar{p}$(secs)	s^2
S	80	2.70	1.17	80	2.69	1.33
L	80	3.01	1.28	80	2.84	0.94
M	17	3.22	1.54	17	3.28	1.81
Immediately prec. stim.				Second preceding stim.		

<u>TABLE XII</u>: Effect of preceding stimuli on estimates of 8W

$\bar{p}$: average period of 8W annulus
s^2: variance
n : number of estimates

The hypothesis to be tested is that there will be a difference between the means of the S and L groups, and that that difference will reflect an effect of expectancy similar to those already found under different circumstances, i.e. $\bar{p}_L > \bar{p}_S$.

Table 12(a) shows the results. The difference between $\bar{p}_L$ and $\bar{p}_s$ is in the expected direction and is significant (P = 7.5% for a two-tailed test). The entries in the table opposite N are based on those estimates made which are not immediately preceded by another estimate; since these cases are more likely to occur for subjects who find the measurement task difficult, and since there exists some evidence that these Ss often give larger estimates on the whole, it is not surprising that $\bar{p}_N$ is larger than the other averages.

To see how long the memory of a response is able to affect succeeding responses, the same analysis was performed on the estimates of stimulus 8W and the second preceding stimulus, i.e. the ones immediately preceding the ones treated above. The results of this analysis are shown in Table 12 (b); none of the differences between the S and L distributions are significant, although the difference in means which does exist is in the same direction as before.

The conclusion must be that S's estimates are influenced to some extent by the stimuli he has previously seen, that the influence of the immediately preceding stimulus is small, and that the influence of the rest, individually at least, is negligible.

xvi) The effect of objective movement.

Both MacKay and Wilson have reported that omega-movement is to some extent variable, although MacKay would prefer to reserve the term "Omega" for the upper limit to which apparent movement can be driven by, for example, eye movements. The question still remains: can objective movement condition the period of apparent movement seen simultaneously?

A small projector was built, consisting of a 6.3 volt bulb and condenser lens, in such a way that it was light enough to be attached, at an oblique angle, to the shaft of a variable-speed motor. The motor itself acted as one of the connections to the light bulb, while a sliding brush completed the circuit. The apparatus, when started, thus acted as the source of a spot of light following a circular path, the diameter of which could be adjusted by varying the obliquity of the angle between the projector axis and the shaft of the motor. The intensity and size of the spot of light were then set so that the latter could be easily observed even amongst random visual noise, and a circular annulus was then positioned so that the spot, amongst the noise, was always visible in the channel during a full revolution.

Ss were a group of 15 volunteers who were given the usual instructions. It was explained that they would also see an actual revolving spot of light, and that they would be later invited to compare the speed of this light with that of the apparent movement. At no time during the experiment were they permitted to see apparent movement in the absence of objective movement. Three different objective velocities were used, having periods of 5.0, 1.0 and 0.3 seconds.

Results are tabulated in Table 13. The motion of the spot of light is seen to have no significant effect on Ss' estimates of the period of apparent movement. Eight of the Ss participating in the experiment were retested on a subsequent data (which was a sufficiently long time afterwards to prevent

Period of rev. (secs)	$\bar{p}$ (secs)	n	o^2	Number in group
5.0	2.97	26	0.88	15Ss
1.0	3.19	30	1.21	15Ss
0.3	3.00	27	0.96	15Ss
Retest (No movement present)	3.03	27	1.06	8Ss

TABLE XIII: Moving spot of light in annulus

SUBJECT	1	2	3	4	5	6	7	8	9	10	11	12	Mean	Variance
Pref. rate (secs)	5.0	1.9	1.3	2.5	1.2	4.3	1.5	2.0	5.0	4.2	5.7	3.3	3.16	2.42
p (seconds)	3.0	2.0	1.9	4.0	4.3	3.0	4.0	3.5	5.2	3.0	2.3	2.8	3.25	0.90

TABLE XIV: Preferred rates and w-movement them from using their previous estimates as standards) and, as a group, showed no change in their mean estimate, nor does this mean differ significantly from those often found under normal experimental conditions.

Several Ss reported, however, that for the higher objective speeds at least, apparent movement tended to be seen in the opposite sense, that is, if objective velocity was counterclockwise, apparent movement tended to be clockwise, and vice versa, although reversals still took place either spontaneously or voluntarily.

xvii) Correlation with "natural" velocity.

Much evidence has been presented in support of the notion that Ss' basic physiological processes can influence their performance on various grouping and time estimation tasks. Miles (65) found that each S established his own preferred range of free tapping rates, some showing much less variation than others, and that within this range, much like the present experiments, the immediately preceding performance could exert an effect. Seashore (66) had previously tested 117 Ss, with similar findings, and Miyake (67), who instructed his Ss to tap irregularly about 100 times, reported that they invariably reverted to periods of regular tapping. Koffka (68) performed similar experiments with light flashes, and found, unlike the case for sounds (69, 70) no definite correspondence between rate of stimulus presentation, and the ability of Ss to group them in various ways (that is, preferred rates were invariant within their ranges).

More, recently, Baddeley (71) has adduced more evidence to Hoagland's "chemical clock" hypothesis (72), whereby such measures as time estimation and preferred rates of response are subjected to an internal standard, based probably on the velocity of a continuous chemical reaction in the nervous system (although other factors, such as sensorimotor activity, may modify the "clock's" speed, and hence subjective time). Experiments in test of Hoagland's qualification have, at least in so far as a wide range of variables are concerned, proved negative (73, 74), perhaps, in view of the chronic nature of most of the factors involved in these studies, not surprisingly so.

In view of these results, it is relevant to ask whether the velocity of omega-movement is connected with any preference Ss might exhibit for the speed of objective rotary movement.

Twelve naive Ss were asked to adjust the speed of the motor of the apparatus described in the preceding section until they considered that the speed of the revolving spot of light was, for them, "most satisfactory" and such that it could subsequently be easily reproduced "for comparison purposes". After they were satisfied with their setting, and the speed recorded, the revolving projector was turned off and, the usual instructions given, random visual noise played on the annulus instead. Estimates were then obtained of the period of omega-movement. (Table 14).

Although differences between the means and variances of the two measures are not significant, indicating that, on the whole, preferred rates of rotation occur in the same range and are about the same magnitude as rates of omega-movement, there exists no correlation between paired values (r=0.007 N.S.). Thus it cannot be concluded that a given S's preference for, say, a relatively high rotational velocity will be reflected in his estimate of omega-movement.

If, as was hoped, omega-movement can be considered as a correlate of some intrinsic sensitivity to a particular angular velocity, then Ss' own preferences (at least for a single revolving spot of light) do not accurately reflect this sensitivity.

An analogous result was obtained by Gahagen (75) in a study of visual efficiency as measured by dominance-acuity relationships (so that maximum visual efficiency occurs in S's preferential use of whatever eye has greater acuity). Gahagan found that 27% of his Ss showed minimal visual efficiency, and that of these some could as much as double their efficiency by shifting their eye dominance.

xviii) Effect of alcohol.

It is known that various drugs can affect subjective timing, the general rule being that stimulants (thyroxine, caffeine, metamphetamine), which accelerate vital functions, lead to overestimation of time intervals, while depressants (pentobarbital, nitrous oxide) have the reverse effect. (76, pp. 228-30). Certain drugs can also influence the thresholds of apparent movement (77). As far as alcohol is concerned, it is probable that moderate doses act as a stimulant, while larger doses are depressants (12, p.38). Ikeda (78) also found that therapeutic doses caused changes in the human E.R.G. normally characteristic of dark adaptation (increased amplitude of the b-wave, with decreased rise and recovery times).

Since the larger doses necessary for depression were inappropriate (or inadvisable!) for the experimental conditions here of interest, and since the precise parameters of alcohol metabolism obtaining were not available, only a crude test was possible. The alcohol was provided in the form of a standard "double whisky" (two English measures = approx. 40 ccs and contains abou 14 ccs pure alcohol) administered to the experimental group over a period

	Stim:	3W	5N	8N	ALL
Controls:	1st	1.63	2.60	2.56	2.199
	2nd	1.60	2.32	2.43	2.120
Expmtls:	1st	1.58	2.16	2.34	1.981
	2nd	1.54	1.92	1.95	1.802

TABLE XV: Alcohol Experiment: 1st and 2nd half mean values.

of 10 minutes.

Subjects were 9 observers who had already experience the illusion; five additional observers, who disliked whisky, acted as controls. Three different stimulus-annuli were used, and all members of the group were initially required to make 3 or 4 estimates of the period of each. Those acting as subjects were then given alcohol and the experiment was continued.

Results are shown in Figure 24 and Table 15. The former indicates how the average estimates, for both control and experimental groups and for all three stimuli, varied over the course of the experiment. The table compares the mean value of all presentations of each annulus during the first half of the experiment with that obtained during the second half, i.e., after the experimental group had ingested 14 ccs of alcohol.

It can be seen that all second-half averages are less than their corresponding first-half averages, but none of these differences are significant. Furthermore, even the control group reflects this change, although this, as inspection of Figure 24 indicates, might easily be an influence of group participation. In spite of some Ss' reports that apparent movement seems faster and more easily followed after ingestion of alcohol, no essential change occurs in the estimates of either these Ss, or of the group as a whole (although a plot of the standard error of the mean as the experiment proceeds (Fig. 49) shows that this measure tends to decrease - more than likely another indication of group interactions). None of the changes found are without parallel in previous experiments on the same Ss or on different ones, and it must be concluded that small amounts of alcohol do not effect the perception of omega-movement (although group interactions might easily be enhanced!).

This finding confirms that of MacKay (private communication), who also used moderate doses.

xix) Sex differences.

It was early noticed that of those Ss who gave consistently large estimates of p, a higher proportion of women than of men was involved. Sex differences are fairly unusual in perceptual tasks. Those found by Witkin et al. (78) in their studies of the interactions between S's orientation and his perceived vertical, and reaction time differences in favour of men (79, 80), can be explained in terms of muscular and/or environmental differences between the sexes. The latter can probably also be invoked to account for Fraisse and Vautrey's finding of a stronger Vertical-Horizontal illusion for women than for men (81). As the authors themselves point out, men are generally superiorto women in factorial studies involving the aptitude for mental manipulation of spatial figures. Their finding that sex differences were abolished for men and women of scientific background further implies an environmental effect.

No sex differences are obtained in experimental studies of the phi-phenomenon thresholds (52, 82), and those obtained in various investigations of judgements of duration are non-existent (83, 86) or conflicting (84, 85).

Fairly well authenticated differences do exist in male/female E.E.G. records, a greater amount of low voltage fast activity (β- rhythm) being found in women than in men, with correspondingly low alpha indices (87, 88, 89). When various measures of alpha activity (frequency, amplitude, index) are correlated with apparent movement thresholds, Sugarman (52) finds significant sex differences between the coefficients: for males, high alpha amplitudes and indices are associated with thresholds at high flash frequencies, while

FIGURES 25 to 28:

Comparison of estimates made by males and females for various annuli.

FIGURE 25

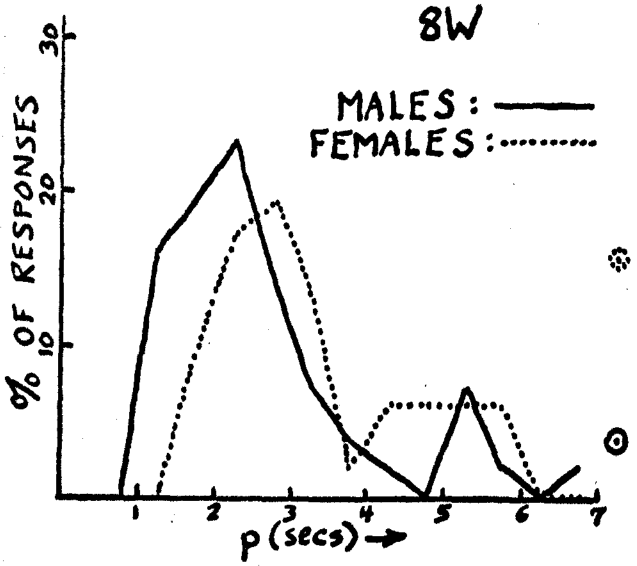


FIGURE 26

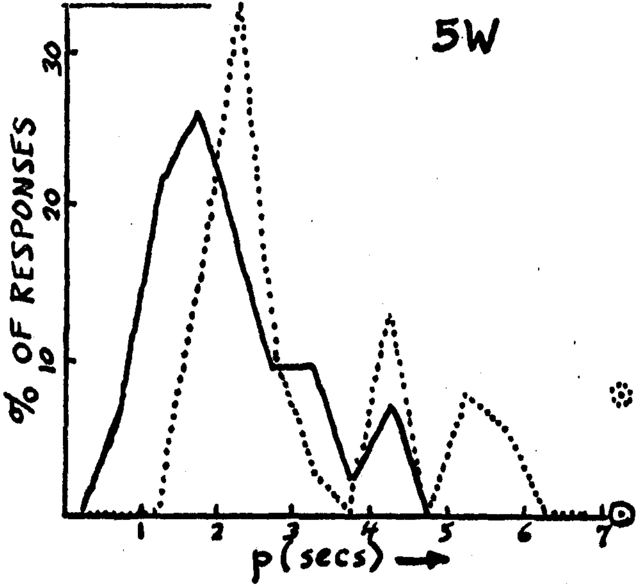


FIGURE 27

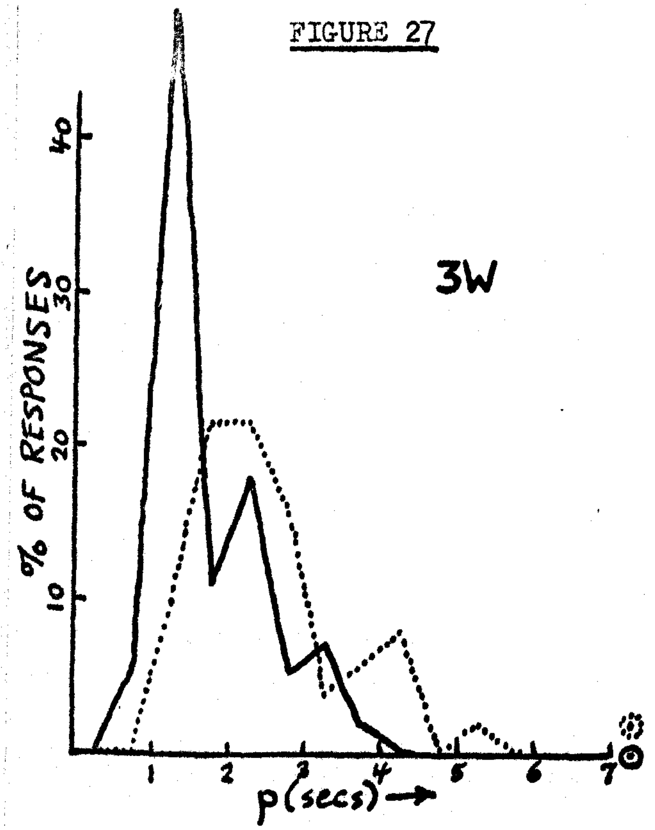
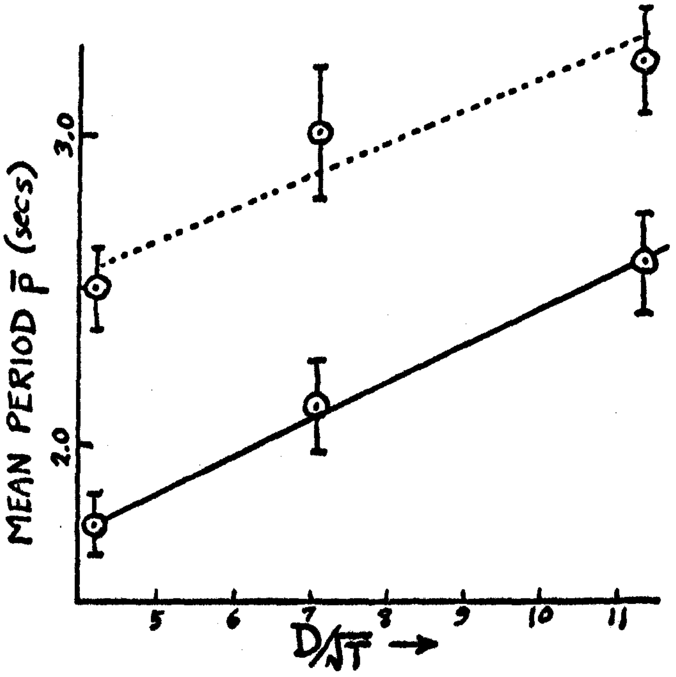


FIGURE 28



for females the reverse is true. This difference she attributes to a higher level of cortical excitability in the female. Barthol (90) reports a similar difference between male and female correlations when the variables compared were the movement-simultaneity threshold for the phi-phenomenon and the amount of kinesthetic figural after-effect. In this case, 20 male Ss gave a correlation of +0.58, while for 20 female Ss the value was -0.61.

Thus sex differences as far as perceptual tasks are concerned are not often reported, even in cases where environmental factors are not likely to be involved, and it was thought well worth while to follow up the indications mentioned in the first sentence with a controlled study.

Thirteen women and fourteen men were presented with a selection of annuli and required to make estimates of p in the usual way. Frequency distributions for some of the annuli are shown in Figures 25, 26 and 27. The mean values for each stimulus and for each group were also calculated, and are shown in Figure 28 plotted against a stimulus "form factor" $^{D}/\sqrt{T}$,* which often linearizes average estimates of annuli in the range,most often used.

The differences between corresponding means for the two groups are all significant ($P < 5\%$), and it is concluded that there exists a real sex difference in estimates of the period of omega-rotation.

It can be further shown that this difference persists for both naive and experienced Ss whether tested in groups or individually, indicating that the effect is not appreciably modified either by group interactions or by practice.

xx) <u>Effect of fixation.</u>

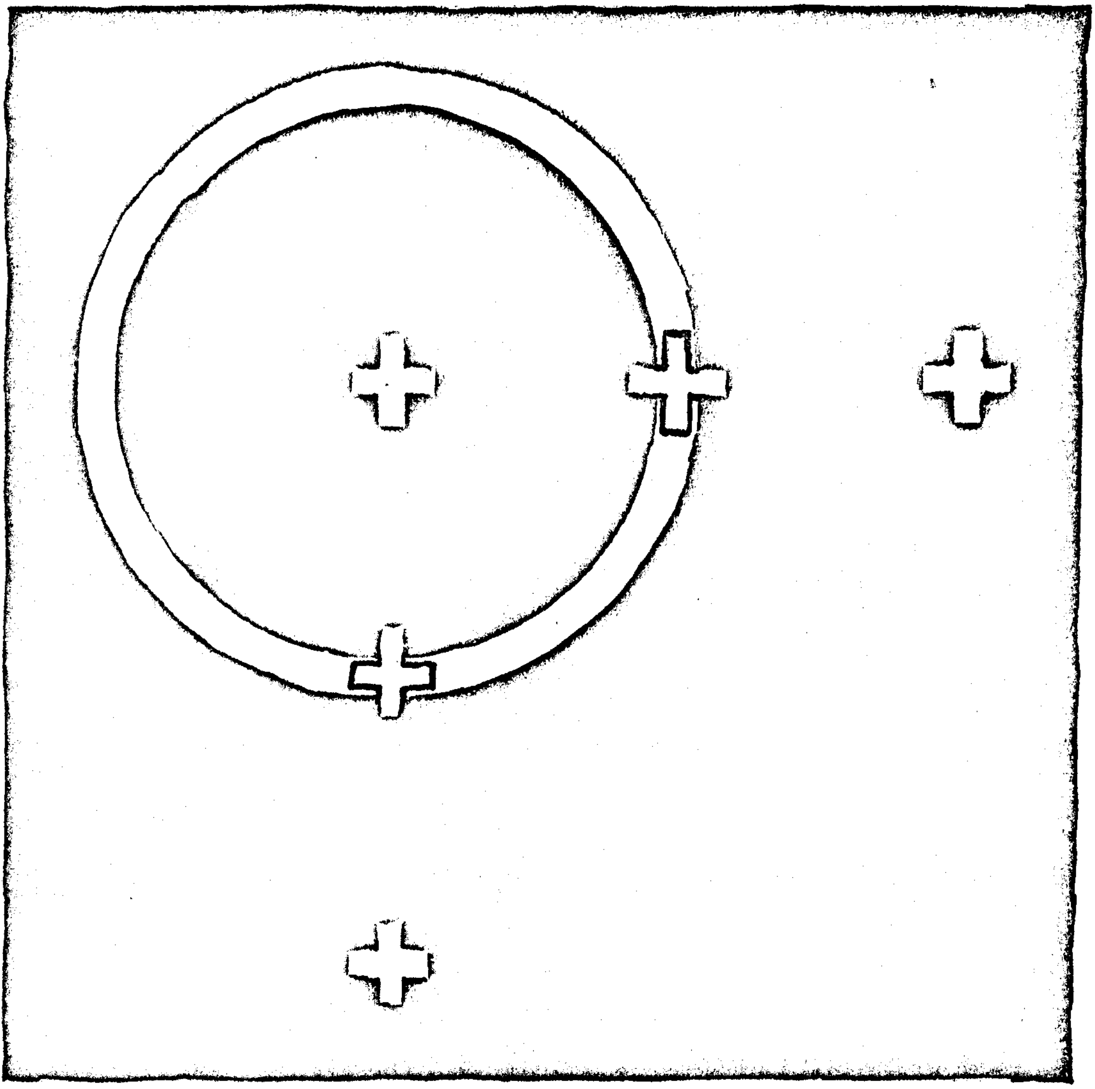
Instead of allowing their eyes to freely follow the omega-movement,

*D = annulus diameter ; T = channel thickness

FIGURE 29

ANNULUS and FIXATION POINTS

Fixation point: ✙



10 Ss were asked to fixate various points presented simultaneously with 8N annulus (Figure 29) and to describe what they saw. Typical reports are as follows:

1. Boundaries (of annulus) become less distinct and "broken up".
2. Red, green and blue-purple colours seen near channel.
3. Whole thing rotating.
4. "Eclipse" appearance, with scintillating "Baily's beads" (94, pg. 70).
5. Radial spokes emerging from channel. Impression of circular movement.
6. Velvety black around inner boundary of annulus.
7. Movement diverging from fixation point (on boundary), which becomes "lost" further out. Individual speckles only visible near fixation point.
8. Fast circular movement but tends to change direction quite often.
9. No movement in channel, but purple-black swirling around its borders.

The subjects were practically unanimous in their descriptions; particularly common were the "eclipse" analogy and the reports of circular motion, which tended to change direction abruptly and quite frequently. When points at or near the annular channel itself were fixated, discrete scintillations could be seen only near the fixation point; there was a fairly stable demarcation border between these scintillations and the more unstructured, and nearly homogeneous illumination further out in the periphery (As expected, when Ss measured the extent of this region by matching it with a length marked off on a foot ruler held at arm's length, it turned out to have very nearly foveal dimensions).

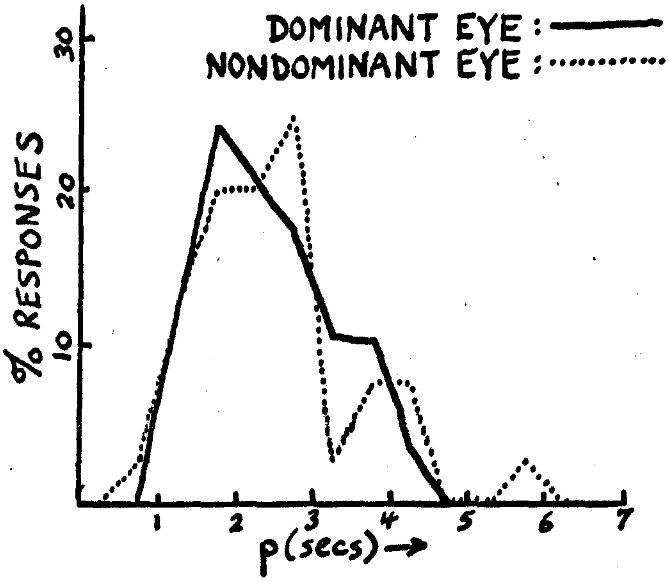
Ss were now asked, while still fixating, to make estimates of the period of the motion they reported, by counting out complete revolutions as E timed them. Only three of the ten were able to do so; the rest complained that the frequent reversals of the motion made it very difficult to follow it completely around the annulus.

When Ss were next instructed not to maintain fixation, but to follow the apparent movement with their eyes, six of those who had reported motion before were able to see no qualitative or quantitative differences, except that reversals were not as frequent. Two thought that, in the second case, motion was somewhat slower, but the estimates of one of them, who had been able to follow it even when fixating, showed no essential change from one case to the other. The other two, who had not previously reported motion, were able to follow it around the annulus; when they were now requested to re-fixate a point at the centre, one agreed that he now was able to discern motion of about the same velocity which was, however, difficult to distinguish because of the "flickering lights and colours". The other said that no convincing movement was present.

It may thus be concluded that, although neither the presence nor the velocity of omega-movement is dependent on eye movements, the latter are probably implicated in the frequency of its reversals; when smooth pursuit movements are executed, reversals are relatively few. It is postulated that, under conditions of ordinary fixation, small involuntary eye movements facilitate reversals, Unfortunately, no sufficiently accurate equipment was available to test this hypothesis on a sufficiently large number of subjects.

FIGURE 30 (right):

Comparison of dominant and nondominant eyes.



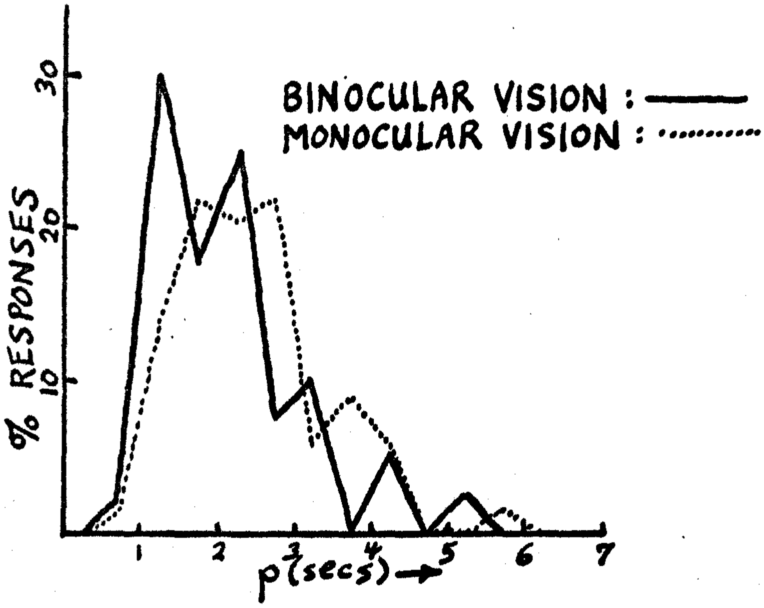


FIGURE 31 (left):

Comparison of monocular and binocular regards.

xxi) Binocular vs monocular presentation.

It has been observed by MacKay (91) that when a field of random visual noise is viewed monocularly, there are qualitative differences in its appearance from that evoked by the same field presented binocularly; in particular, the monocular field appears more densely populated, its "Brownian" motion less "oily", and its scintillations more rapid. If these subjective differences in noise quality are indicative of the total effect of the different modes of presentation, then we should expect to find no significant difference between estimates of the period of omega-rotation, for, as has been shown, this is independent of the statistics of visual noise.

A preliminary investigation indicated that there was in fact no difference, but as this conclusion depended on subjective comparisons which could easily have been in error, the experiment was repeated on a more quantitative basis.

Subjects were nine volunteers, six of whom had never seen the omega-effect before. They were tested individually and on a variety of annuli, and at the beginning of the experimental session, each S's dominant eye was determined by having him sight a distant object through a small circular hole in a piece of cardboard. (92, 93). The subject was then asked to make estimates using his dominant eye, his non-dominant eye, or both eyes, the orders being randomized in the usual way.

Results are shown in Figures 30 and 31. There does not appear to be any significant difference between dominant-eye and non-dominant eye presentations (Figure 30), and so these results were pooled to give the Monocular curve of Figure 31. In this case, proportionately more estimates are seen to be grouped at the leading edge of the Binocular curve, i.e. estimates of p tend to be smaller in the Binocular than in the Monocular case. This difference is reflected in the calculated mean values of the two distributions: $\bar{p}_B = 2.104$ secs., while $\bar{p}_m = 2.353$. It is, however, not significant at the 10% level either when the distributions are considered to be independent or when a paired variate test is performed.

It must be concluded that binocular or monocular modes of stimulus presentation have little effect on perceived apparent motion.

xxii) Haploscopic presentation.

If an annulus (either black on a white background or white on a black background) is presented to one eye and a field of visual noise is presented to the other, the reports of 5 Ss indicate that no convincing omega-movement can be seen. This, according to the Ss, is due mainly to the suppression of the visual noise in the immediate vicinity of the annulus and extending about $\frac{1}{2}^{\circ} - 1^{\circ}$ from its borders. Retinal rivalry operates strongly in this situation and occasionally, if the relative brightnesses of the stimuli are suitably adjusted, a "neck" of visual noise is seen to cross the annulus, joining the interior and exterior noise fields, and then to widen rapidly, until all that is visible is a homogeneous noise field. Under no circumstances was it possible to view a complete, stable annulus in close proximity to noise.

If a point near the annulus was fixated, results were essentially the same, although the periods of dominance of the noise field tended to be longer. For more distant fixation points (greater than about 4° from the border of the annulus), the annulus usually dominated to such an extent that (for the bright annulus on a dark ground) its central region was

FIGURES 32 and 33:

p-distributions for 7 subjects.

FIGURE 32

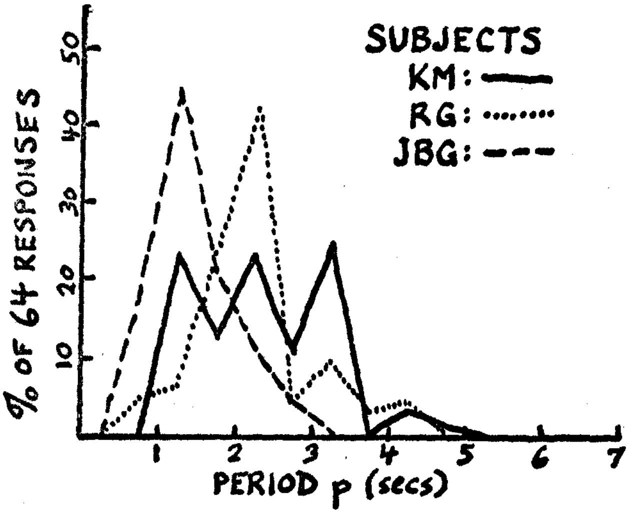
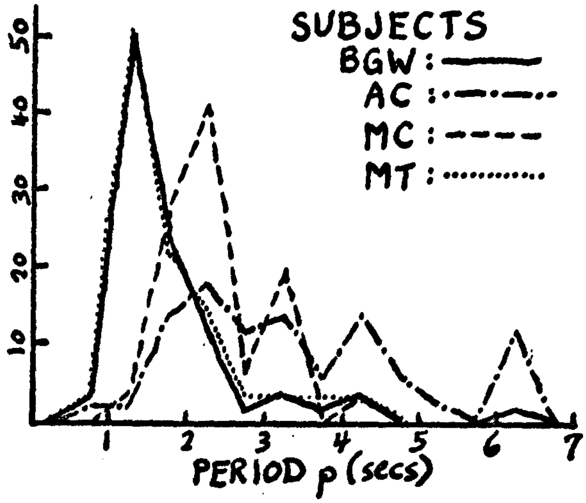


FIGURE 33



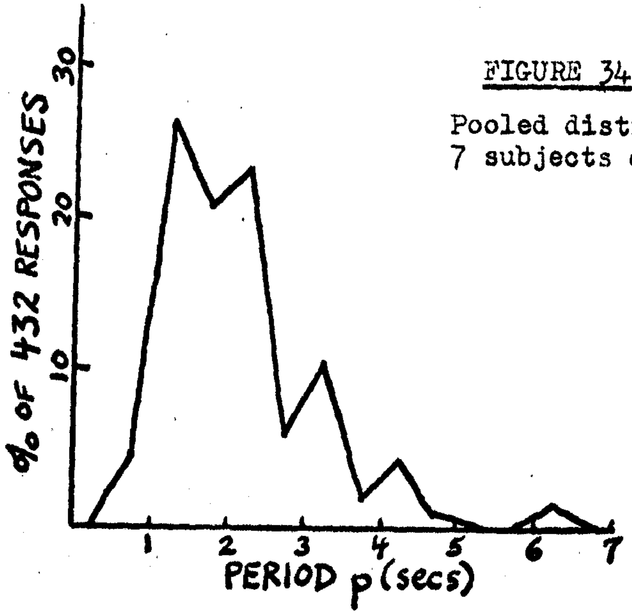


FIGURE 34:

Pooled distribution for the 7 subjects of Figs. 32 & 33.

completely noise-free, and of a homogeneous dark black appearance.

Under normal conditions, without fixation, there were a few reports of swirling of the noise field in the central region of the annulus, but as this effect is occasionally observed when both patterns are presented to the same eye (and can be easily distinguished from omega-movement, which occurs only in the immediate vicinity of the contour, and is much slower) it cannot be considered as evidence that higher than retinal centres are involved in the production of omega-movement.

All that can be concluded from these results is that the appearance of omega-movement during haploscopic presentation is prevented by rivalry between the two stimuli; because of the latter it is impossible to view both stimuli in sufficient proximity for the production of apparent movement.

xxiii) The form of the distribution of p.

As has already been indicated, the distribution of p for a group of subjects is noticeably skew, rising to a maximum in the vicinity of p=2.0 seconds, and tailing off gradually for higher values (Fig. 7, 11, 25, 26, 27, 30, 31). Individual Ss, when required to give a sufficiently large number of responses, present a similarly-shaped distribution, although the position of the maximum, and the mean and variance of the distribution differ from subject to subject (Figures 32, 33,and 34).

When the results of a large number of Ss are pooled, inter-subject differences exert a smaller effect, whereas their similarities become enhanced; this is accompanied by only a relatively small increase of variance. Thus the size of the maxima at 3.25, 4.25 and 6.25 seconds, in Fig. 34, is due mainly to the contributions of subjects K.M., M.C. and A.C. (Fig. 32, 33). The dominant maximum is present in the distribution of each

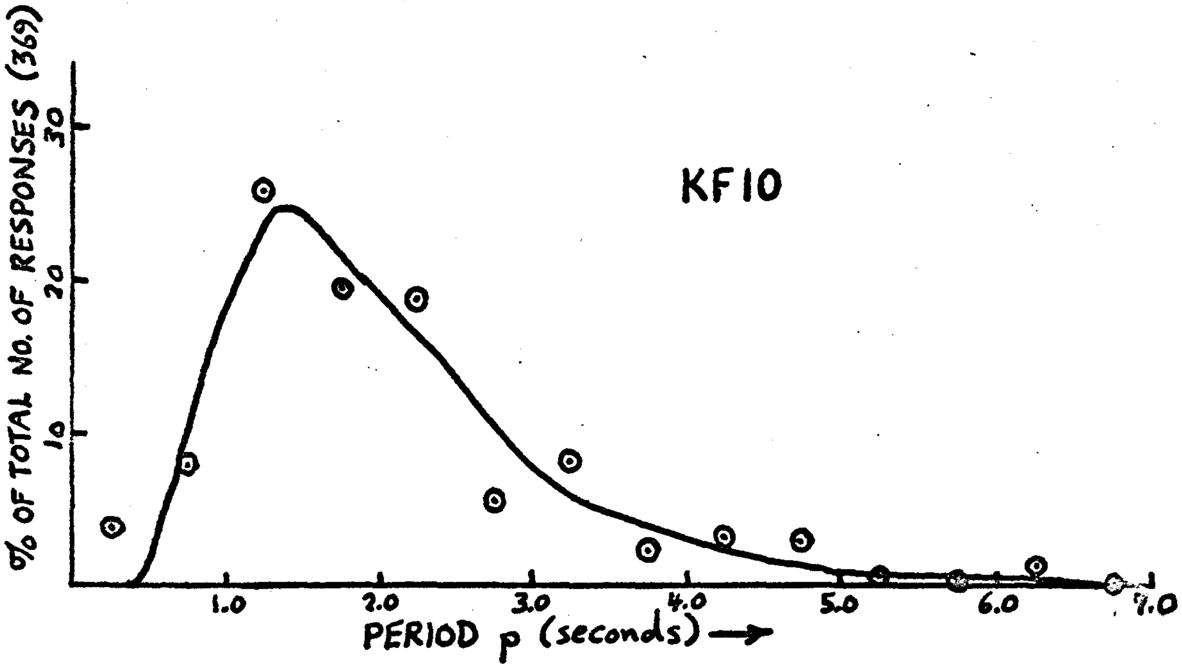


FIGURE 35:

Group KF10. Pooled results and fitted curve for 20 subjects.

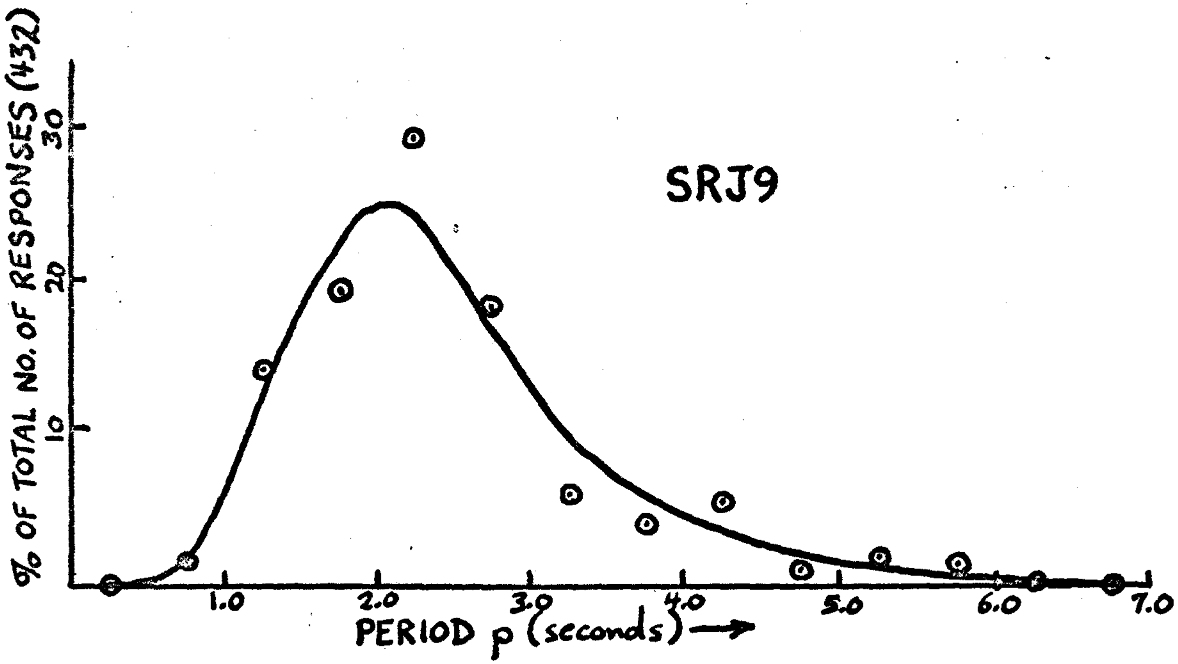


FIGURE 36:

Group SRJ9. Pooled results and fitted curve for 22 subjects.

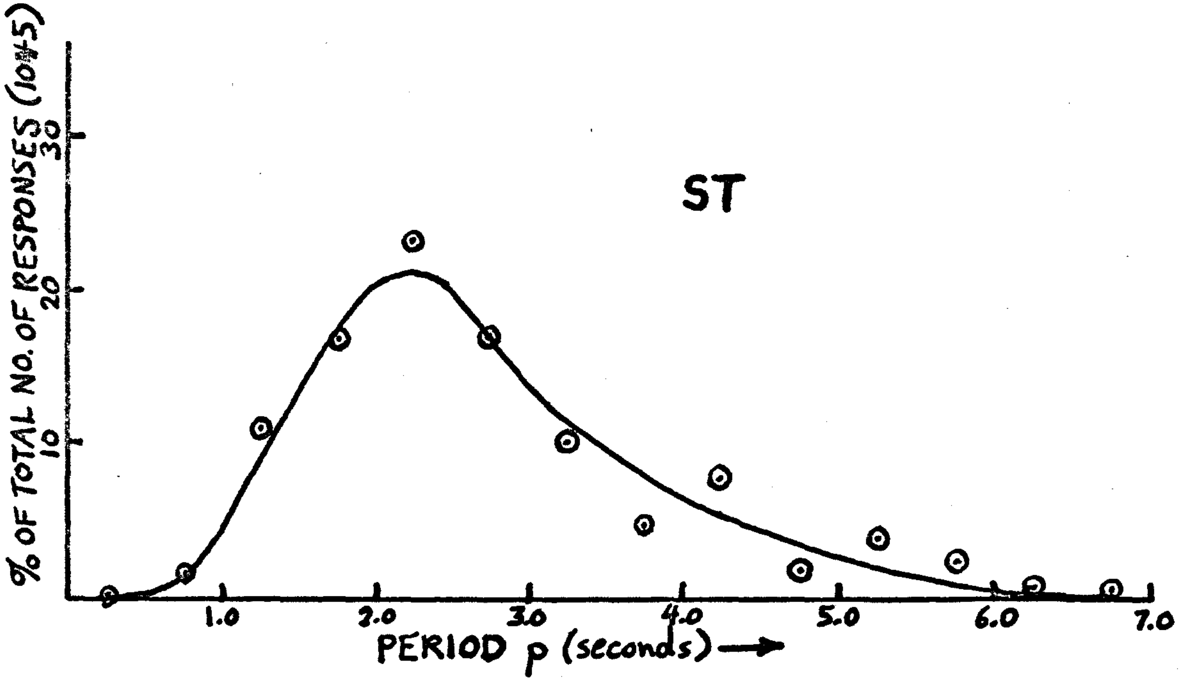


FIGURE 37:

Group ST. Pooled results and fitted curve for 55 subjects.

of these Ss, but it is often of the same order of magnitude as another peak elsewhere.

These secondary peaks are themselves of interest, but it is the purpose of this section to investigate Ss' similarities, and not their differences. Figures 35, 36 and 37 show the frequency-distributions of the pooled results of a sufficiently great number of subjects to rule out any but gross inter-subject differences. As is indicated on these figures, a normal curve gives a reasonable fit to the results, provided that the frequency of each class-interval is plotted against log p, rather than p. To demonstrate this, the values of Fig. 37 have been replotted, after the proper transformation, in Figure 38. The normal curve fitted to the data in Fig. 38, and those fitted to the data of Figs. 35, 36 and 37 (after taking antilogs), were determined graphically by the method to be described later.

That a logarithmic transformation should tend to normalize the results is certainly not implausible, for much the same reason that a logarithmic transformation normalizes the distribution of r, the coefficient of correlation, if it is significantly different from zero: whereas there is no theoretical upper limit to positive values of p, negative ones are not allowed, and the range of possible estimates is thus constrained to non-negative values. A logarithmic transformation, of course, makes the range $(0,1]$ symmetrical with the range $[1,\infty)$, and allows a normal curve to be fitted directly to the data.

When a X^2-test of Goodness of Fit is applied to the curve fitted to the data, as a rule the value of X^2 found is highly significant. This turns out to be due mainly to the contributions to the normalized squared deviations associated with the higher values of p; an inspection of Figure 37 shows that relatively large deviations start to occur at p=3.75 seconds, and that from about this point, observed frequencies "oscillate" about the fitted curve. This alternation of positive and negative deviations is also apparent in Figures 35 and 36, and is usually to be found in the other distributions obtained.

These deviations are artefacts of the method of measurement used, and arise as follows. Given a combination of i) a fixed set of stimulus exposure-times and ii) a specified distribution class-interval, it can be demonstrated that a set of perfectly random numbers, considered as the set of Ss' estimates of the number of perceived revolutions per time interval, will result in the disproportionate filling of some class-intervals at the expense of others, provided that the numbers mentioned are rectangularly distributed and that the magnitude of the differences between adjacent numbers is not too variable. In practice, as far as these experiments are concerned, all these conditions are fulfilled; in particular, since Ss tend to make their estimates of the number of revolutions per interval to the nearest half-revolution, disproportionate class representation is practically assured.

As an example of the presence of this effect, suppose that an experiment consists of the presentation of a variety of stimulus-annuli for randomly-spaced intervals chosen from the set (6, 9, 12, 15) seconds. Now let the estimates of the number of revolutions per given interval be chosen at random from the set ($\frac{1}{2}$, 1, $1\frac{1}{2}$ ... $19\frac{1}{2}$, 20), each number of the set being equally likely, with the only provision being that no choice, in combination with the corresponding interval, should result in a value of p less than 0.75 seconds (this stipulation is, of course, arbitrary, and is only made

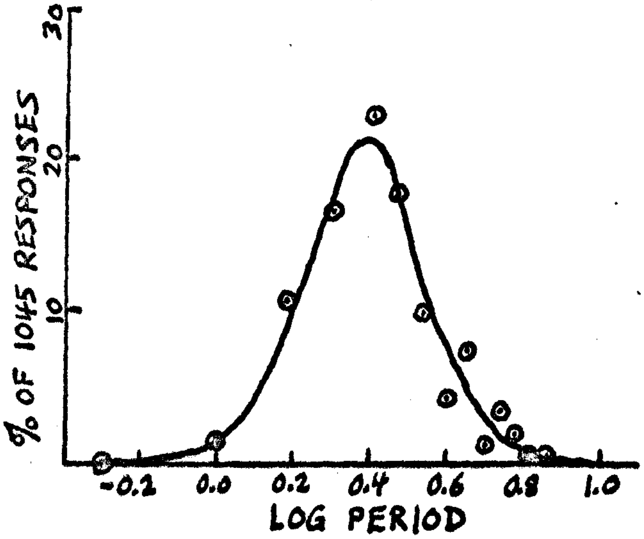
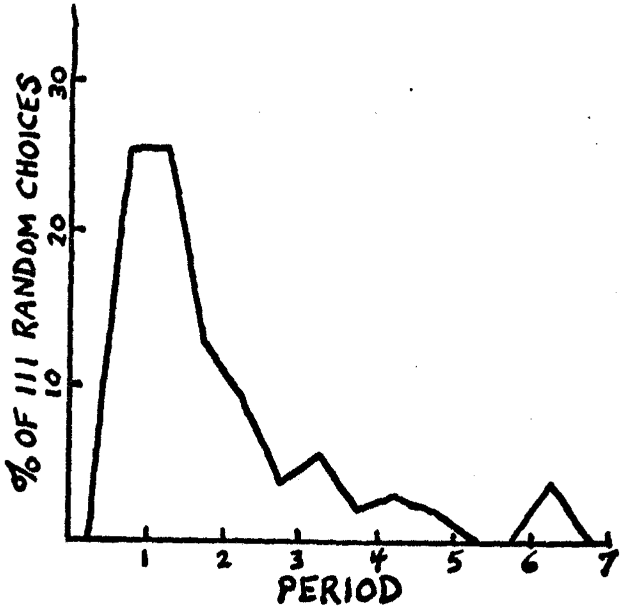


FIGURE 38 (left):

Group ST. Normal curve fitted to plot of log p vs relative frequency.

FIGURE 39 (right):

Distribution arising from a restricted random choice of revs/interval values.



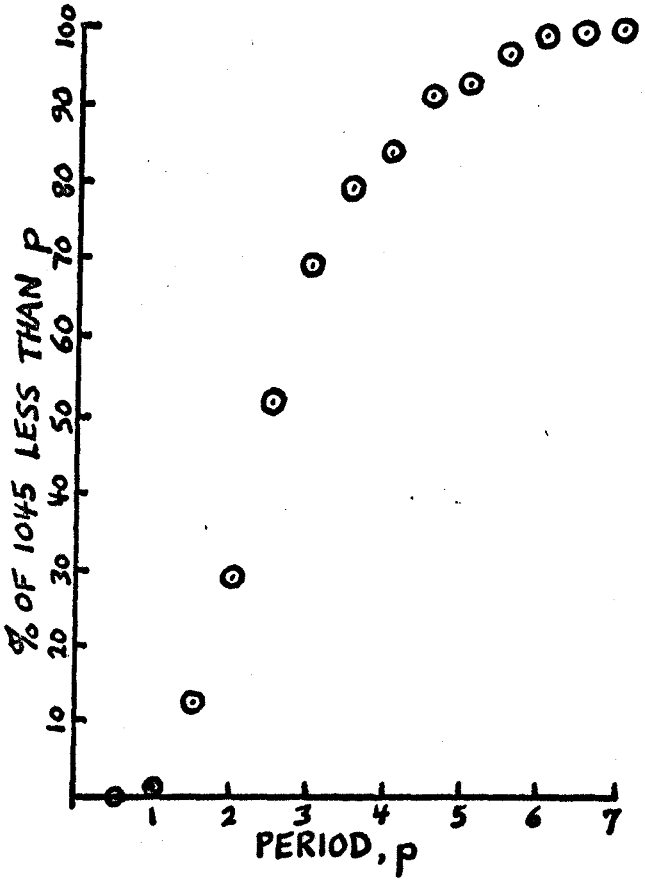


FIGURE 40:

Group ST. Period versus relative accumulative frequency for 55 subjects.

FIGURE 41:

Group ST. Log period versus probability.

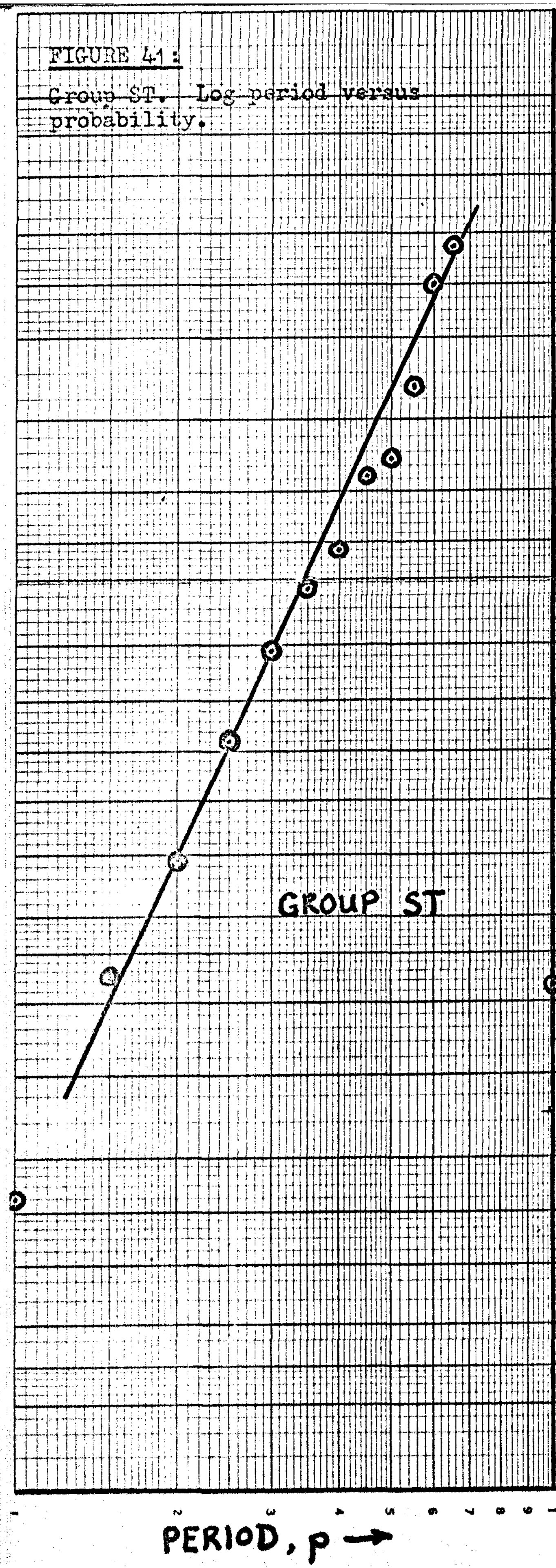
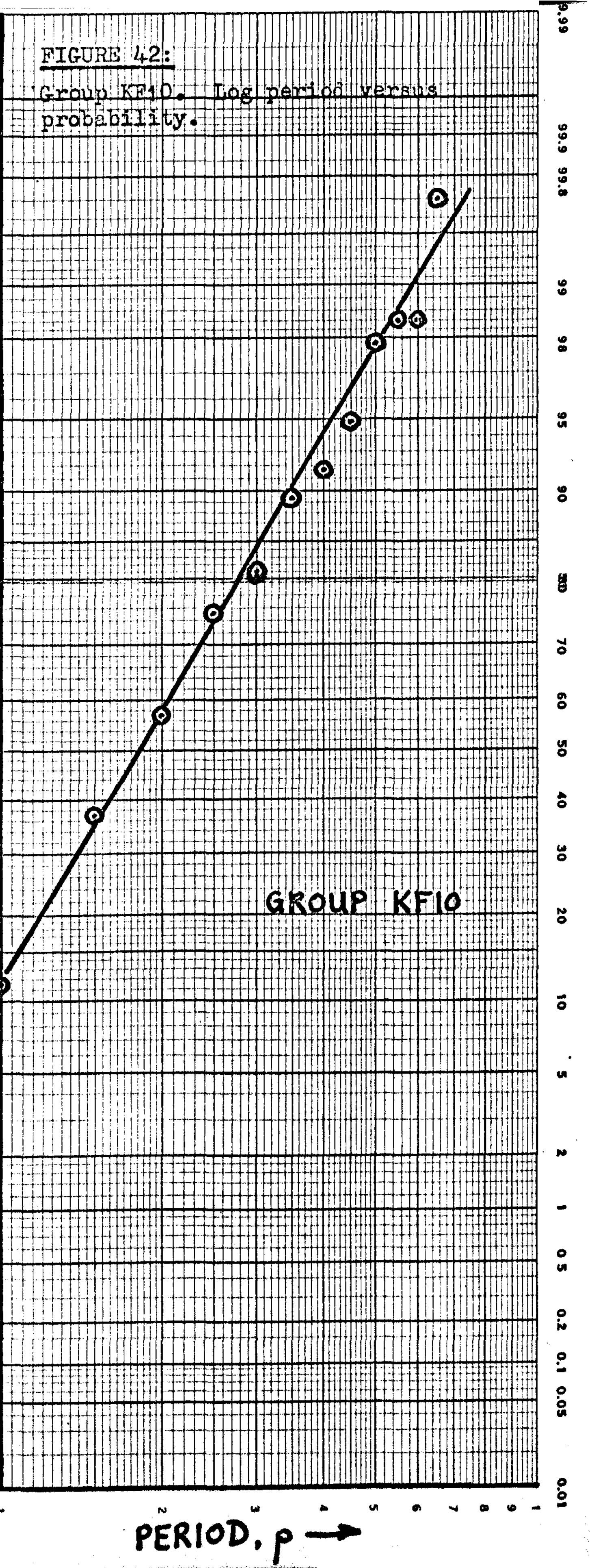


FIGURE 42:

Group KF10. Log period versus probability.



because, in practice, such values are in fact quite rare). Then if periods are calculated, and their frequency distribution plotted (Figure 39), it can be seen that purely random variation can result in the type of secondary maxima often found in actual, experimental distributions (Compare Figure 39 with, for example, Figure 34).

It must be concluded that such secondary maxima cannot be considered to be real effects, but that they could easily arise from the method used to measure apparent motion.

The distorting influence of these artefacts is an obvious disadvantage of the method used, but the convenience of the latter, especially in the group situation, more than compensates for this. Furthermore, there exist several methods of minimizing the effect of the distortion. For example, the use of a different set of presentation time-intervals would re-distribute the spurious maxima and give a check on the extent of their influence, or large class intervals could be used to smooth them. Both these methods were used from time to time with adequate results.

Better still, however, is a consideration of accumulative frequencies, since in this case, spurious maxima have a much smaller percentage effect on the area under the whole distribution than they have on any given class frequency. Figure 40 is such a plot for the data of Figure 37. As is apparent, an asymmetrical ogive is obtained. Finally, if a plot of relative accumulative frequency is made against log p, using for convenience Log X Probability paper, as in Figure 41, a straight line can be made to fit the plotted points over the greater part of their range. From measurements made on this line, the parameters of a normal distribution can be found, and these were used to calculate the ordinates of the curve drawn in Figure 37.

FIGURE 43:

Group SR. Log period versus probability.

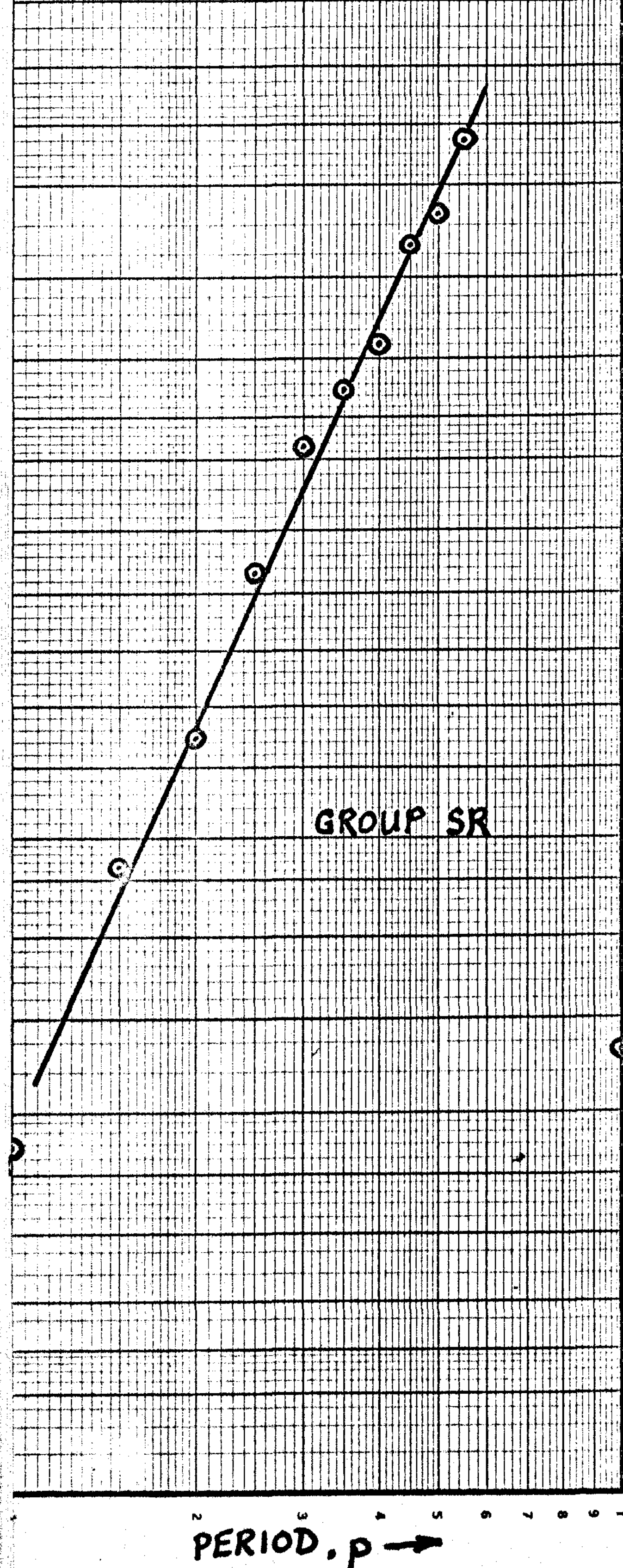
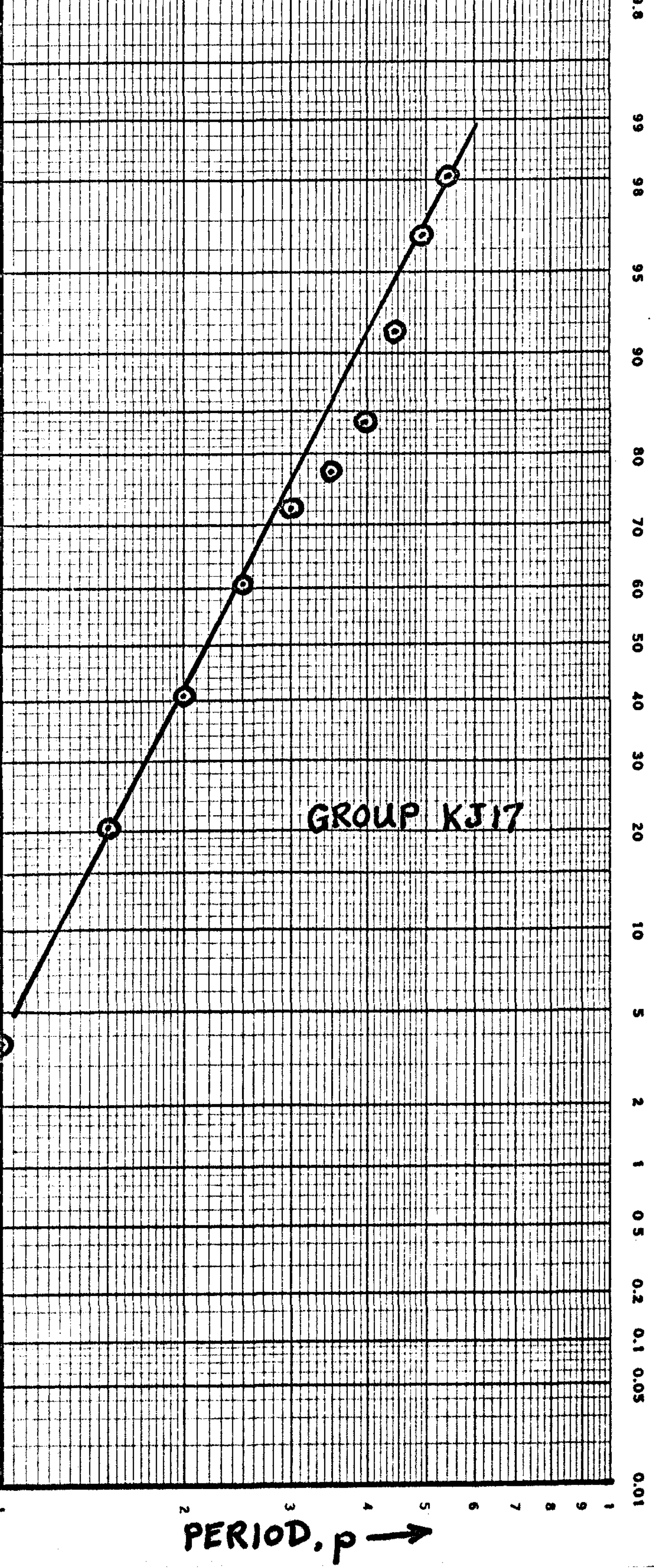


FIGURE 44:

Group KJ47. Log period versus probability. Note departure from linearity.



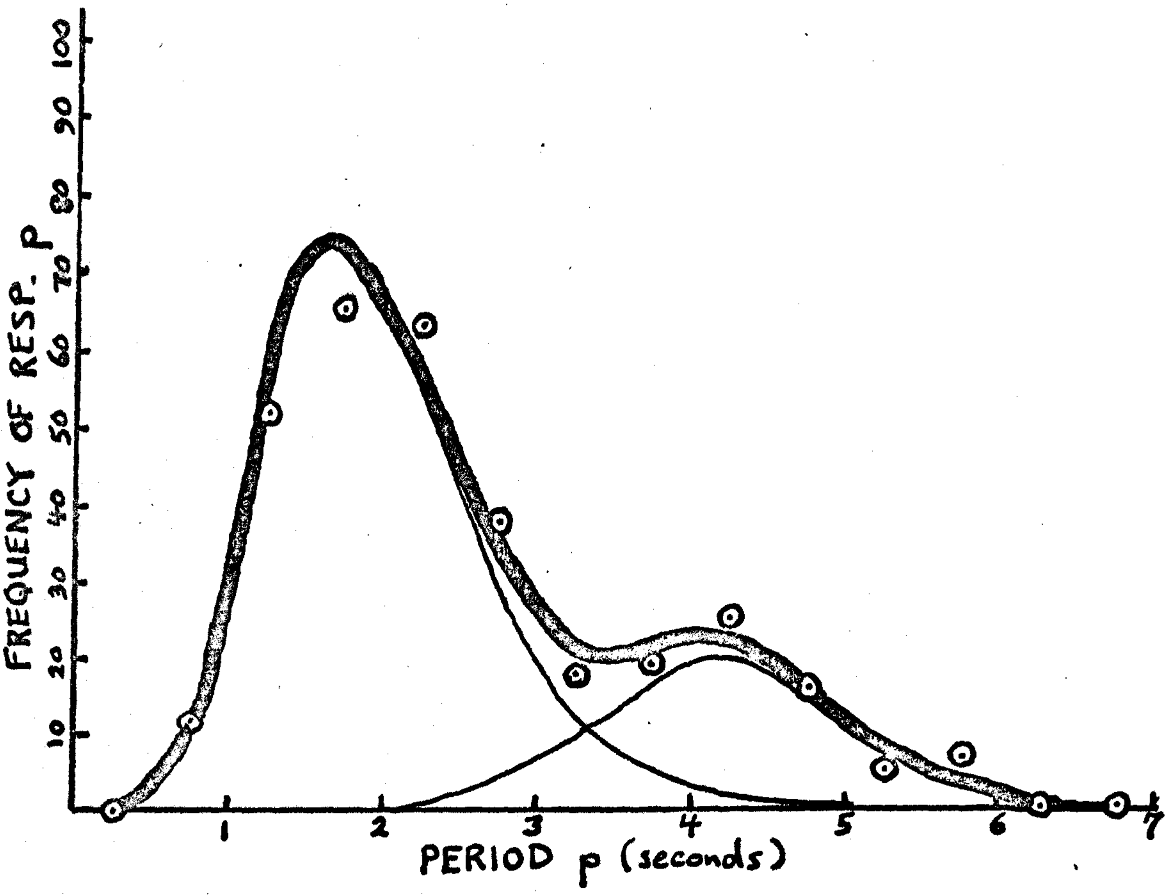


FIGURE 45:

KJ17 distribution resolved into two normal curves. A logarithmic transformation has been made, as usual, on the primary curve.

Figures 42 and 43 are similar plots made for other groups of Ss under other conditions, and correspond to Figures 35 and 36, respectively.

A finding mentioned earlier, in connection with projector speed (Experiment v)) and noise-field brightness (Experiment ii)) complicates the situation. In these experiments, it was found that there appeared to exist a secondary maximum, in the vicinity of p=4.0 seconds. That this effect is real, and not due to artefacts of measurement is indicated by inspection of Figures 41 and 42. Besides the deviations from linearity which often occur for extreme values of the variable, there is an indication that non-normality occurs in the region p=4.0 seconds, as previously suspected. This is not apparent from the original frequency distributions (Figs. 37 & 35), and illustrates an advantage of the accumulative-frequency method of presenting the data.

Figure 44 is a plot of the results of a group of 16 naive Ss, and gives a good indication of the presence of a real effect. Owing to the relatively small numbers of estimates which compose the secondary maximum, it proved impossible to make precise tests as to its nature; however, it certainly has the appearance of a near-normal distribution superimposed on the distribution of the main effect. By a method of successive approximation it is possible to determine the parameters of this secondary distribution, and to express the total distribution as the sum of two others (Figure 45).

Formally, it is possible to interpret the presence of the secondary maximum as being due to nothing more than systematic mistakes on the part of Ss. Thus, if there existed a small tendency for Ss to be taken by surprise at E's "Go" signal (in spite of the preceding "Ready" signal),

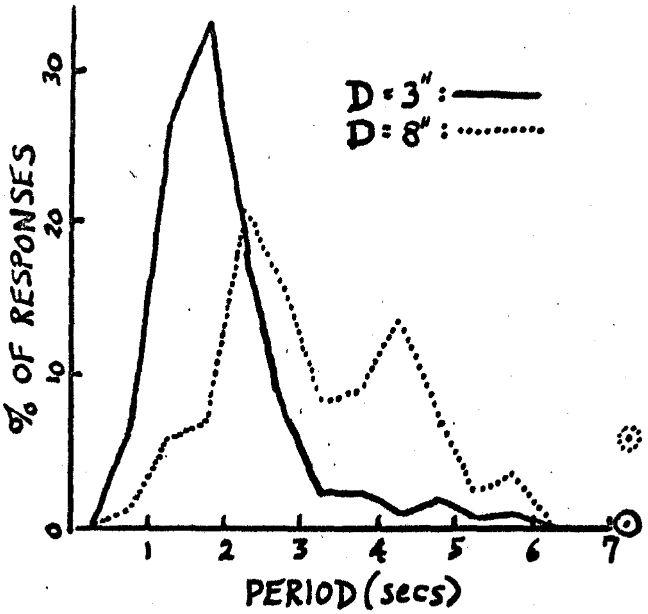


FIGURE 46 (left):

KJ17 distributions for 3 and 8-inch diameter annuli showing prominent secondary maximum for latter.

FIGURE 47 (right):

KJ17 distribution partitioned into stimulus exposure-time intervals.

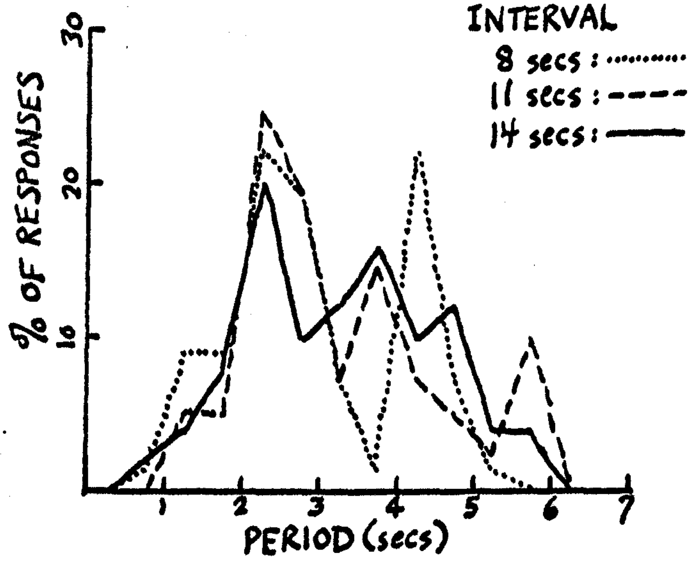
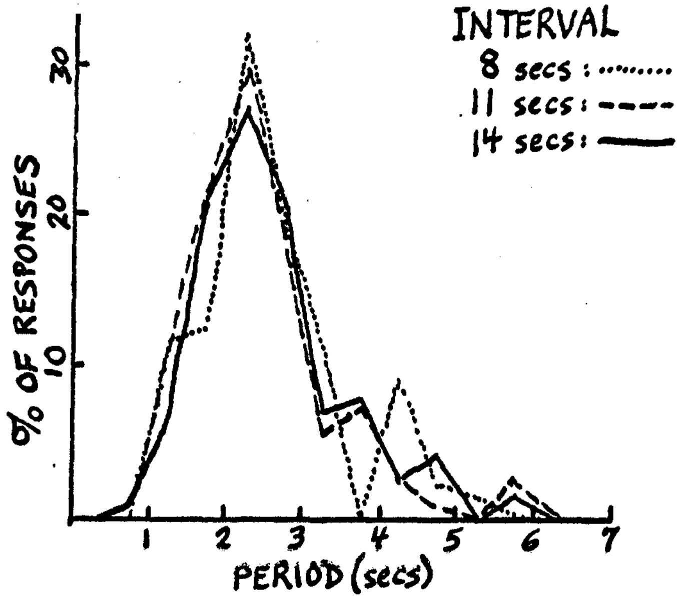


FIGURE 48 (right):

Group SR p-distribution partitioned into stimulus exposure-time intervals.



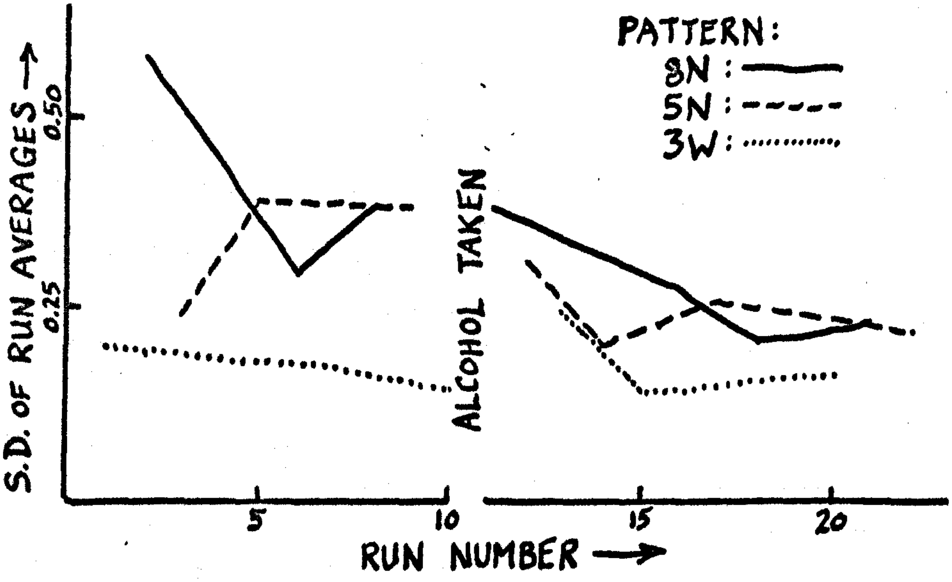


FIGURE 49 (left):

Group KM5. Standard deviations vs. Run Numbers for 3 annuli.

and this caused S to miss the first revolution or two before commencing his count, one could expect a secondary peak to be built up in a position $p = \bar{2}\big/\left[1-\bar{2}\left(\frac{\bar{n}}{t}\right)\right]$ seconds, where $\bar{n}$ is the number of revolutions mistakenly missed, and t is the duration of the stimulus exposure-time. In the expression given, $\bar{2}$ is a number about 2, and represents the position of the primary maximum of the distribution. It therefore indicates the approximate mean value of p in the absence of any mistakes ($\bar{n} = o$).

Since it is plausible to assume i) that $\bar{n}$ is independent of t but that ii) $\bar{n}$ might tend to increase as the difficulty of making an estimate increases, the hypothesis predicts that i) as t increases (making the effect of the fixed number of errors relatively unimportant), the secondary maximum should shift back towards the primary one and ii) for a difficult stimulus there should exist a more prominent secondary maximum than for a fairly easy stimulus.

These predictions do in fact seem to be borne out, as is shown by an inspection of Figures 46, 47 and 48. Figure 46 is a comparison of the total distributions of two different annuli, one of which is assumed (from the criteria listed earlier) to be 'difficult' with respect to the other. (It should be pointed out that the secondary maximum in this case is somewhat more prominent than is usual). Figure 47 shows the 'difficult' distribution of Fig. 46 partitioned into the three different stimulus exposure-time intervals which were used. By far the most prominent secondary maximum is associated with the shortest time-interval, and as this interval increases there is a tendency for the predicted shift to occur. Figure 48 gives a more typical result; the magnitude of the secondary maximum amounts to only about $\frac{1}{6}$ of that of the primary. Again, it can be seen that the peak occurring at about p=4.0 seconds is a feature of the distribution for the shortest time-interval, and that there are signs of this peak shifting to smaller values of p as the time-interval increases.

It was originally hoped that the etiology of secondary maxima might somewhere involve a definite neurological factor giving rise to preferential angular velocities occurring as first, second ... nth harmonics of some basic value. It is to be seen from the above considerations, however, that the present evidence offers no support for this hypothesis; it seems that secondary maxima are merely effects of Ss' indecision or lack of attentiveness, and that any such 'harmonic' velocities are, for the present, purely conjectural.

The presence of secondary maxima for certain values of frame speed or of intensity, mentioned at the beginning of this section, must, according to the evidence, be attributed to random variations of the relative frequencies of the contributory time-intervals. When this was checked, it was found that, in both cases, those distributions with large secondary maxima had a disproportionate number of smaller exposure-time intervals, as was expected.

Another check was made, similar to experiments already performed, by impressing upon 5 Ss the necessity to follow apparent motion as rapidly as possible. As has been shown, instructions of this sort have little effect on the primary maximum, and should have little effect on Ss' hesitancy, i.e. on the value of $\bar{n}$ (the effect might even be an increase in $\bar{n}$, if Ss became anxious enough). On the other hand if S's responses are based on an harmonic series of standards, the choice being under his conscious control to a certain extent, then the effect of the instructions is to tell him to

TABLE XVI: Table of annuli used.

Designation	Description
3N	Circular annulus; diameter = 3"; thickness = ¼"
3W	" " " 3"; " ½"
5N	" " " 5"; " ¼"
5W	" " " 5"; " ½"
8N	" " " 8"; " ¼"
8W	" " " 8"; " ½"
OCT	Octogonal " ; diameter of circumscribed circle = 9"; thickness = ¼"
Sq	Square " ; sides 8" long; thickness = ¼"
8NB	As 8N, except annular channel is occluded by 25 opaque ½" bars at regular intervals
8N5B	As 8N, except for 5 equally spaced 2½" occlusions
8N3B	As 8N, except for 3 equally spaced 4" occlusions
HE	Elliptical annulus, oriented so that major axis (of length 5") is horizontal, Eccentricity = $\frac{3}{5}$. Thickness = ½"
VE	Identical with HE, except that major axis is now vertical
S	Linear channel; length = 18"; continuously variable thickness
A	Arc of circle of radius 18"; thickness = ½"
C	Three concentric circular annuli, of diameters 3", 5" and 8"; all of thickness ¼".
V	Variable-thickness circular annulus; diameter of outer border = 5"; diameter of inner border = 4¾, 4½, 4, 3, 1 inch.

Stim	K7, 11, 25	n	K28	n	K30	n	S6	n	S8	n	K29	n	K25	n
3N	2.32	28					2.29	89	2.35	83				
3W	1.48	11	1.72	29	1.53	39	2.12	85	2.08	79			1.84	54
5N	2.75	29	2.56	16	2.04	29	2.80	69	2.08	57				
5W	1.79	12					2.40	74	2.53	61	2.04	17		
8N	2.92	29	2.52	31	2.56	40	3.61	85	3.38	71			2.68	55
8W							2.82	96	2.85	78				
OCT			3.39	25	2.96	36					5.47	11		
Sq			2.75	17	2.77	24					5.16	7		
8NB	4.75	9	1.70	19	2.80	21								
8N5B	3.71	11												
8W3B	3.80	11												
HE											2.08	17		
VE											2.30	18		

TABLE XVII: Group Means $\overline{p}$ and Numbers of Estimates

Subj.	Stimulus Annulus 1 5N	2 8N5B	4 3N	7 3W	8 5W	9 OCT	Averages
DB	1.41	1.91	1.36	1.16	1.26	2.15	1.542
MT	1.43	1.42	1.22	1.23	1.17	2.07	1.423
AL	3.29	6.85	2.29	1.57	1.88	5.45	3.555
RG	2.63	3.37	2.04	2.02	2.60	3.88	2.757
BW	1.23	2.76	1.40	1.25	1.16	2.50	1.717
JBG	1.21	1.64	1.09	0.95	1.05	2.02	1.327
KM	2.63	2.69	1.50	1.10	1.60	3.00	2.087
CC	1.64	2.58	2.06	1.50	1.61	2.18	1.928
PMC	1.32	1.59	2.13	1.50	1.29	1.40	1.538
MB	1.37	1.56	1.24	1.12	1.24	1.84	1.395
JG	1.86	2.92	1.44	1.16	1.46	3.18	2.003
MC	2.10	2.58	1.89	2.06	2.21	2.50	2.223
Averages	1.843	2.656	1.638	1.385	1.544	2.681	1.9579

TABLE XVIII: Individual Means (seconds) for Different Annuli.

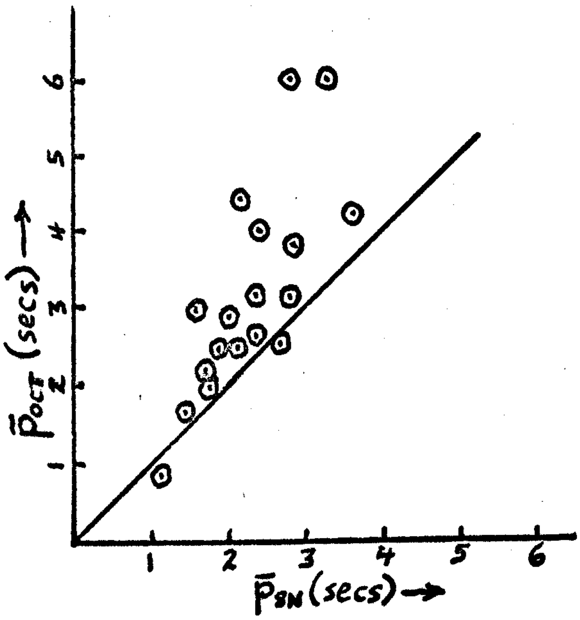
'tune in' to his fundamental frequency, and the representation of large values of p in his set of responses should decrease.

The results of the experiment were consonant with the former argument; the secondary maximum was still present, and its size and position were not unusual. It would seem that we have here more evidence for the 'inattentiveness' hypothesis, as opposed to its alternative.

xxiv) Correlates of the stimulus pattern.

As has already been indicated, a variety of annular patterns were used on various occasions during the experiments. For reference purposes, the ones most frequently employed are listed in Table 16, along with a short description of their dimensions. Table 17 gives representative values of the average estimated period for some of the annuli, as obtained from different groups of Ss at various times. All Ss were naive, never having seen the omega-effect before. An analysis of variance of selected values of Table 17 shows that both differences between groups and differences between stimuli are significant, although the latter usually contributes most heavily to the total sum of squared deviations. For any given group, however, much the same pattern emerges: small circular annuli are associated with the smallest values of $\bar{p}$, there is a more or less continuous gradation to larger values as annuli become larger, and the largest $\bar{p}$ values of all are found for incomplete annuli, or annuli composed of straight-line segments.

Much the same pattern is obtained when individual Ss are given a chance to make estimates on various stimuli. Table 18 gives $\bar{p}$ for each of 12 Ss and 6 different stimuli; each value of $\bar{p}$ is based on 3 or 4 individual estimates. An analysis of the results again indicates significant differences both between subjects and between stimuli; in this case the former accounts for the greater variation of the results.



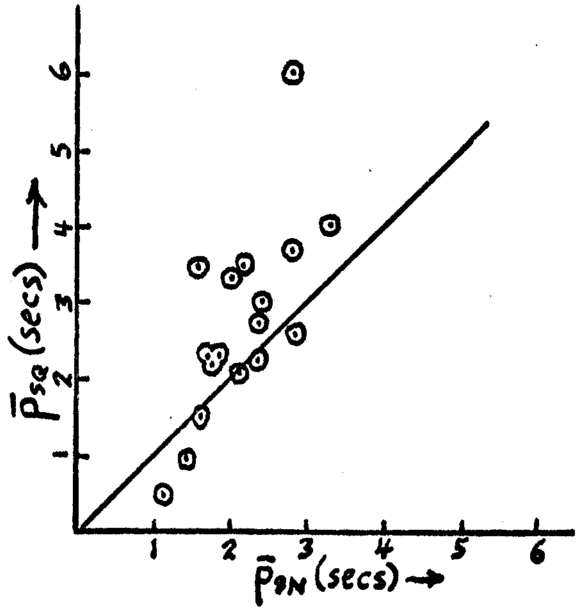


FIGURE 50 (continued).

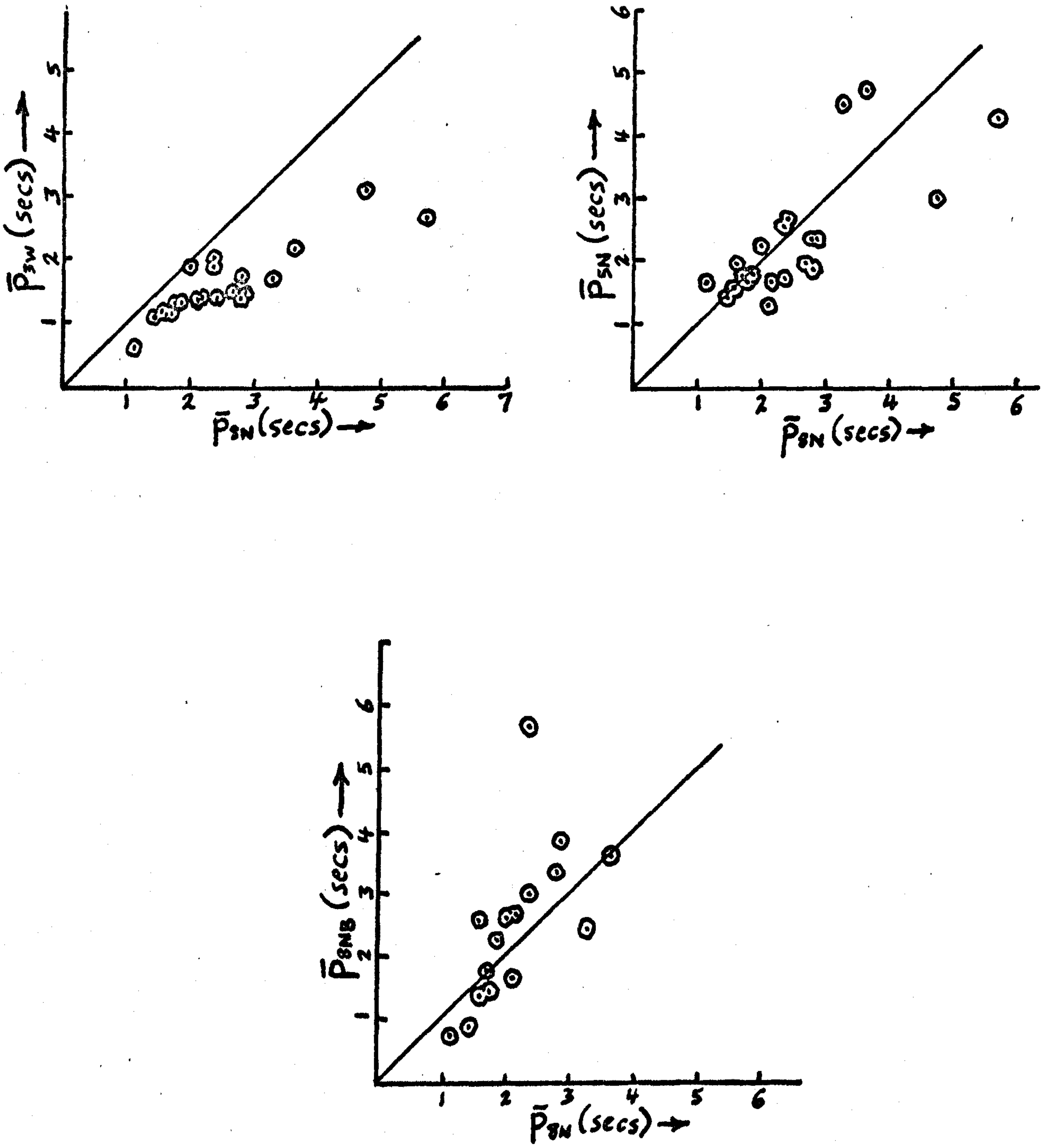


FIGURE 50:

Various stimuli. Comparison of $\bar{p}_{STIM}$ and $\bar{p}_{8N}$ for 21 subjects.

Other typical findings are demonstrated in Figure 50. Twenty-two Ss were required to make estimates of the period of apparent motion, using patterns 3W, 5N, 8N, 8NB, OCT and SQ; three or four presentations of each figure were made. Arbitrarily choosing average estimates of the 8N figure as abscissae, the corresponding average values for each of the other five figures have been plotted as ordinates for each S (One of the Ss made a mistake early in the experiment which resulted in his estimates being reported out of order; his results are therefore not included). The 45°-line drawn on each diagram affords a quick visual check on the null hypothesis that there exists no difference between average estimates of the 8N figure and those of the other five; for this hypothesis to be tenable, the plotted points of the diagram under consideration must be randomly distributed about the 45°-line. Several conclusions may be drawn from the figures:

1. There is a positive correlation between estimates of $\bar{p}_{SN}$ and estimates of $\bar{p}$ for each of the other stimuli; that is, a S who tends to report a large value of $\bar{p}_{SN}$ also makes large estimates of the rest.

2. Estimates made on the 3W stimulus are clearly lower, and estimates on the OCT and SQ stimuli clearly higher, than the corresponding 8N standards. Results in the other two cases are equivocal, and do not provide sufficient evidence to reject the null hypothesis. The 5N estimates do, however, tend to be lower, and the 8NB estimates somewhat higher, in agreement with other findings.

3. The variance of the distributions of the simple circular annuli is, in agreement with the general finding, significantly smaller than that for the more complex figures. Other things being equal, this is indicated by an

increase of the slope of the regression line drawn to the plotted points.

4. Although all 21 Ss were able to report apparent movement in the 5N 3W and 8N annuli, 3 were unable to do so for OCT, 4 for SQ and 5 for 8NB (14%, 19% and 24%, respectively). This is a reflection of the difficulty Ss have in viewing and following apparent movement in the latter type of stimuli; even those Ss for whom an average has been calculated and plotted were rarely able to make an estimate for each presentation of the stimulus. Typically, it is found that fully 25%-40% of all responses attempted by all Ss on the 8NB, 8N5B, 8N3B, OCT and SQ figures cannot be used. This is in contrast to the 2%-10% rejection rate for simple circular annuli.

As far as the annuli consisting of straight-line segments (OCT, SQ) are concerned, Ss' comments give some indication of their difficulty: "very little impression of rotation"; "disconcerting flash in corners"; "angles are obstruction to eyes trailing dots". Some Ss report "pouring" motion of the noise particles into and out of the corners, and base their estimates on an extrapolation of this movement.

A plain, straight channel does not, in general, sustain an impression of apparent movement. When stimulus S, set for various widths between ¼" and 1", was viewed by 8 Ss from a distance of 7 feet, random 'Brownian" motion was reported for the greater widths but no S spontaneously reported movement along the channel, even though five of them were fairly experienced with the omega-effect. When pressed, six said they sometimes saw a very slow 'trickling' motion of the noise particles along the border of the channel, and were occasionally aware of a very fast transitory 'flash' which travelled rapidly in either direction (the latter particularly when fixating).

Of the practised Ss, none thought that anything he saw resembled omega-movement, which is much smoother and more regular. When two straight channels intersecting at a right angle were viewed, motion was evidence in the vicinity of the angle and for perhaps 2^o-4^o along its arms, but beyond this it was very difficult to be able to report its presence. In none of the cases, however, was movement as compelling as that obtained with a regular, circular annulus.

Although movement associated with angles is variable and not particularly strong, the greater number of angles in an octogon, as opposed to a square, coupled with the relatively shorter straight-line segments joining them, should favour the perception of apparent movement around the former. Some hint of this is, in fact, found; in one experiment, for example, 32% of the presentations of the square did not evoke apparent movement, while 24% of the OCT estimates had to be rejected. Although this difference is not significant, it is at least suggestive.

If difficulty was experienced in making estimates on patterns S, SQ and OCT, the situation is not much better for 8N3B, 8N5B and 8NB; in fact the latter are often associated with a greater number of unusable responses than the former. It was originally hoped that by patterning the background, in a manner analogous to Brown's experiments on real motion (41) the perception of omega-motion would thereby be enhanced, but this effect was not obtained either for the present patterns or for a different set, in which semi-opaque occlusions were employed. By Ss' own comments, any gap or discontinuity in an annular ring is a source of difficulty in following the apparent movement present, and although the impression of movement still exists, reversals and oscillations are frequent. It is to be expected that a breakdown of eye 'pursuit' movements are also implicated in the significantly greater values of p obtained, since with a number of the Ss tested, both periods and numbers of errors increased with the number of occlusions present. When the eyes of a number of Ss were watched during the course of an experiment, it was indeed found that pursuit movements were discontinuous and tended to be interrupted by momentary fixation, but as this was an observation frequently made in difficult cases, it would be necessary to find a significant correlation between the occurence of such pauses and the presence of a corresponding occlusion at the site of fixation. The effect was not thought to be of sufficient importance to warrant the careful measurements needed to test this hypothesis.

In general, it may be concluded that occlusions or straight-line segments in a pattern make the perception of omega-movement much more difficult and much more variable. The increased periods obtained in the former case are probably due to distorted estimates associated with frequent movement-reversals and momentary fixations, while in the latter case it has been shown that omega-movement is not sustained by linear boundaries.

For circular annuli, the two variables studied were diameter D and thickness T. These were varied within ranges imposed by the conditions under which the experiments were carried out; for example, since the size of the visual noise field (as determined by theprojector lens characteristics) at a distance of 10 feet was about 18" by 24", it was impossible to use a complete annulus whose diameter was greater than 18" at this distance, and since under actual experimental conditions it was rarely possible to attain a

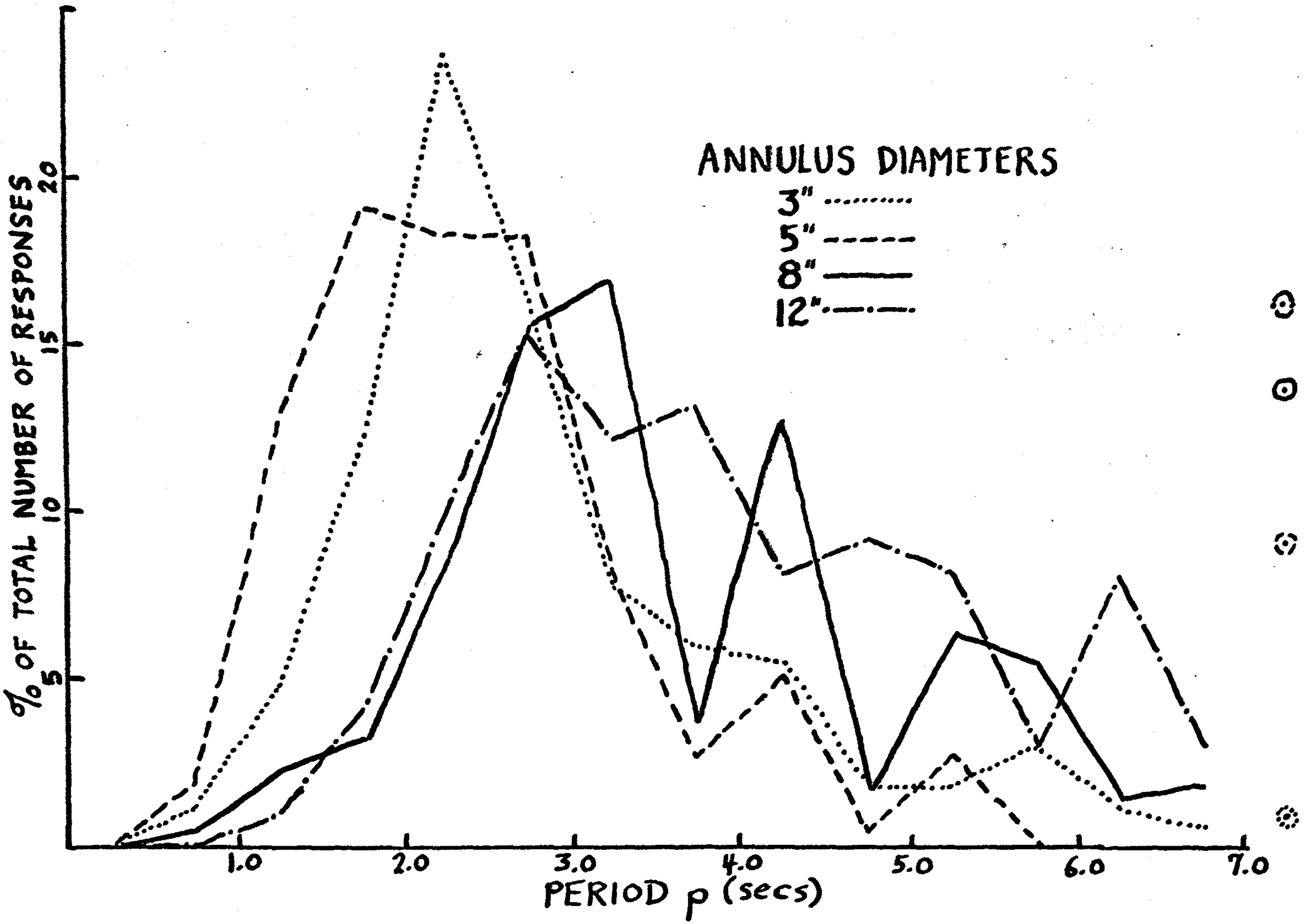


FIGURE 51:

Distribution of estimates of p for narrow annuli of various diameters.

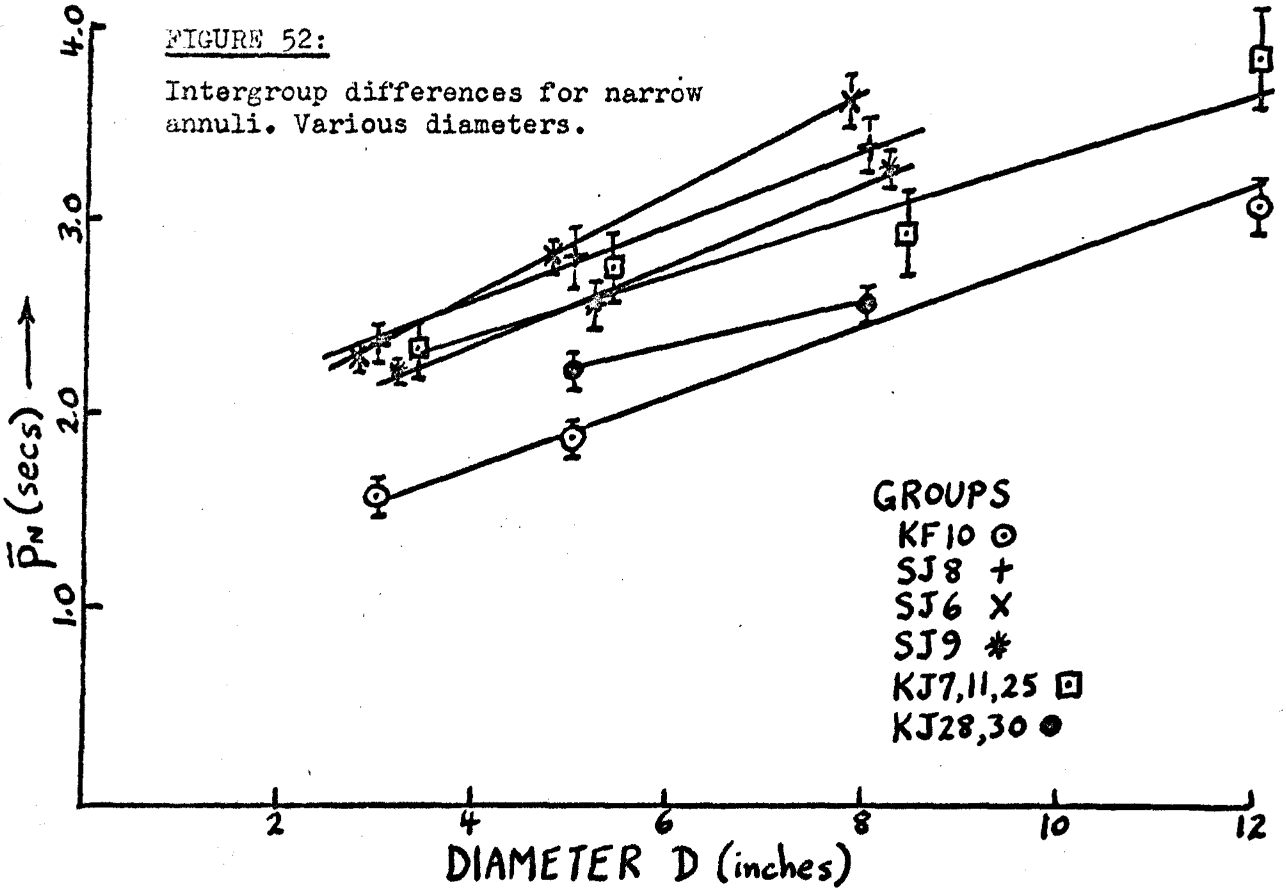


FIGURE 52:

Intergroup differences for narrow annuli. Various diameters.

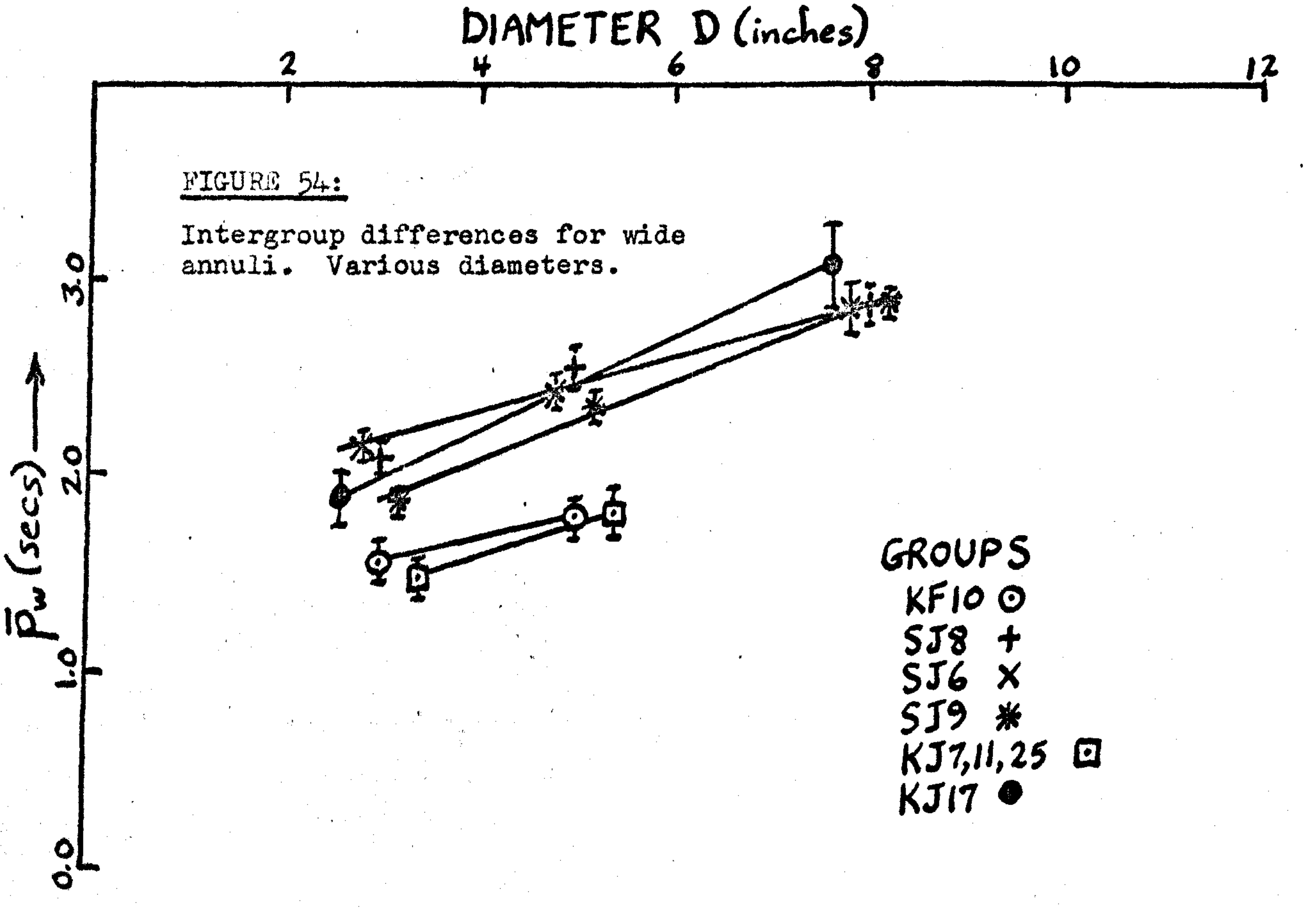


FIGURE 54:

Intergroup differences for wide annuli. Various diameters.

distance of even 10 feet between projector and annulus, a size of D=12" was the practical maximum. Incomplete annuli, such as A (Table 16) could of course be used, but in this case group experiments could not easily be made, and Ss had to be tested individually.

As is indicated by the entries of Table 17, as the diameter of the stimulus-annulus is increased, the period of perceived apparent movement also goes up. Typical distributions of perceived periods for 4 different diameters are shown plotted in Figure 51. Other general tendencies may be noted from these: large diameters tend also to be associated with large variances and a greater number of errors on the part of Ss (this latter is indicated, not only be the greater proportion of responses greater than 7 seconds, as indicated by Figure 51, but also by the increasingly greater percentage of non-responses).

The means of different groups of Ss were calculated for the narrow annuli presented to them, and the results plotted in Figure 52. It can be seen that differences between group means can be quite large but that, independently of this, there always exists an approximately linear relationship between the average estimated period and the annulus diameter, whose slope is of the order of 0.2 $^{\text{seconds}}/\text{inch}$.

D cannot be increased indefinitely, of course, and still be accompanied by an impression of apparent movement sufficiently strong to be measured accurately. When 5 Ss were each given 15 chances to estimate the time T_A taken for omega-movement to traverse the arc-stimulus A, they were able to follow a complete 'crossing' in only 61% of their attempts, and the spread of the responses actually made was quite large. The average value of the 46 estimates made was 1.80 seconds. From the dimensions of A it can

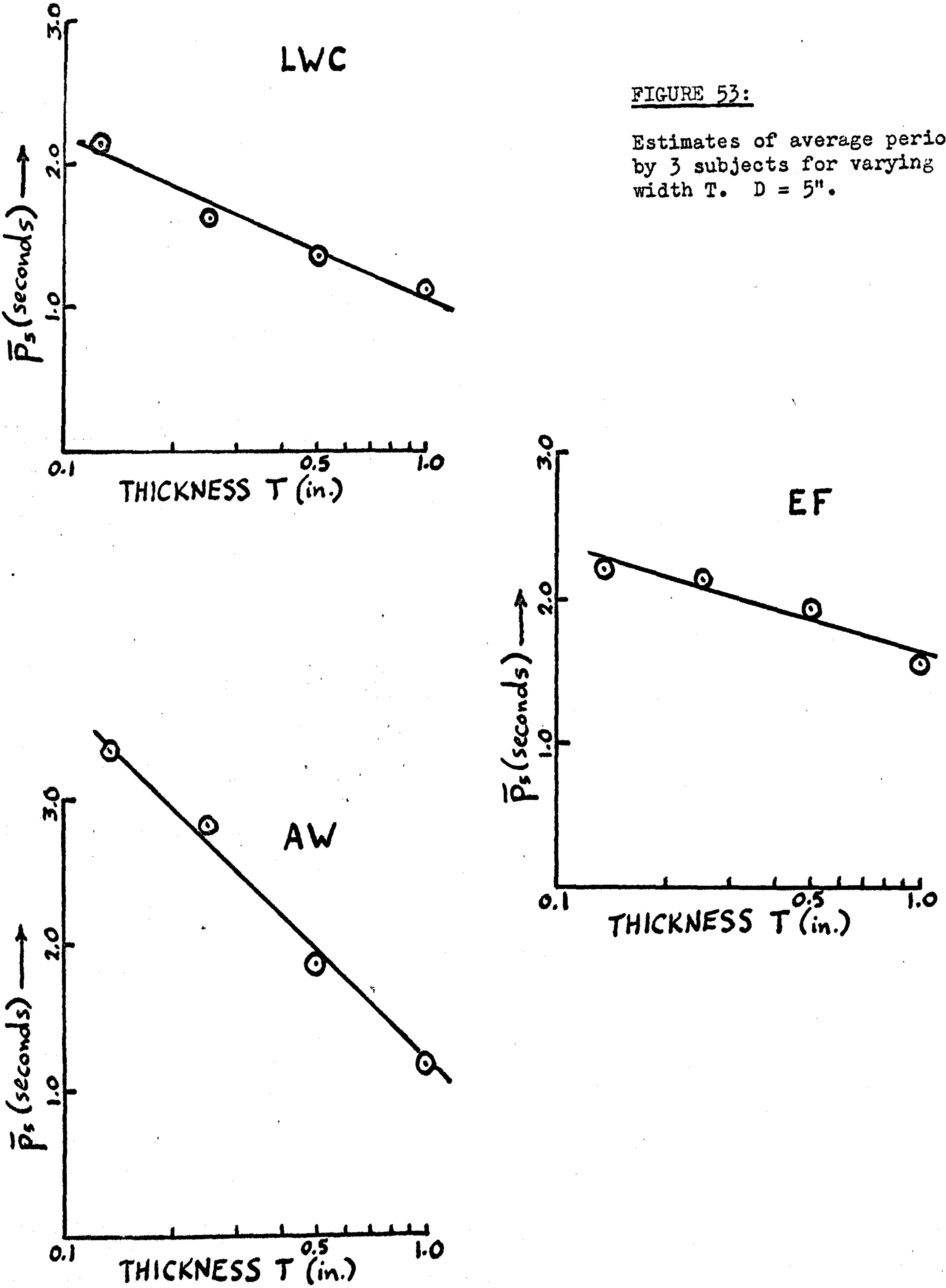


FIGURE 53:

Estimates of average period, $\bar{p}$, made by 3 subjects for varying annulus width T. D = 5".

be calculated that the time necessary for a revolution of the complete 36"-annulus, of which A is a segment, would be $p_{36}=4.2T_A$; in this case, $p_{36}=4.2\times1.80 = 7.55$ seconds. This is of about the same size as one would expect if the linear relation found for smaller annuli extended to larger values, and for all practical purposes such a relationship may be assumed to hold.

If, for an annulus of constant diameter D, the thickness T is allowed to increase, this is usually accompanied by a reduction in the period of omega-movement. The results of 3 Ss, who were required to make estimates on figure V, as the thickness was varied, are shown in Figure 53. For thicknesses greater than 1" (which subtended about 1° at the distance of the Ss) motion became very rapid and difficult to distinguish, and this thickness was therefore considered to be the practical upper limit for the conditions of the experiment.

It can be seen that over the range of T considered, $\bar{p}$ can be described by an equation of the form

$$\bar{p} = a + b \log T \quad (1)$$

This relationship was also verified for larger and smaller diameter annuli; in general, the constants a and b vary with both diameter and subject, the slope b tending to increase with increasing diameter. (It should be noted that, in the experiment as described, it cannot, strictly speaking, be assumed that D remains constant, so far as the underlying perceptual mechanisms are concerned. Whereas the outer diameter of the annulus remains unchanged at 5", T is varied by varying the diameter of the inner border; it is probably true that this results in an accompanying functional decrease in D.

Thus for an outer diameter of 5" and an inner diameter of 3" (so that T=1"), D would more accurately be given as a value of about 4". However, this should result in a change of $\bar{p}$ of only about 1 inch x 0.2$^{\text{seconds}}$/inch = 0.2 seconds at the worst, a magnitude that can be resolved only with difficulty in the results of an individual subject. There is nothing in the data to suggest that relationship 1) would break down if the correction were applied).

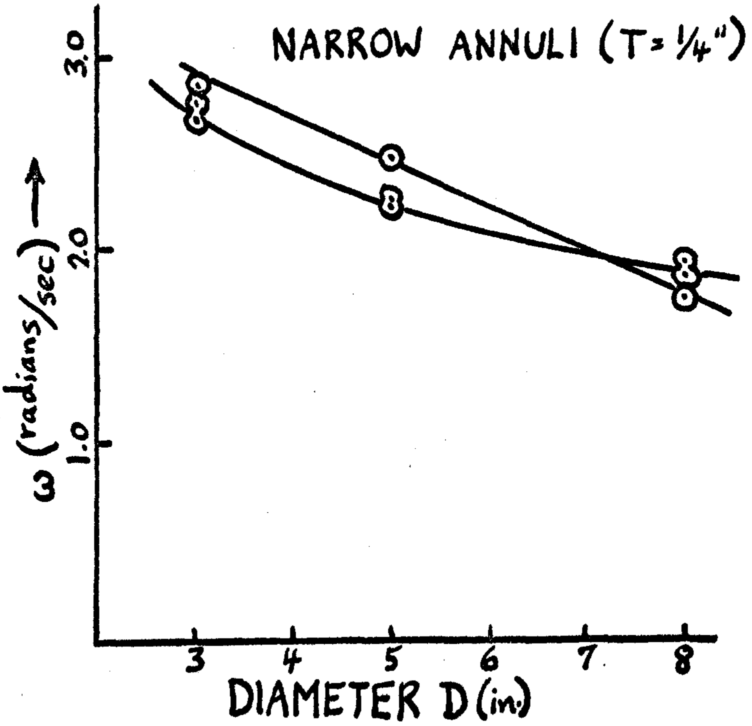
In the main experiments, only 2 different widths T were employed, 0.25 and 0.50 inches, both values which are well within the range for optimal omega movement. Group comparisons have already been made for narrow annuli in Figure 52; some typical values for $\bar{p}_w$ are given in Figure 54. It can be seen that, as before, the slopes of the lines joining the plotted points are each about 0.2$^{\text{seconds}}$/inch, while mean values are lower than for corresponding narrow annuli. (The figure 0.2 is, of course, an order of magnitude from which an actual result will normally deviate. Furthermore, as will turn out, the slope of the $\bar{p}$ vs D does in fact depend on T).

If the central position of stimulus V is offset, so that the annulus is not of constant thickness, a very compelling impression of omega-movement is obtained, and the continuous change of its velocity as it passes from narrower to wider regions is well marked. No measurements were made of the period of apparent movement for this configuration.

As a consequence of the findings reported in this section, Wilson's observation (22) of the dependence of the angular velocity on the stimulus diameter is verified. This is demonstrated in Figure 55, which shows the average values of angular and linear velocities as calculated from the

FIGURE 55 (continued).

Angular velocities, ω:



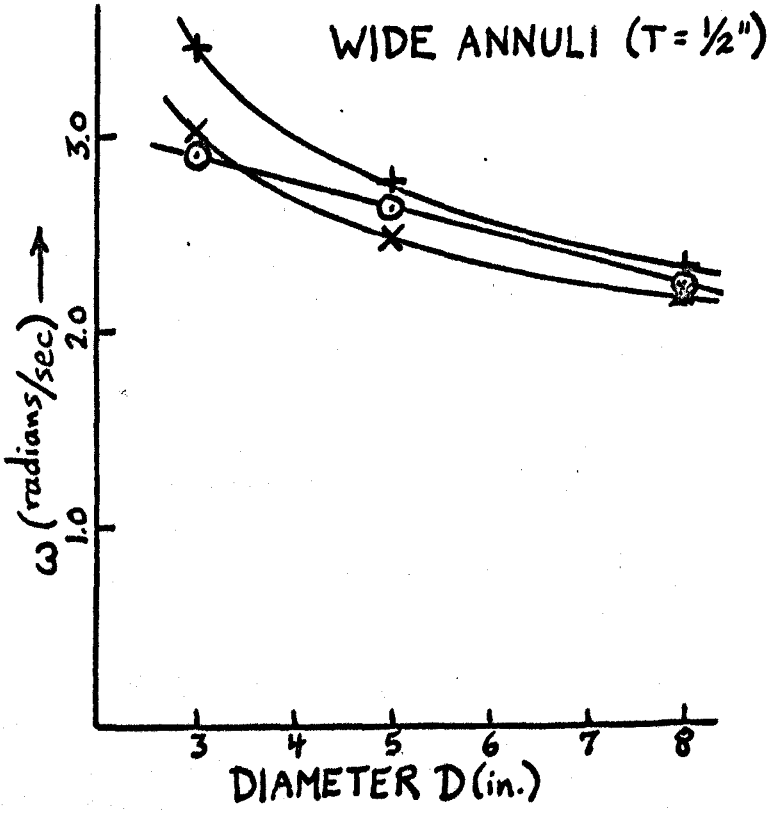
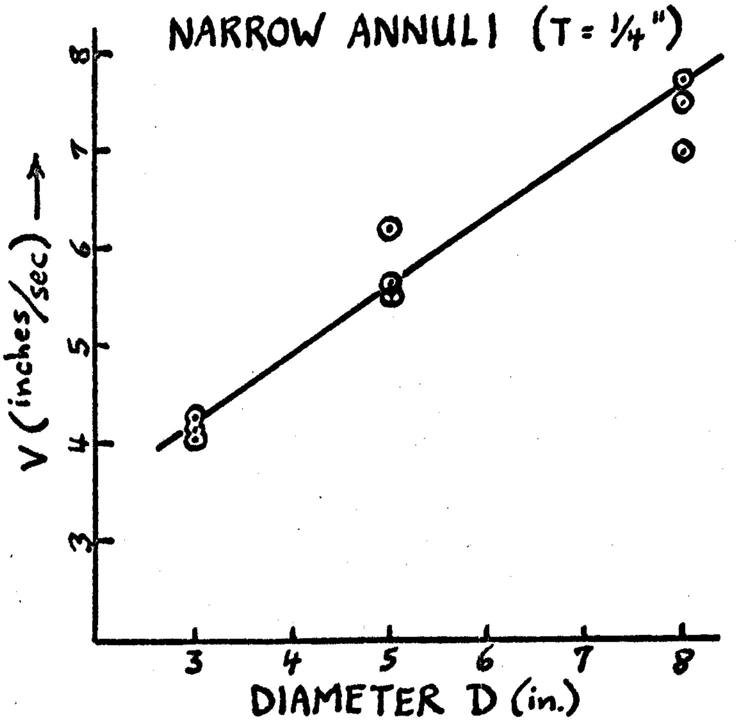
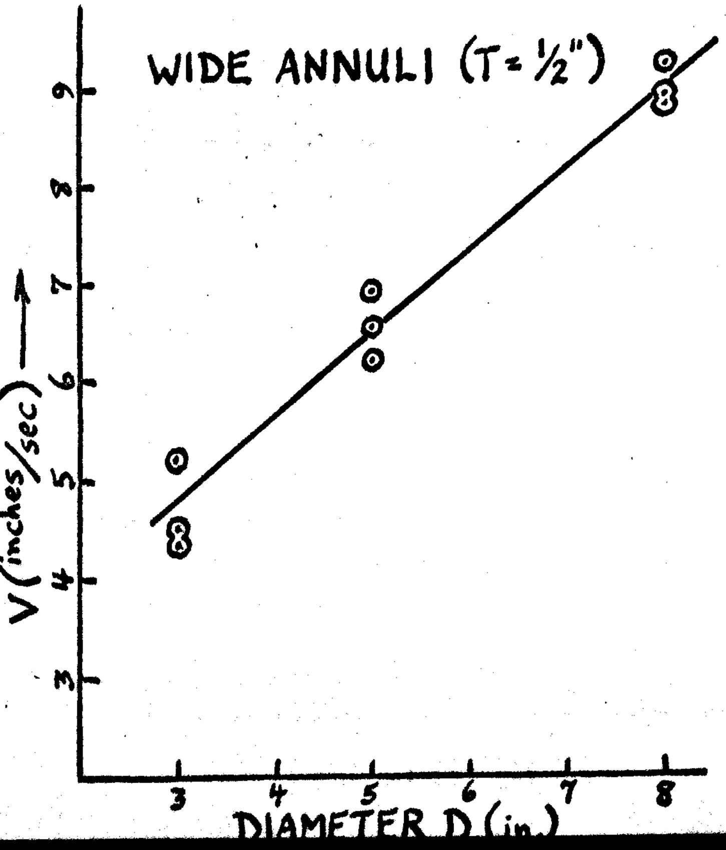


FIGURE 55:

Group ST. Linear and angular velocities as a function of annulus diameter D.

Linear velocities, V:





results of 3 groups of subjects. (The only figures presented to these Ss were 3N, 3W, 5N, 5W 8N and 8W, and the 3 groups thus represent the most intensive study performed on simple, circular annuli). In general, as found by Wilson, angular velocity decreases as stimulus diameter goes up, and (not recorded by Wilson) increases as annular thickness increases. Corresponding statements can be made for linear velocity as far as T is concerned, but an increase of diameter is accompanied by an increase of linear velocity. (The latter is just a reflection of the fact that the rate of decrease of the angular velocity with D is not sufficient to offset the rate of increase of the annulus radius with D). As has been mentioned previously, the variation of $\bar{p}$ with D for constant T is approximately linear i.e.

$$\bar{p} = c + d\,D \qquad (2)$$

It follows that the angular velocity, being an inverse function of $\bar{p}$, can be expected to deviate from linearity, and this tendency can be seen in the data of Figure 55. The linear velocity, on the other hand, is given by $\pi D/\bar{p}$, so that both numerator and denominator are linear functions of D. Thus, provided the range of D is not too large, it is possible to describe the dependence of the linear velocity on D in a linear form: use will be made of this fact in a later section, but for the present, the effect can be seen by an inspection of the plotted points of Fig. 55.

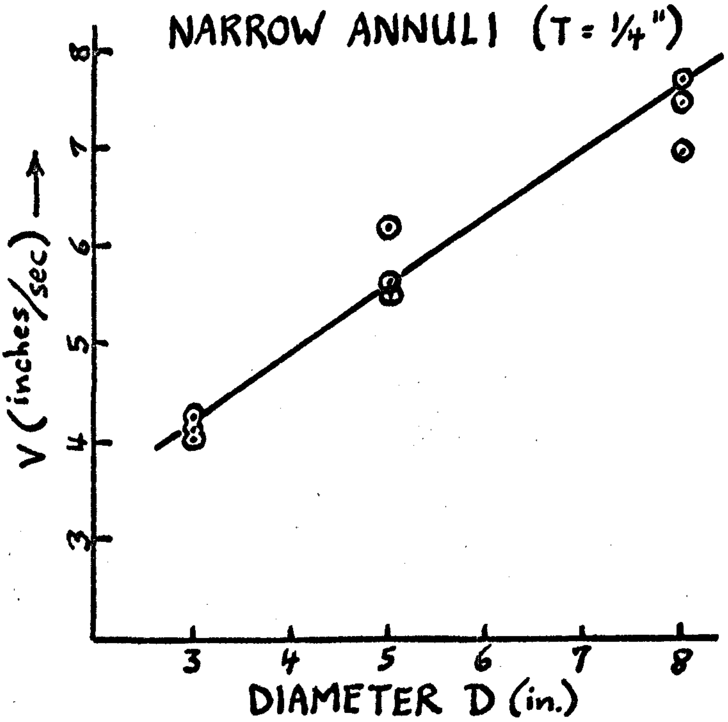
From equations 1) and 2), it follows that the following fundamental relationship holds between $\bar{p}$ and the diameter D and thickness T of a circular annulus:

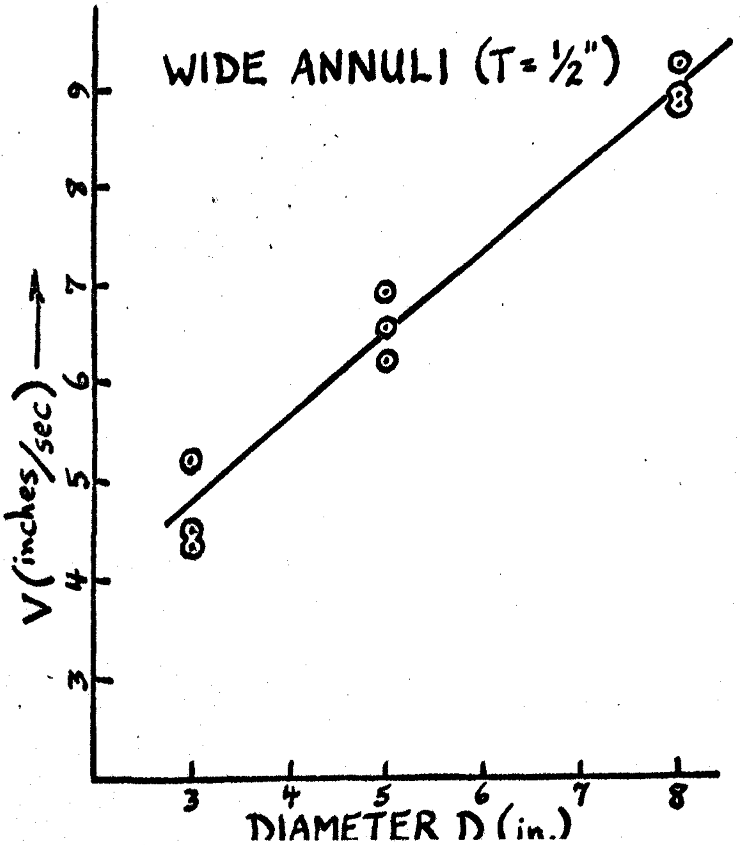
$$\bar{p} = K_1\, D \log T + K_2 \log T + K_3\, D + K_4\,, \qquad (3)$$

FIGURE 55:

Group ST. Linear and angular velocities as a function of annulus diameter D.

Linear velocities, V:





results of 3 groups of subjects. (The only figures presented to these Ss were 3N, 3W, 5N, 5W 8N and 8W, and the 3 groups thus represent the most intensive study performed on simple, circular annuli). In general, as found by Wilson, angular velocity decreases as stimulus diameter goes up, and (not recorded by Wilson) increases as annular thickness increases. Corresponding statements can be made for linear velocity as far as T is concerned, but an increase of diameter is accompanied by an increase of linear velocity. (The latter is just a reflection of the fact that the rate of decrease of the angular velocity with D is not sufficient to offset the rate of increase of the annulus radius with D). As has been mentioned previously, the variation of $\bar{p}$ with D for constant T is approximately linear i.e.

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$$\bar{p} = K_1\,D \log T + K_2 \log T + K_3\,D + K_4\,, \qquad (3)$$

where K_1, K_2, K_3 and K_4 are constants depending only on the subject or group of subjects under consideration.

For any individual case, the K_i can be determined either by selecting 4 experimentally determined values of $\bar{p}$, substituting these in the equation with corresponding values of D and T, and solving the resulting four simultaneous linear equations for the K_i, or by a graphical method. The former method, which obviously results in an exact fit for 4 points, disproportionately weights these points by assuming them to be exact; the extent of the approximation thus made can be measured by the deviations from prediction of the unused points. The graphical method, on the other hand, accepts the variability of the results and smooths it, giving each experimental point equal weight. The method is based on the following deductions from equation (3):

1. If two stimulus-patterns of thicknesses N and W have equal diameters $D_N = D_W = D$, then substituting and subtracting in (3) yields

$$\Delta_T \bar{p} = \bar{p}_N - \bar{p}_W = K_1 \, D \log \left({}^{T_N}/_{T_W} \right) + K_2 \log \left({}^{T_N}/_{T_W} \right) \qquad (4).$$

Thus the difference between the average period of a narrow and a wide annulus is a linear function of the (common) diameter. A plot can be made of these two variables, a straight line fitted, and the slope and intercept of the latter measured. Then, from (4), the equations $K_1 \log \left({}^{T_N}/_{T_W} \right)$ = slope and $K_2 \log \left({}^{T_N}/_{T_W} \right)$ = intercept give estimates of K_1 and K_2 respectively.

2. If, for the two patterns of diameters B and S, $T_B = T_S = T$, then

$$\Delta_D \bar{p} = \bar{p}_B - \bar{p}_S = K_1 \, (D_B - D_L) \log T + K_3 \, (D_B - D_L) \qquad (5),$$

Group	K_1	K_2	K_3	K_4
SJ6	-0.413	0.680	0.015	1.908
SJ8	-0.173	-0.375	0.103	1.499
KJ7,11,25	-0.206	-2.16	0.020	0.619
SR	-0.095	-0.780	0.150	1.089

Group	SJ6		SJ8		KJ7,11,25		SR	
STIM.	PRED.	EXPTL.	PRED.	EXPTL.	PRED.	EXPTL.	PRED.	EXPTL.
3N	2.29	2.29	2.35	2.35	2.35	2.32	2.18	2.22
3W	2.12	2.12	2.08	2.08	1.52	1.48	1.86	1.81
5N	2.82	2.80	2.76	2.80	2.64	2.75	2.60	2.53
5W	2.40	2.40	2.39	2.53	1.68	1.79	2.22	2.27
8N	3.61	3.61	3.38	3.38	3.07	2.92	3.22	3.27
8W	2.82	2.82	2.85	2.85	1.93	-	2.75	2.72

TABLE XIX: K_i and predicted $\overline{p_s}$ for 4 groups

TABLE XX: K_i and fitted values for 2 Ss.

	KAS	KB
K_1	-0.382	-0.041
K_2	0.581	-1.821
K_3	0.038	0.050
K_4	2.208	1.179

	KAS		KB	
	PRED.	EXPTL.	PRED.	EXPTL.
3N	2.44	2.45	2.50	2.43
3W	2.26	2.22	1.91	1.88
5N	2.82	2.92	2.65	2.74
5W	2.42	2.25	2.04	2.17
8N	3.40	3.08	2.87	2.76
8W	2.65	3.06	2.23	2.22

a linear function of $\Delta D = (D_B - D_L)$, with slope $(K_1 \log T + K_3)$ and intercept zero. A plot can then be made of $\Delta_D \bar{p}$ vs ΔD, a measurement made of its slope and, from a knowledge of T and K_1, as found above, K_3 can be calculated. If several different values of T are available, each results in an estimate of K_3, and in this way an average value of K_3 can be found.

3. Having determined K_1, K_2 and K_3, a set of values $(\bar{p} - K_4)$ can be calculated, one for each combination of T and D. These are now subtracted from the corresponding experimental values of $\bar{p}$, and estimates of K_4 obtained in this way. The value of K_4 finally used is that found by averaging those estimates.

The K_i were calculated for four groups of Ss, and predictions made from equation (3) and compared with the actual experimental results. The values are shown in Table 19. For groups SJ6 and SJ8, the K_i were found by the first method, using the results of stimuli 8N, 8W, 3N and 3W; the graphical method was employed for the other two groups. It can be seen that, irrespective of the method used, the fits are quite good; the largest deviations are of the order of 0.15 seconds, a value comparable to the standard errors of the means under consideration.

As far as individual Ss are concerned, a surprisingly good fit is often attained by the graphical approximation method, even when the straight lines are drawn by eye, and despite considerable variability. Table 20 shows the results of 2 Ss chosen at random. Again, deviations are not significantly greater than the standard errors of the means.

xxv) Effect of distance.

MacKay (27) reports that the period of omega-movement is not critically dependent on the angular subtense of the annulus being used, and, under certain conditions, this was found to be the case. In MacKay's experiments, angular subtense was varied by changing the distance between the stimulus-annulus (which remained of constant dimensions) and the observer. It is obvious that the effect of this is to change all linear dimensions of the retinal image of the annulus by a factor $a = {}^{d}/d^{1}$, where d is the original distance of S from the annulus and d^{1} is the second distance. Suppose for the moment that the period of the apparent movement depends only on the retinal dimensions of the annulus, and that d^{1} is greater than d. Then $a < 1$, the diameter of the retinal projection at d^{1} is less than it was at d, and, other things being equal, the period of omega-movement should decrease. But this is only the case if the thickness T of the retinal projection remains unaltered; in fact, T will suffer a proportional reduction which, of course, will tend to increase $\bar{p}$.

Thus a change in distance involves the interaction of two antagonistic factors, and the net change to be expected in the value of $\bar{p}$ will be i) less than the change resulting from independent variation of the parameters D and T, and ii) dependent on the relative strengths of these two variables, as far as the visual system is concerned, in producing a change of the period. Nor can it be said that these relative strengths act independently of one another. Partially differentiating equation (3) with respect to D and T, and setting the ratio of the derivatives, $\frac{\partial \bar{p}}{\partial D} / \frac{\partial \bar{p}}{\partial T}$, equal to -1 (the condition for equal and opposite effects) leads to the relation:

$$(K_1 \log T + K_3)\, T + (MK_1)\, D + MK_2 = 0 \qquad (6)$$

where M = constant = $\log_{10} e$. Since there generally exists a positive solution (D,T) to this equation for values of the K_i normally encountered, small changes about these values will have no effect provided they are in the same direction. Larger deviations, on the other hand, will lead to the ascendancy of either the D-effects or the T-effects, depending on the sign of these deviations and the particular values of the K_i involved.

It can be seen that, for example, group and individual differences in sensitivity to angular subtense will be just as marked as differences in some function of the coefficients K_i. Thus one would expect different subtense effects (even to the extent of sign changes) from subject to subject and stimulus to stimulus, and, since the effect is small in any case, the overall change measured could quite easily be zero.

(Implicit in all that has been said is the assumption that changes in the characteristics of the visual noise, contingent upon changes in distance, do not result in any significant effect. In view of the experiments on the noise statistics already described, this assumption is probably justified).

From the fundamental equation, (3), it is possible to make an explicit prediction of the effect which should be observed when distance is changed from an old value d to a new one d^1. If $a = {}^{d}/d^1$, then $D^1 = aD$ and $T^1 = aT$, where the notation is as before. Substituting ,

$$\overline{p}^1 = aK_1\, D \log T + K_2 \log T + a(K_3 + K_1 \log a)\, D + (K_4 + K_2 \log a). \qquad (7)$$

The new period is $\overline{p}^1$, and the coefficients are the former values of the K_i, as determined at distance d, modified by terms depending on a. The expression for the change in period, $\overline{p}$ to be expected, is

$$\Delta\overline{p} = \overline{p}^1 - \overline{p} = K_1(a-1)\, D \log T + (aK_1 \log a + K_3(a-1))\, D + K_2 \log a \qquad (8)$$

and it can be seen, in agreement with the former qualitative arguments, to be a complicated function of both stimulus and group-to-group variables.

To put the above predictions to the test, the following experiment was performed. Stimuli used were the simple circular annuli 3N, 3W, 5N, 5W, 8N and 8W; subjects were 22 volunteers who each participated in two group sessions within three days of one another, although, since other Ss were present during the experiments, the groups were not composed of the same members. Thus a total of 44 response sheets were obtained from the 22 Ss, representing test and retest conditions. Since each pattern was presented either 3 or 4 times during a single session, values of $\bar{p}$ based on up to 132 or 176 separate responses, respectively, to each pattern could be calculated, pooling all the results of each S for each stimulus, Values of the K_i were then found, and equation (3), for all the results, turned out to be

$$\bar{p} = -0.137 \, D \log T - 0.531 \log T + 0.137 \, D + 1.293 \qquad (9)$$

The goodness of fit of this expression can be evaluated from the predicted and actual results presented in Table 21(a). The average distance $\bar{d}$ of all Ss taken over both sessions (and therefore a total of 44 values) was calculated and found to be 6.973 ± 0.3 units, and this was taken as the value of d below ('Units' are not Ss' actual distances, but are in direct proportion to these: 10 units approximately equal 1 foot).

Now considering the 2 x 22 = 44 Ss as members of a single group, whose performance is described by equation (9) above, it is assumed that any random selection of a sufficiently large number of Ss from the group will result in a set of $\bar{p}$ which approximate those predicted by (9). The 44 Ss were then redivided into two groups of 22 each, called for convenience F and N, according to the following criterion: since each S was tested twice, and since he generally observed from a different distance during each session,

(a) Predicted and actual values of pooled TEST/RETEST results of 22 Ss.

STIMULUS:	3N	3W	5N	5W	8N	8W
PRED:	2.27	1.99	2.71	2.35	3.37	2.88
EXPTL:	2.30	1.97	2.65	2.36	3.41	2.87

(b) Predicted and actual values of $\bar{p}_N$ for N group

PRED:	2.31	2.00	2.79	2.39	3.53	2.98
EXPTL:	2.23	1.91	2.58	2.30	3.59	2.91

(c) Predicted and actual values of $\bar{p}_F$ for F group.

PRED:	2.24	1.97	2.64	2.30	3.24	2.79
EXPTL:	2.43	1.91	2.77	2.40	3.29	2.72

TABLE XXI : DISTANCE EFFECT

he was obviously nearer the stimuli in one case than in the other. One of his response sheets, then, was placed in category N (near) and the other in category F (far). The two groups N and F are thus approximately matched in all respects except that of distance; the average values of the latter were calculated and found to be $\bar{d}_N = 5.968 \pm 0.4$ units for group N and $\bar{d}_F = 7.977 \pm 0.3$ units for group F. Therefore, the ratios a for the two cases are, respectively $a_N = d/\bar{d}_N = 1.1684$ and $a_F = d/\bar{d}_F = 0.8741$. By the assumption made, it is possible to invoke equation (7) and, using the values of a_N, a_F, and K_i as obtained from (9), get

$$\bar{p}_N = -0.160\ D \log T - 0.531 \log T + 0.148\ D + 1.252 \qquad (10)$$

and

$$\bar{p}_F = -0.120\ D \log T - 0.531 \log T + 0.127\ D + 1.324 \qquad (11)$$

The values of $\bar{p}$ predicted by these formulae for each of the annuli are shown in Table 21(b) and (c); the actual experimental averages are also entered for comparison.

It can be seen that the fit is not as good as would normally be expected, except for the larger annuli (where predicted values start to diverge significantly). For the rest, the small differences in expected values probably cannot be expected to be resolved even by a more accurate fit; the standard errors of the means swamp any difference which might exist. What is found, however, is that 4 out of 6 predicted 'F' values underestimate the true values, while 5 of 6 predicted 'N' values overestimate these, by average values of 0.06 seconds and 0.08 seconds respectively. Since, according to prediction, 'F' averages should be uniformly smaller than corresponding 'N' averages, this means that experimental values tend to be more closely packed than the theory developed predicts: the Ss who were members of the F group behaved as if they were nearer and the Ss in the N group as if they were farther from the stimuli than they actually were. This could be interpreted as the presence of a slight degree of size constancy, although the variability of the results and the slight amount of constancy to be expected under the experimental conditions (95, 96) interact to make the effect uncertain.

The only difference between mean values that is statistically significant is that obtained for the 8N stimulus and, assuming that the various predicted values are subject to standard errors of similar size, this statement is also true of differences between predicted values. As has been mentioned, the former difference is in the direction predicted by theory, and is of about the same magnitude.

One of the difficulties of the experiment just described is the relatively small difference between the average distances of the two groups which, as has been shown, does not result in sufficient divergence of predicted values to enable theory to be adequately tested. This situation could be remedied by only using Ss at the extremes of their groups, but both total number of Ss and group matching with respect to subjects would then suffer, with consequent greater variability of experimental averages (as well as less justification for making predictions from an equation based on the average results of all Ss combined). If the latter difficulty must be endured, it is at least possible to modify its effect somewhat by increasing the total number of Ss participating, and this is what has been done in the next experiment.

The results of a total number of 55 naive Ss, all of whom had been

STIM.	TOTAL		GROUP N		GROUP M		GROUP F	
	PRED.	EXPTL.	PRED.	EXPTL.	PRED.	EXPTL.	PRED.	EXPTL.
3N	2.30	2.33	2.52	2.56	2.25	2.34	2.18	2.00
3W	2.08	2.04	2.16	2.18	2.05	2.16	2.01	1.72
5N	2.76	2.71	3.14	3.05	2.67	2.56	2.54	2.48
5W	2.41	2.46	2.56	2.76	2.37	2.45	2.29	2.08
8N	3.45	3.49	4.07	3.86	3.31	3.22	3.09	3.28
8W	2.91	2.87	3.16	3.25	2.83	2.70	2.70	2.54

TABLE XXII: Predicted and experimental values of 49 Ss, grouped according to distance and stimulus.

presented with the usual simple, circular figures under similar conditions were analyzed according to the method outlined above. Of the Ss, 6 gave results that were fragmentary, either due to mistakes in which the sequence of responses got out of order, or due to the absence of a large number of responses, and all the results of these 6 Ss were rejected. The remainder were divided into three groups, N, M and F, consisting respectively of 20 Ss, 15 Ss and 14 Ss; the average distances of these three groups from the stimuli were about 3.50 feet, 7.00 feet and 8.75 feet. The average distance for all Ss in all groups was 6.07 feet, and so, for the three groups, $a_N = 1.735$, $a_M = 0.867$ and $a_F = 0.694$, where the a_i are, as before, the factors by which linear dimensions must be multiplied to allow for a change in distance. Again, for each stimulus, an average period $\bar{p}$ was calculated from the pooled results of all Ss, and these averages were fitted by equation (3):

$$\bar{p} = -0.212\ D \log T - 0.100 \log T + 0.102D + 1.552 \qquad (12)$$

From equation (7), the K_i exhibited in (12), and a_N, a_M and a_F, it is possible to obtain:

$$\bar{p}_N = -0.368\ D \log T - 0.100 \log T + 0.089\ D + 1.528 \qquad (13)$$

$$\bar{p}_M = -0.184\ D \log T - 0.100 \log T + 0.100\ D + 1.558 \qquad (14)$$

$$\bar{p}_F = -0.147\ D \log T - 0.100 \log T + 0.094\ D + 1.568 \qquad (15)$$

Values of D and T were then substituted in equations (13), (14) and (15) and the resulting predictions compared with corresponding experimental values in Table 22. Data associated with equation (12) are also included.

Although differences between theory and experiment are often of the same order of magnitude as before, it can be seen that predicted values for the three groups now diverge sufficiently to make the result clear. With respect to groups N and F it may be stated that 1) each pair of experimental values differs significantly 2) this difference is always in the direction predicted by theory 3) each pair of predicted values, except for 3W, differs significantly 4) no pair of predicted/experimental values differs significantly, except for 8 N (group N) and 3W (group F). Furthermore, in accordance with prediction, with one exception, there is a continuous gradation of larger to smaller values of average periods through groups N, M and F, in that order.

As for group M, much the same situation exists as for the experiment reported previously; since a_M is close to unity, predicted values on the whole do not diverge sufficiently to detect differences between group M means and those of all Ss taken together.

It should be noticed that the finding of systematic over-and under-estimation of 'N' and 'F' values made during the first experiment, and tentatively attributed to size constancy, is reversed in the present experiment. These results are difficult to reconcile on a constancy hypothesis; the most probable explanation is that both sets of deviations are due to random errors.

The data for the three groups are plotted against angular subtense in Figure 56 and 57. The solid line represents the theoretical expectation for each stimulus, while the plotted points are those values actually found experimentally; the latter can be seen to be grouped fairly well about the theoretical lines. There is perhaps some indication that the predictions are less accurate when angular subtense is smaller than about 2°-$2\frac{1}{2}^\circ$, actual

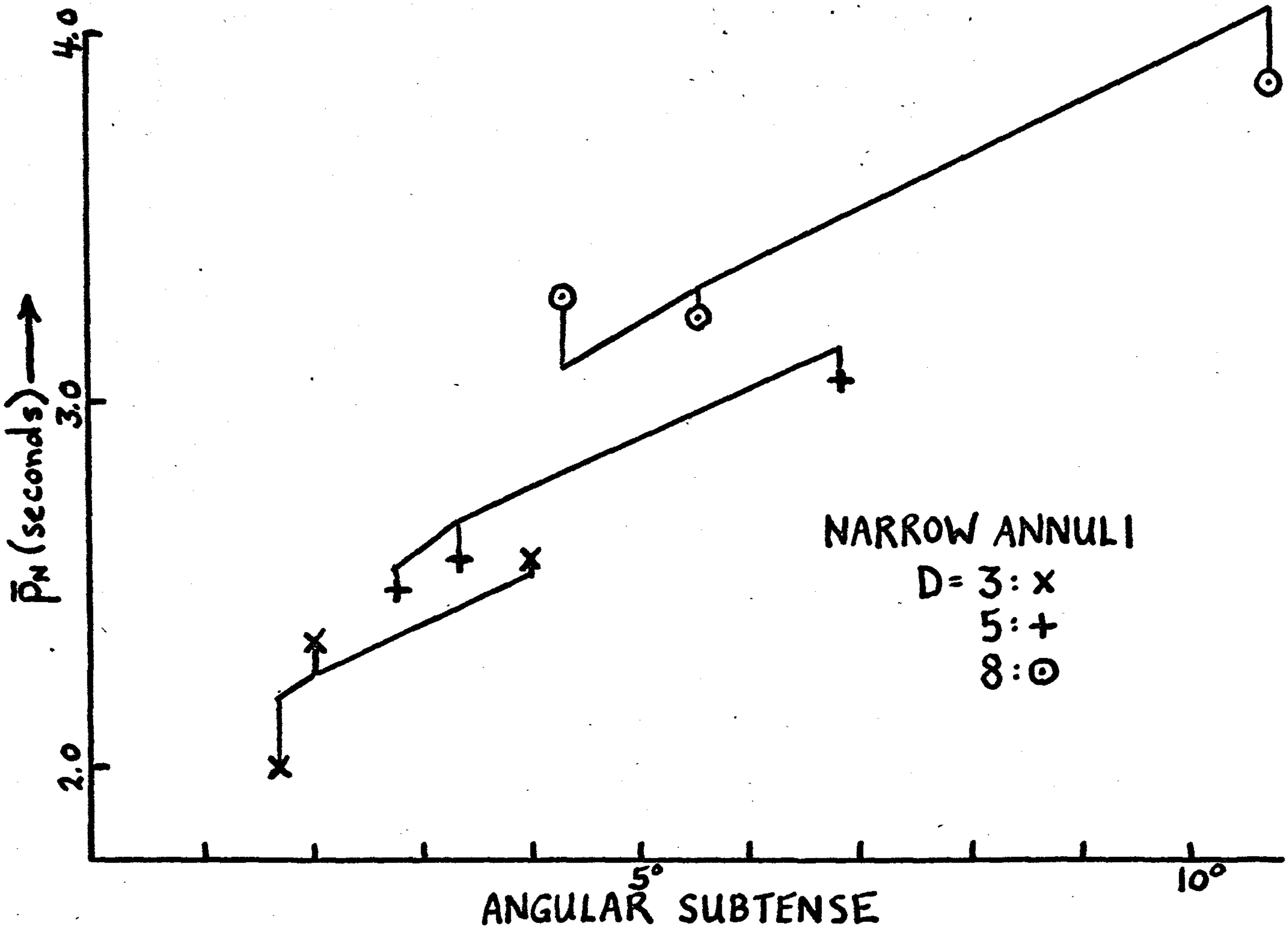


FIGURE 56:

Average periods vs angular subtense. The solid lines drawn represent predicted values.

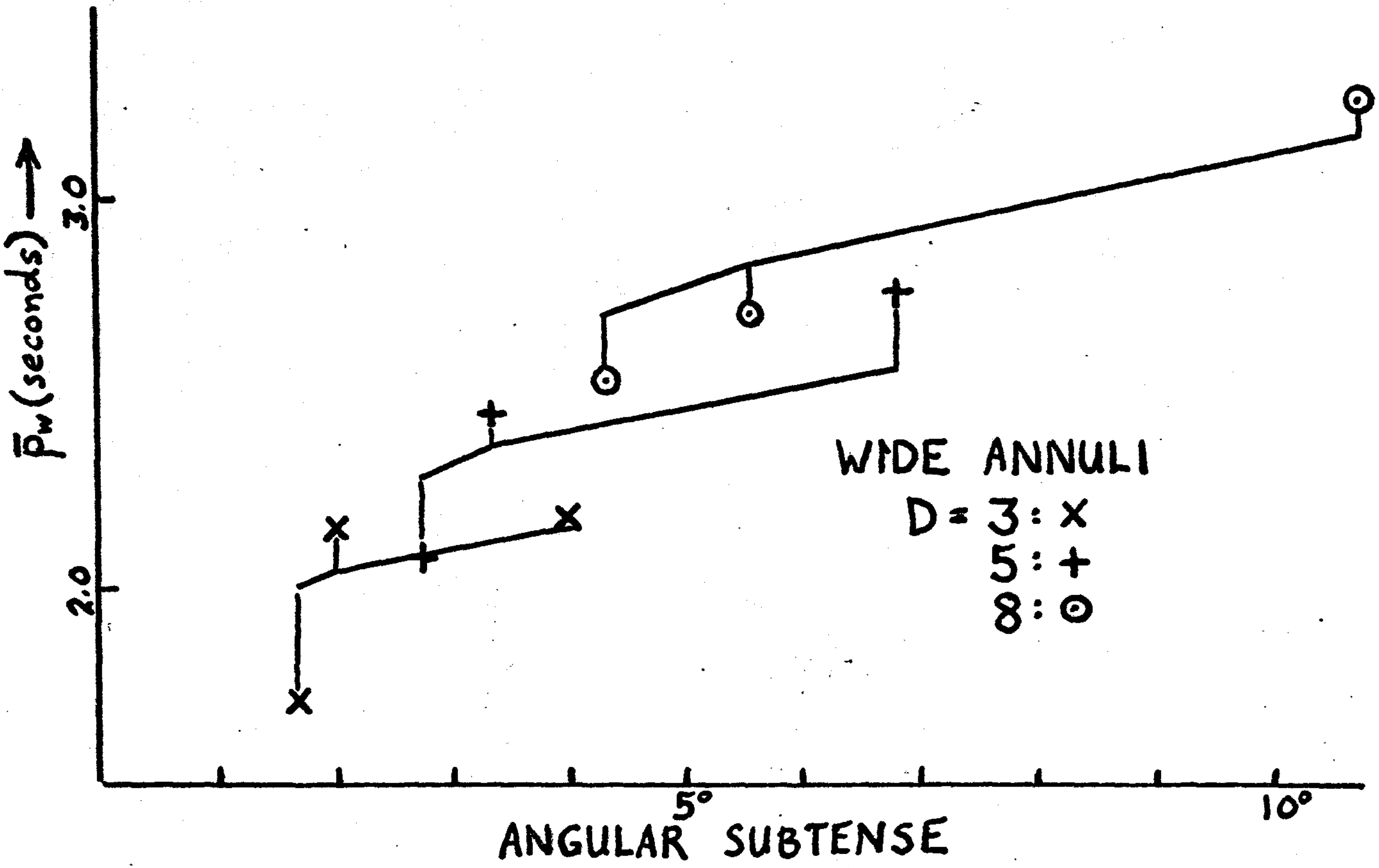


FIGURE 57:

Average periods vs angular subtense. The solid lines drawn represent predicted values.

values tending to be lower than expected ones. If this effect is real, the subtense at which it starts to appear suggests that foveal characteristics are somehow involved, and that when a significant fraction of the whole image of a figure falls on the fovea, these characteristics result in increased velocity of apparent movement.

Figures 56 and 57 also summarize the differences in subtense-sensitivity to be expected among annuli of different dimensions as subtense varies by a factor of about 2.5; in general, wide annuli are less affected by changes in subtense than narrow ones while, for annuli of constant thickness, diameter differences result in little change of sensitivity.

It may be concluded that the fundamental equation (3) can safely be used to predict the behaviour of $\bar{p}$, not only for independent changes of D and T, but also for more complicated cases, where a change of one variable results in a change of the other. For the experimental conditions obtaining, variations in $\bar{p}$ are a function of variations of the retinal image of the annulus.

xxvi) <u>Effect of angle of regard.</u>

The results of the preceding experiment implied that characteristics of the retinal image of the stimulus used play a dominant part in the production (or at least the modification) of omega-movement. If this is true, then it might be suspected that there will exist differences between the results of Ss who are positioned directly in front of a circular annulus, and those who are viewing it from some angle. For the former Ss, the retinal projection of the annulus is, of course, a circle; for the rest, the retinal projection is an ellipse of greater and greater eccentricity as angle of regard θ increases. The projection in any particular case can be described by the equation:

$$x^2 + y^2 \cos^2 \theta = b^2 \cos^2 \theta \qquad (16)$$

where b is proportional to the radius of the circular annulus used, and θ is the angle between S's line of regard and the normal drawn from the plane of the stimulus.

It is possible to argue that any effect of this distortion might be modified by shape constancy; Corbin (97) reported, for example, that under similar circumstances the simultaneity-movement threshold of the phi-phenomenon remained invariant even though his stimuli were viewed at visibly oblique angles of up to 60°, resulting in a change of retinal projection by a factor of 2. Although the effect of size constancy, as shown in the preceding section, is slight, experimental conditions still afford some cues to depth, and shape constancy involvement is a real possibility.

Having made two assumptions, it is possible to make a precise prediction of the effect of non-zero θ. These assumptions are:

1. Constancy effects are absent (Apparent motion is a function of the retinal projection alone).
2. The velocity of apparent movement at any point is a linear function of the local radius of curvature at that point only. (Interactions between contours whose projections are widely separated on the retina, as far as the omega-effect is concerned, do not occur). That the velocity of apparent movement can be approximately described as a linear function of diameter for a given constant annulus thickness has been pointed out in Section xxiv) (cf. Figure 55). It follows that, over the range of interest,

$$V = p + q\rho \qquad (17)$$

where v is the linear velocity of omega-movement and ρ is the local radius of curvature of the figure.

Now, for an ellipse, the radius of curvature p is continuously changing and by equation (17) and the above assumptions, it can be seen that so is the velocity of apparent movement, the latter going through maxima and minima with the former. Since the velocity of apparent movement is therefore not constant, it cannot be said that its period will be any simple function of the annular parameters; in fact, it can be shown to be given by the rather formidable expression

$$\bar{p} = 4\int_0^a dx/\left\{a\sqrt{a^2-x^2}\left[(a^4 + (b^2-a^2)x^2)\,q/ba^4 + p/\sqrt{a^4 + (b^2-a^2)x^2}\right]\right\} \qquad (18$$

where p and q are the constants which appear in equation (17), and a^2 and b^2 are defined by the equation of the ellipse $x^2/a^2 + y^2/b^2 = 1$. Equation (18), then, gives the time $\bar{p}$ required for a point to move completely around the circumference of the given ellipse, if its linear velocity varies with the radius of curvature according to equation (17). If a = b, the ellipse becomes a circle of a radius a, and (18) reduces to

$$\bar{p} = 4\int_0^a dx/\left\{a\sqrt{a^2-x^2}\left[q/a + p/a^2\right]\right\}$$

$$= \frac{4a}{p+qa}\int_0^a dx/\sqrt{a^2-x^2}$$

$$= 2\pi a/(p+aq)$$

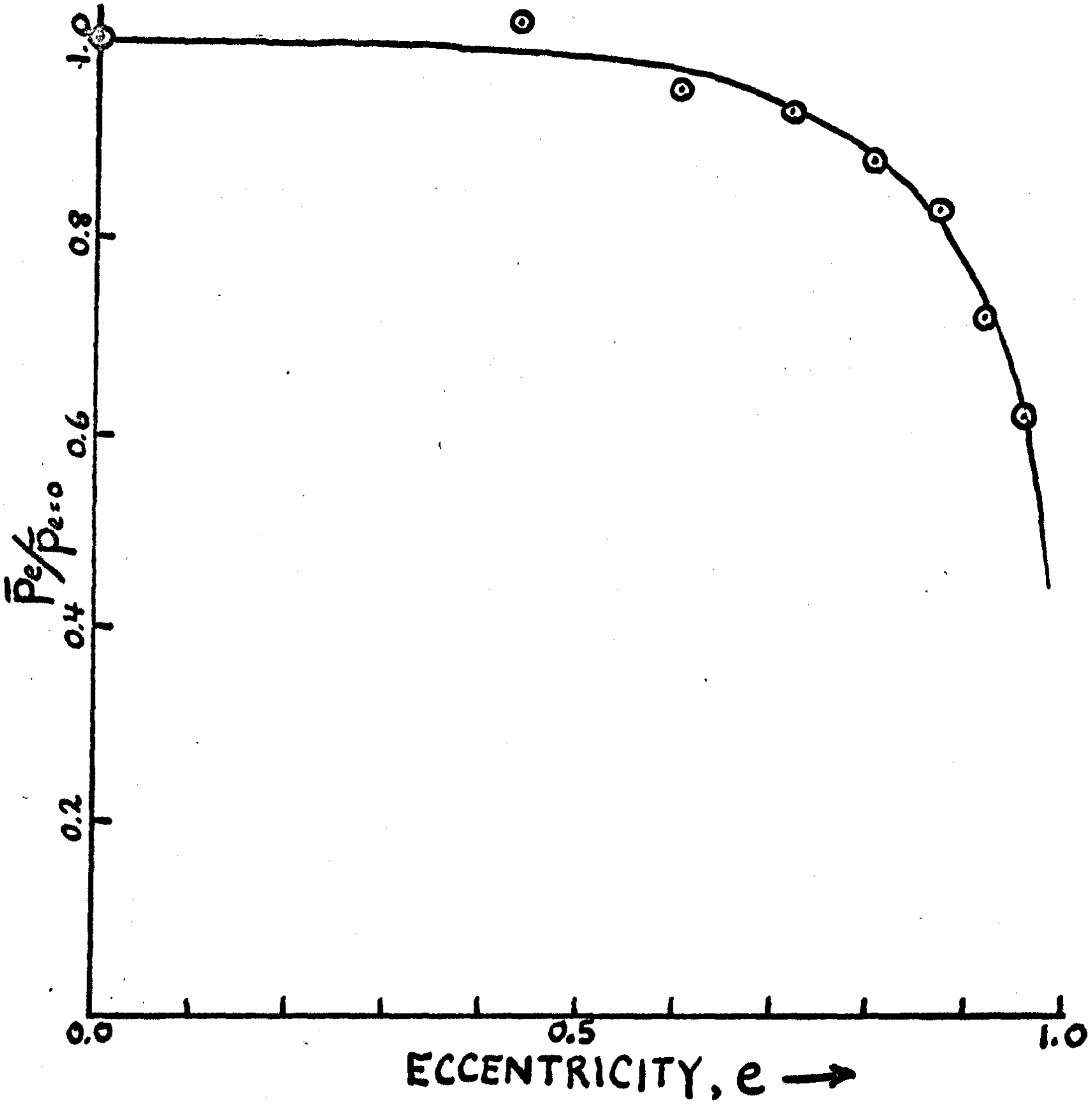
$$= \text{circumference of circle}/\text{linear velocity},$$

as required.

It was not possible to obtain a closed form of the solution of the general equation, so analytic methods were abandoned and resort had to approximations. It turned out that by setting a = 5.0, for example,

FIGURE 58:

Theoretical variation of average period with angle of regard θ. The latter values are expressed in terms of ellipse eccentricity e.



	a) S Repeats		b) 55 Ss	
Stim.	S	L	S	L
3W	1.95	1.99	2.09	2.21
5W	2.36	2.37	2.25	2.54
8W	2.82	2.93	2.62	3.07

TABLE XXIII: Comparison of stimulus period as angle of regard varies.

and $b = 1.5, 2.0, 2.5 \ldots 5.0$, the ratio of $\bar{p}$ to its value for $b = 5.0$ (that is, the ratio of $\bar{p}$ for an ellipse, to $\bar{p}$ for the circle of equal thickness whose radius equalled the (constant) semi-major axis of the ellipse), when plotted against e, the ellipse eccentricity, resulted in a curve of the form shown in Figure 58. The values used for p and q were obtained from the results of Ss for whom θ was small, but otherwise are nothing more than typical.

The theory as developed thus predicts that as the eccentricity increases, the period of perceived movement decreases, and the magnitude of this change can be obtained from (18) if p, q, a and θ are known.

The results of the 22 Ss already described in the last section were analyzed in a similar fashion as for distance, only instead of each S participating once in a 'near' group and once in a 'far' group, he was now assigned to a 'large angle of regard' group, L, and a 'small angle of regard' group, S. There was no significant connection between the two variables, distance and angle of regard, in this experiment or in either of the others to be described; as was expected, Ss' distributions in the laboratory during the experiments were very nearly random.

The average angle of regard, $\bar{\theta}_L$, for the L group was about 36°; for the S group, $\bar{\theta}_S = 16^{\circ}$. Unfortunately, the difference in $\bar{p}$ to be expected because of these variations is very slight, the corresponding eccentricities being only 0.59 and 0.27, respectively. Average values of $\bar{p}$ for the 3W, 5W and 8W stimuli and for each group were calculated, and are entered in Table 23(a).

No significant differences between corresponding means for the two groups existed, and those differences which did exist were in a direction contrary to that expected from the above theory. Coefficients of correlation were also calculated between θ and d for each figure; these were all positive, but not significantly so.

Table 23(b) presents similar data obtained from the results of 48 Ss. Again the predictions of theory are contradicted in all cases, and the differences between group means for the 5W and 8W stimuli are significant ($P < 10\%$). When the coefficient of correlation for the 5W results was calculated, it was found to have the significant value of 0.46.

A study of the results of a third group, consisting of 22 Ss, completed the picture of the general trend. There was only one significant difference occurring for the 8N annulus, and this and differences between 8W, 5W, 5N and 3N were all in the opposite direction to that predicted by theory. The difference between 3W means was in accord with prediction, but was not significantly different from zero.

It is therefore necessary to re-examine the basis on which the theory rests, since this has clearly been shown to be deficient by the significant differences between means which do exist, and the general trend of the rest. The assumption concerning constancy seems sound, since Ss were attending a particular feature of by far the most prominent object in a semi-darkened room (and their comments often indicated that the limited cues available were not used, i.e. the annulus was sometimes seen to 'float in space'). Furthermore, to explain the direction of the differences found, it would be necessary to attribute the mechanism of shape constancy with rather implausible characteristics. The lack of constancy phenomena found previously is at least indicative, although no check was made as to the relative contributions of any size or shape constancies which might have been present. (Even if such a control were made, it would be a very dubious procedure to apply the results to the experimental circumstances under which measurements of apparent movement were made).

The assumption regarding local curvature therefore needs examining, since if small retinal areas were not independent of their neighbours a few degrees distant, then it is possible to establish a spatial interaction mechanism, in terms probably of distance and curvature, which could explain the results. The fact that the effect tends to be greatest for the largest annuli does not embarrass the theory, since supposedly these interactions would also operate in a similar fashion on the perceived velocity of apparent movement in the reference annulus, and the differences existing as size is changed would merely reflect, for example, differences in the parameters of the interactions according to the area of the retina being stimulated. The mathematics involved, however, is complex, and closed forms for the integrals obtained do not exist.

Contours falling near the fovea do exhibit inhibitory effects on one another up to distances of about 4° apart (25, 98), and if they are spatially repetitive, interactions can occur over much greater distances (22), although these are probably of a different nature. Similar to the minimum range found by J.P. Wilson for the production of complementary after-images in these latter experiments was that reported by M.E. Wilson (44) in his study of the effect of contours on the phi-phenomenon. Since the 8" annuli concerned in the present experiment subtended about 5° at the average distance from which it was viewed, and about 10° at the very closest distances, it can be seen that a substantial portion of the pattern falls into the range over which inhibitory effects can occur, although longer-range interactions of the type suggested by J.P. Wilson, because of the absence of pattern 'saturation' which seems to be necessary, are probably not involved.

Equation (17) probably holds over the range of p involved. Although some extrapolation from experimentally determined values is involved in certain regions of the projections of the 3" and 8" annuli, for an angle of regard of 35°, the relation need be valid only within the range D=2"-10". Any effect that variations in T might have should also be able to be considered small, although these would, in fact, tend to produce changes in the observed direction. If it were desired, nevertheless, to take T-changes into account, the mathematics involved becomes prohibitive.

There is no significant tendency for Ss observing from a large angle to make more errors than those almost directly in front of the stimulus, although there often exists a tendency for the secondary maxima in the response distributions of the former Ss to be somewhat larger than those of the latter. This has previously been shown to have a connection with Ss' hesitancy and the general level of difficulty of the task they are required to perform, but the change in estimated period is not an artefact caused by these variables; the primary maximum itself is typically shifted towards larger values of p if θ is large. Obviously, allied effects are to be expected if θ becomes too large; the curvature of portions of the projected image will then, in places, approach zero, with a consequent reduction or even elimination of the impression of apparent movement in those regions.

As an auxiliary experiment, 10 Ss were each tested individually and each required to make 6 estimates of the period of each of stimuli 5W, VE and HE, while sitting directly in front of the patterns at various distances. Average values $\bar{p}_{5W}$, $\bar{p}_{VE}$ and $\bar{p}_{HE}$ were then calculated for each S. Although only three differences were significant, between the means for ellipses and circles, these were all in the direction previously found; of the insignificant differences, all but two were also in this direction. None of the variances differed significantly, although variances for ellipses were generally larger than those for circles. There was no tendency for ellipse averages to differ according to orientation of the major axis, and no distance effects were detected.

With the results of the preceding observations in mind, it seem feasible to conclude that the effect observed as the angle of regard changes is due to the interaction of the activity caused by more distant portions of the stimulus projection with that present locally. The spatial characteristics of this interaction must be such that the net effect on the perception of apparent movement is one of inhibition.

xxvii) <u>Miscellaneous.</u>

During the course of the experiments already described, and others performed in conjunction with them, several observations were made that relate to the omega effect but which were not followed up, either because they were expected or because to do so would require a separate, and generally extensive, investigation. For reference, these observations are enumerated below.

1. Apparent rotation is still present when the contours of the annulus are not sharp, but are blurred. These conditions may easily be

realized by projecting a dynamic noise field through an annular transparency held close to the projector lens.

2. There seems to be no essential change in the motion if de-synchronized noise is used, that is, if a detuned television set, for example, is used as a noise source instead of the successive frames of a movie film.

3. An additional noise source, which had also been previously used in the Department, also resulted in the motion. This consisted of a circular disc of static noise which could be rotated at high speeds in a slide projector. The lamp of the projector had previously been replaced with a stroboscopic flash tube, which was operated at a rate which was independent and non-synchronous with the rate of rotation of the noise disc. The apparatus thus resulted in a dynamic noise field which, unlike the movie projector, consisted of 'frames' only a few microseconds long.

4. There occasionally, and perhaps generally, exists a variation in the perceived rate of movement, even around a circular annulus. Only a few Ss reported this, however, and for these, angle-of-regard effects could not be ruled out. On the other hand, this might be the same effect observed by Wilson (22), and probably correlated with eye movements and lack of attention, although Ss in the present study often associated variations of speed with direction: "Slower movement going up in circle than coming down"; "It changes across the top and bottom".

5. Movement still exists, although its impression is much weaker, and the adjacent noise field very distracting, near the borders of a black ring in a noise field, or those of a black disc or hole in a piece of black

cardboard. It is, however, very difficult to see under such circumstances, and tends to be very rapid and transient in nature.

SUMMARY OF RESULTS

a) Parameters of the noise field.

i) The amount of ambient lighting has no effect on the period of omega-movement.

ii) The brightness of the noise scintillations does not affect omega-movement.

iii) Omega-movement is independent of the size of the noise 'particles' involved in its production, even if these are large enough to overlap.

iv) The period of apparent movement is not dependent on the spatial density of the noise scintillations.

v) There is a slight dependence of the period of apparent movement on the temporal rate of the noise flicker; that is, as the noise film frame speed goes down, so does the period of omega movement.

vi) Neither the frequency nor the amplitude of an auditory stimulus affects the velocity of apparent movement.

vii) There is no apparent change between the results arising from noise composed of circular particles, and those obtained when the noise is made up of straight line segments.

b) Parameters of the observer

viii) There are marked individual differences in estimates of the period of apparent movement.

ix) On the average, there is no significant tendency for Ss' estimates to either increase or decrease during a normal experiment. If intensive practice is given, however, there is a small tendency for the rate of apparent rotation to decrease. There is no tendency for high or low mean values to be associated with a progressive shift either up or down. It is postulated that what changes do occur are the results of boredom or drifts of attention rather than short-term adaptation.

x) There exists a correlation of about +0.50 between results obtained during different experimental sessions. No systematic long-term drifts are present. As the test-to-retest interval becomes larger, this correlation becomes smaller, but in general, changes are not significant.

xi) Within the range of stimulus presentation times used, this factor does not affect the period of apparent motion.

xii) Naive Ss tend to make a large number of estimation errors at the beginning of an experiment, but improve as the experiment progresses. Ss with some experience make fewer errors, and show no such tendency. The mean number of errors per naive S is about twice as great as that per experienced S.

xiii) Overt suggestions by the experimenter as to the period of w-movement do not affect Ss' average estimate. The variance of the results, however, increases if Ss' expectation deviates from actuality.

xiv) Ss tested in groups show a slight tendency to be affected by the other Ss present; low positive correlations exist between the responses of Ss sitting near one another.

xv) Ss' estimates are influenced to some extent by the estimates made on immediately preceding stimuli. This effect is, however, small.

xvi) The motion of a spot of light moving around an annulus does not interfere with the perception of omega-movement.

xvii) The value chosen by S when he was requested to adjust the speed of circular movement of a light to an 'optimal' value does not correlate with the speed of his omega-movement.

xviii) Moderate dosages of alcohol have no effect on the perception of omega-movement.

xix) There exist well-marked differences between average estimates made by men and those made by women.

C) Mode of observation.

xx) Fixation affects neither the presence nor the velocity of omega-movement, but it becomes less stable and more subject to involuntary reversal. It is postulated that eye movements play a part in the frequency of these reversals.

xxi) There is no difference in the effect as viewed with either the dominant or the non-dominant eye. Monocular and binocular modes give slightly different results, but the difference is not significant.

xxii) During haploscopic presentation, apparent movement is not reported. This is mainly due to rivalry between the two fields; it proved impossible for the two stimuli to be viewed in sufficient proximity for the production of motion.

d) Parameters of the stimulus pattern.

xxiii) The distribution of individual responses, both for single Ss and for groups, is positively skewed. It can be normalized, however, by means of a logarithmic transformation. Certain secondary maxima which appear in the distribution can be attributed to random effects, and arise as artefacts of the method of measurement used. Most of these can be smoothed out by the use of accumulative frequency displays; this method often indicates that a true secondary maximum exists in the distribution. Evidence is presented to show that this maximum is an effect of hesitancy or indecision on the part of Ss.

xxiv) Any deviation from circular symmetry of the annular pattern results in increasing difficulty in detecting apparent movement; in particular, a straight-line 'channel' does not sustain the impression of movement. For circular annuli, both means and variances increase with diameter and decrease with 'thickness'. As either diameter or thickness increases, however, apparent movement becomes more difficult to detect and is much less stable, values of D=36" and T=1" being the practical limits. Within the ranges tested, it was found that the average period $\bar{p}$ of the apparent movement in an annulus of diameter D and thickness T is given fairly accurately by the equation

$$\bar{p} = K_1 D \log T + K_2 \log T + K_3 D + K_4$$

where the constants K_i vary from person to person and from group to group. Methods of determining the K_i are described.

xxv) The period of omega-movement varies with distance from the stimulus in a manner predicted by the above equation. Variations in $\bar{p}$ depend on the retinal image of the stimulus.

xxvi) There is found a positive correlation between the average period and the angle of regard of the stimulus-annulus. This finding is not in agreement with predictions based on an assumption of negligible contour interactions, and it was concluded that such interactions must exist.

xxvii) Miscellaneous observations, for which no quantitative measurements were made, indicate that the omega effect is indeed largely independent of noise statistics, and that it is still present under various conditions of stimulus modification.

DISCUSSION

Of the questions originally to be answered in the course of this investigation, one at least has been unequivocally resolved: the omega effect is an apparent movement phenomenon in its own right, and has little or no connection with the phi-phenomenon. Several pieces of evidence bear out this contention, and these are discussed below.

In the first place, as has been pointed out in the introduction, the evidence arising from the study of various aspects of the influence of contours in the visual field upon the perception of apparent movement is scanty and often irreconcilable; at best, any net effect would seem to be due to the action of two apparently antagonistic factors, as exemplified in the work of Deatherage and Bitterman (48), who found that the path of apparent movement 'avoids' a contour in its vicinity, and in that of Wilson (44), who reports facilitation. A direct comparison of the two experiments is difficult, however, and the difficulty hinges on the fact that Wilson needed more than one contour, and usually 4-5, before his effect became established. It is known that such a number of parallel contours is adequate to give a well-defined complementary after-image (19, 22) which is roughly perpendicular to the contours present, and Wilson's observations could depend on a similar mechanism. Hart (121), however, who measured the thresholds, the range and the position of optimal apparent movement seen against backgrounds which were either vertically-barred, horizontally barred or non-figured, found no significant difference between the mean optimal rates for figured as opposed to non-figured grounds, nor did the movement-succession threshold change. The background did, however, influence the simultaneity-movement threshold and the range over which movement occurred. Although the summary available on Hart's work is not explicit on this point, it is probable that to avoid the complications known to arise when the direction of apparent movement is involved (122), the configurations were such that the path of movement fell along (horizontal) bars in some cases, and across (vertical) bars in others. If this is the case, the findings of Hart are difficult to reconcile with those of Wilson, at least on a fairly peripheral basis.

It almost certainly cannot be assumed that a single contour, without prolonged fixation, exerts a measureable effect on the parameters of the phi-phenomenon. On this basis, the following points found during the present study are relevant:

1. The period of omega movement decreases as the annular thickness increases. On a phi-hypothesis, one would probably expect the reverse to be true for, as the channel is made wider, the possibilities of radial phi-movements between suitably situated scintillations would go up. This component would result in an increased number of equispaced phi 'steps', and so the total time required for a complete transit should go up.

2. The linear velocity of omega-movement increases with the annulus diameter. Although it is true that a phi-hypothesis would predict an increase of period with diameter, there is no reason to suppose that this would also involve an increase of linear velocity.

3. Evidence has been presented that indicates that the period of apparent motion is a function of the characteristics of the retinal projection

of the annulus. Corbin (97) has shown that this is not always a feature of the phi-phenomenon, and the varied experiments of Brown and Voth (123) also indicate that other factors are involved.

4. The lack of dependence of the omega effect on the statistics of the visual noise field is strong circumstantial evidence against the phi-hypothesis.

5. Omega movement cannot be seen in a straight channel or, if it can, it is very much weaker than corresponding movement in a circular channel. There is no reason, on the other hand, for phi-movement to show this preference.

Most of the above arguments are open to objection if it can be granted that contour curvature, as such, is able to condition phi-movement. In the absence of any independent evidence of this, however, all such objections must be of an <u>ad hoc</u> nature, and would find it difficult to account for certain other findings.

For example, as has been seen, there exist significant sex differences in estimates of the period of omega rotation, which are never reported in studies of the phi-phenomenon, and although the only legitimate basis of comparison between the two would be measurements of the apparent velocity of phi-movement made under similar circumstances, this, as far as the present writer is aware, has yet to be done, and positive results would be unlikely. There is also a formal similarity between the omega effect and some of the observations made by Zapparoli and Farradini (23), although a quantitative comparison is not possible. Their Ss reported streaming or revolving light 'flux' around circular or elliptical annuli, but not around squares or incomplete annuli. Furthermore, the effect was enhanced for annuli of non-constant thickness. All these observations are suggestive of analogous findings in the present experiments, and it is possible that Zapparoli and Ferradini's streaming phenomena are related to the omega effect. If this is true, the phi-phenomenon must be ruled out, for Zapparoli and Ferradini used single, repetitive flashes, and all parts of the stimulus were thus illuminated at the same time. (Since a flash stimulus of this sort can be considered as a noise field of very large 'density', and since this parameter has little effect on the velocity of the omega movement at least in the ranges tried, it would not be surprising if the two effects matched in this respect as well).

Another hypothesis that was at one time considered to account for omega-movement, but which subsequently had to be rejected, is one based on the latency differences known to exist between peripheral and foveal areas and amounting to about 20-30 ms (124). If, for example, one were fixating a point on the circumference of a circular annulus at a time when a noise field was flashed upon it, then the signals arriving centrally would be spread out in time owing to these latency differences, and although these are not large individually, if enough of them were recruited by the centres responsible, they might collectively sustain an impression of movement. This, it can be seen is in many ways similar to, and makes the same predictions as the phi-phenomenon hypothesis. It can therefore be rejected for the same reasons plus one or two others: it would supposedly predict that fixation at the centre of the annulus would prevent motion from being seen at all, and that inspection of a noise field in the absence of any annulus at all would still reveal radial movement. Neither effect has been observed.

The main facts that any account of the omega effect must take into consideration are its variation with the diameter of the stimulus-annulus and that with its thickness. It is on the former point that MacKay's idea of incorporating a 'neural standard of angular velocity' breaks down in its simplest form; neither the angular velocity nor the linear velocity remains constant as the diameter increases, but respectively decrease and increase as this happens. Nor is the variation with annulus thickness accounted for by the hypothesis, but this is probably not as serious.

Since the two boundaries of the annuli used in the present experiments were never separated by more than about 1°, which was the practical upper limit that could be attained without apparent movement becoming obscured by the random noise in the channel, it is to be expected that there were interactions between them. Such interactions are ordinarily of an inhibitory nature, and operate over ranges of up to 4°, the generalization being that formed contours exert an inhibitory influence upon similar processes in their immediate surround (98). Various physiological evidence which makes probable the existence of contour-sensitive receptive fields in the visual system (37, 38, 39).suggests that perhaps direct interaction between the units upon which such receptive fields converge could account for this effect, in much the same way that activity in a unit of the compound eye of Limulus can suppress similar activity in nearby units (125). That contour sensitive elements fatigue easily is known from studies on stabilized images; sharp edges present in the stabilized field fade from view first, leaving only a poorly-defined remnant of the image to disappear in its turn (A. Fiorentini, private communication). One other effect of contour 'satiation' is of interest: if a circular outline is fixated for a few seconds, its continuous curvature disappears and is replaced by short, straight-line segments meeting at angles, much like the appearance of a threepenny bit (56). Of course, these two effects are the result of receptive-field fatigue which takes some time for establishment, and cannot as such play a direct role in ordinary contour interactions. This does not prevent particularly the last one from being suggestive: if curvature-sensitive elements are strongly stimulated, the phenomenal curvature becomes progressively smaller.

For an annulus whose borders are very close together, then, there will supposedly exist strong mutual inhibition between the contours and perhaps, although this is not necessary, distortions of the curvature itself. As the borders are moved apart, the mutual inhibition will decrease, but so will the amount of contour overlying a given area. The net change of contour information that will occur then depends on the relative importance of these two factors and hence directly on the amount of interaction between different receptive fields. It seems possible that the characteristics of the omega effect also depend to some extent upon this interaction.

MacKay (19, 27) has used the concept of 'directional satiation' to account for the spatial relationship usually found between a series of parallel contours and the complementary image they invoke. In his view, directions at right angles are treated as 'competitive' by the directionally sensitive part of the visual system, so that if highly redundant contour information causes fatigue of the units sensitive to a certain direction, this leads to enhanced sensitivity of the units responsible for the orthogonal direction. This interpretation fits the observed facts quite well, and coupled with Wilson's finding (21) that faint complementary images can be evoked even by a single contour, it might at first sight be expected to be applicable to the present case. However, no complementary-like phenomena were ever observed; the 'Bailey's beads' seen by some Ss while fixating are easily understood in terms of contrast enhancement. In view of the lack of direct evidence as to the applicability of MacKay's prinipile of contour interaction, what follows must be purely speculatory.

In order to get an impression of movement from one part of the visual field to another, at some level of the contour-processing portion of the visual system, there must exist a spatial gradient of activity which itself is changing with time. This state of affairs can arise either from the effects of external stimulation, such as the passage of an object through the visual field, or as a manifestation of some internal organization, such as a return to a steady-state position of equilibrium. Now, evidence has been presented by Wilson (22) to the effect that contour interactions can occur over a wide area of the visual field (although probably not at the retinal level) and some of the findings of the present study, in connection with elliptical annuli, can be interpreted as signs of similar, long-range interactions. If it can be assumed that directions at right angles to one another act in complementary pairs, such that strong stimulation of one direction enhances the sensitivity of the other, and that these effects are not completely local, but can extend over an appreciable distance (with suitable attenuation as distance increases), then if one is fixating a point on the circumference of an annulus, it is apparent i) that the excitatory and inhibitory effects of all parts of the annulus, depending on the local curvature and distance of each point, are active at the site of fixation and ii) that any inhomogeneities existing in either spatial distributions or connective properties of the direction-sensitive elements could result in unequal patterns of interaction around the circumference of the annulus.

If now the whole system is 'shock-excited' by visual noise, as in the present experiment, or by more extensive flash stimuli, as in that of Zapparoli and Ferradini, these patterns would be disturbed, and omega-movement might arise in association with whatever time-constant is involved in their re-establishment.

The difficulty with such a model is that there are too many degrees of freedom available for any decisive tests to be made in the light of present physiological and psychophysical knowledge. In a similar fashion, MacKay's 'neural standard of angular velocity' hypothesis, as he anticipated, would have to undergo serious modification, perhaps to such an extent as to make questionable the use of the word "standard". Until data is available concerning long-and short-range interactions between the responses to curved edges in the visual field, the mechanism subserving the omega effect must remain obscure.

SUGGESTIONS FOR FUTURE WORK

1) The dominant requirement for a satisfactory explanation of the omega effect is that of more extensive knowledge of the interactions of contours. Several psychophysical investigations would elucidate this problem; one of particular value would involve making judgements of the directions of small, tachistoscopically presented straight line segments in the vicinity of contours of various curvatures.

2) A direct test of MacKay's hypothesis of 'directional satiation', by a consideration of single unit activity in the visual centres of some higher mammals, should be possible, and is highly desirable.

3). An extension of M.E. Wilson's experiments on the perception of the Ø-phenomenon in the presence of contours could be made with profit. It is possible that the behaviour of apparent movement of this sort, for a sufficiently practiced S, might prove to be a sensitive method of detecting 'preferred directions' induced by the contours present. Any interaction that might exist between complementary afterimages and real or apparent movement would also be of interest.

4) Studies of omega movement between blurred contours should be performed; these would give an indication of the amount of contour information necessary to sustain the illusion as well as further information as to the relative roles of short-and long-range interactions.

5) Some of the experiments resulting in differences of marginal statistical significance would be worth repeating. There is, for example, a small tendency for binocular estimates of the period of apparent motion to be

somewhat smaller than monocular estimates. If this is real, then analysis of the differences between the two modes, for annuli of different dimensions, will perhaps indicate what additional interactions exist. For such experiments, it would probably be necessary to work with fewer Ss for longer periods of time.

6) The origin of individual differences, including sex differences is a problem in itself. It might be possible to associate intelligence or personality, for example, with certain aspects of the response pattern.

7) Certain physiological variables, like the basal metabolic rate and the E.E.G., could possibly be implicated in the production of omega movement and also have relevance to 6) above.

8) Certain drugs have a fairly well known effect on specific parts of the nervous system. It would be of interest to see what effects arise in the perception of omega-movement as such drugs and their dosages are varied; this could give valuable information as to the origin of the movement.

Appendix: A Possible Physiological Correlate of the Omega Effect

When contours are present in the visual field, it is known from various studies that anomalous effects occur that are not observed, or that exist in a modified form, in the absence of these contours. Besides the effects already noted, the following phenomena, for example, have also been found.

1. Visual acuity varies systematically with the size of the surrounding field provided that there exist brightness differences between test and surrounding fields (99).

2. Judgements of the point of apparent luminance equality are influenced by the spatial relationships of the test, comparison and inducing stimuli (100).

3. The critical fusion frequency varies both with surroundedness (101, 102) and with contour proximity (103, 104).

4. Shape and orientation of the visual surround exert a predictable effect on the vertical-horizontal illusion. (105).

5. The relative weights which can be assigned to the two eyes in order to predict binocular brightness, when fields of differing luminance are presented to contralateral eyes, must be adjusted in favour of that eye which also received contour information. In the region close (less than 1°) to a monocular contour, the relative weight for that eye approaches unity, and binocular brightness becomes dependent on the luminance of the field for that eye only (106).

Some of these effects are contingent upon the brightness enhancement and inhibition which occur in the immediate vicinity of an edge in the visual field, while distortions in the metric of the latter, due to the contours present, can account for others. Since in none of the investigations known to this author was contour curvature a variable of main interest with respect to a parameter relevant to the present study, it was decided to conduct a few supplementary experiments in an attempt to determine the influence of this factor.

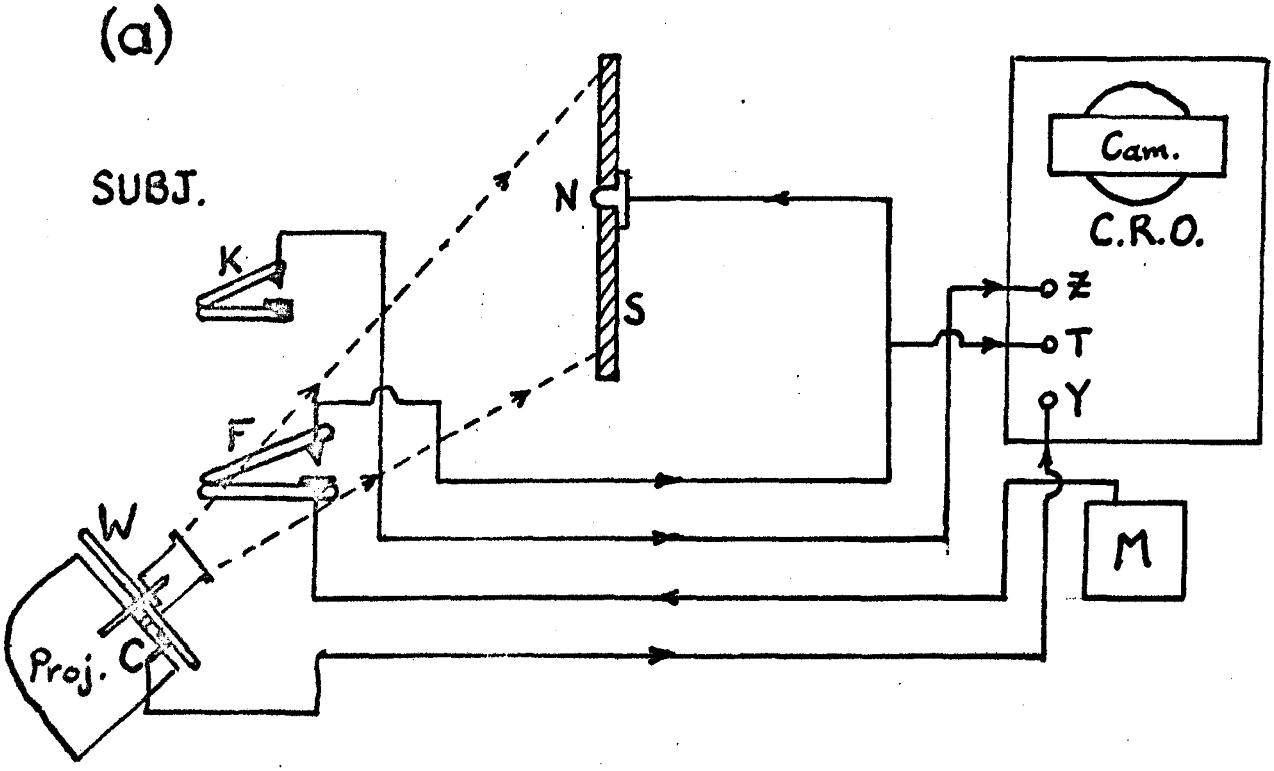
The dependent variable studied was the latency L, at various levels of the system of response, of a small flash of light (an attempt was made to maintain the size and brightness of the latter in the range of those generally obtaining for an individual noise 'particle' in the main experiments). The independent variable was curvature of either black/white borders, or single or multiple parallel lines which could be presented simultaneously with the flash, at various distances from the latter, and at various orientations in the visual field. If a relationship of the form $L = f\ (C\ (d),\ d)$ can be obtained from such a study, where C is the amount of contour curvature at a distance d from a reference point, in most cases the point of fixation and of the occurence of the flash, then since in general the distribution of curvature about different points in the visual field will be different, for a flash occurring at the same time on two distinct retinal points there will exist a latency difference L between the visual responses to the two flashes, other things being equal. If in addition there exist inhomogeneities of the spatial pattern of the sensitivity of the visual system to contour information, then the function f must also vary with the direction angle α of each contour present, as measured from some fixed reference line.

By such a model, then, upon stimulation, latency differences would be expected to exist between the points of any figure of variable curvature, or between the points of any figure of constant curvature whose orientation is different from the points of view of stimulated retinal areas. No such differences would exist, however, between points stimulated along a straight line, provided that the length of the latter was large with respect to the distance over which interactions can occur. It is apparent that such an organization of the visual system could formally approximate the actual mechanism which subserves the omega effect; what remains to be seen is whether the latency differences predicted by it actually exist.

Three preliminary studies, designed to answer this question, are to be described. Since no systematic difference was found in any of the three except some which can be attributed to brightness enhancement, independently of the curvature of the proximal contours, this description will be mainly restricted to a summary of the methods employed.

1. Reaction time studies.

The total elapsed time between the onset of a visual stimulus and S's reaction to this may be considered as the sum of four arbitrary components: first, time is required for photosensitive pigments in the retina to be broken down and for afferent impulses to reach the visual cortex via the optic pathways; second,, there is a lag while this visual information is being processed and transmitted to the motor cortex; third, there is another lag while efferent impulses travel along motor fibres to initiate muscular contraction; and finally, due to the mechanical inertia, for example, of the hand/response-key system, there is a time delay between the beginning of the muscular contraction and the completion of the required response. Since



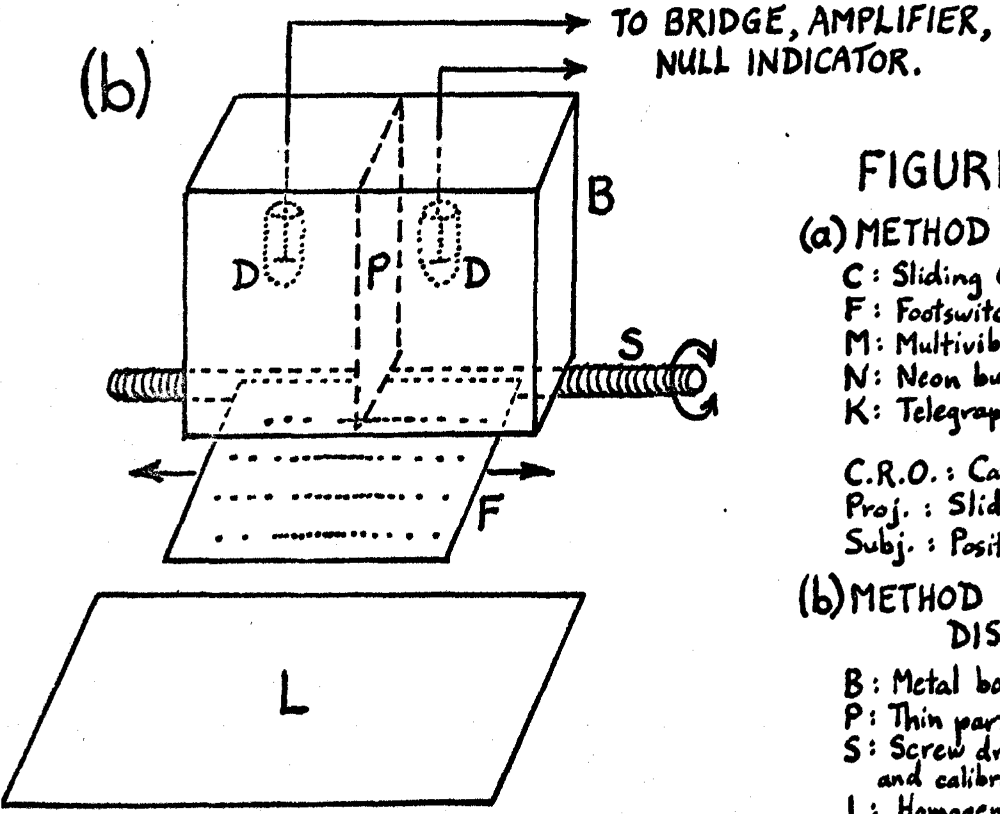


FIGURE A1:

(a) METHOD OF RECORDING R.T.s

C : Sliding Contact
F : Footswitch
M : Multivibrator
N : Neon bulb
K : Telegraph key
S : Opaque screen
T : Trigger input
W : Slide holder
Y : Vertical input
Z : Brightness modulation input
C.R.O. : Cathode-ray oscilloscope
Proj. : Slide projector
Cam. : Camera
Subj. : Position of subject

(b) METHOD OF MEASURING R.T. DISTRIBUTIONS

B : Metal box
P : Thin partition
S : Screw drive (slide mount and calibrations not shown)
L : Homogeneous light source
D : Photodiodes
F : Exposed film to be measured. (Masking not shown)

the first lag, or 'latent period', amounts to only 10%-20% of the total reaction time (a typical value for which is 180 ms), and since most of the variability of the results is contributed by the other factors, in order to measure latency differences by this method it was realized that i) a very large number of measurements and ii) preferably a semi-automatic method of processing these, once they were obtained, would prove to be desirable features of the experiment.

These features were implemented in the following fashion; a schematic diagram of the apparatus employed is presented in Figure A1(a). An asymmetrical, free-running multivibrator was used to operate a neon bulb, which provided the flash stimulation.. The duration of the flash was 150 ms, and the time between successive flashes about 4 seconds. The neon bulb was connected to the multivibrator through a series foot-switch, which could be operated by S. The neon side of this switch was also connected to the external trigger input of an oscilloscope, so that when S closed the switch, he was presented with a flash stimulus sometime between 0 and 4 seconds afterwards, and simultaneously with the appearance of the flash, the oscilloscope was triggered and started a single scan. S responded to the appearance of the flash by closing a telegraph key, whose spring was as light as possible, and whose contacts were very close together. This action, by means of a suitable circuit, discharged a small capacitor, the resulting impulse being led to the Z-input (brightness modulation) of the same oscilloscope. The brightness control of the oscilloscope was then adjusted so that the trace was invisible at all times except when an input-signal appeared on the Z-terminal. A camera, whose shutter was left open, was mounted in front of the oscilloscope screen so that a record of each of S's reactions, in the form of a small spot somewhere along the path of the oscilloscope scan, could be made. A series of reactions, then, appeared as a distribution of these spots along a horizontal line; a calibration trace was added to the top of the exposure at the beginning and end of each experiment.

The neon bulb was mounted on a white, cardboard background about 6 feet in front of S. Different background fields were provided by a slide projector, which was positioned near S and directed at the white cardboard. In order to facilitate randomization of these background fields, a rotatory slide-holder was constructed in which positions were provided for up to five different slides. As a refinement, and to obviate the necessity of varying the Y-shift controls of the oscilloscope for each change of background, a resistor chain was mounted on the rotatory slide-holder. The ends of the chain were connected, via sliding contacts, to a low voltage battery; each junction between adjacent resistors was made available when a different slide was in position, and when this was the case, contact was made between the appropriate junction and a fixed spring terminal connected eventually to the Y-input of the oscilloscope. Thus, for each slide, there was available a different voltage level, and by this means the reaction-time distributions corresponding to each background configuration were able to be distinguished.

S took his place in front of the screen, and was told how to operate the apparatus. The usual reaction-time instructions were given, the room semi-darkened, and he then did a number of practice reactions, while E adjusted the oscilloscope time-base controls to a suitable value (this was usually in the neighbourhood of 200-250 ms for one complete scan).

During the experiment, E varied background patterns in a predetermined, random fashion. After each change, E gave a 'Ready' signal, and S closed the foot-switch and tapped the key as rapidly as he could after the flash appeared. Up to about 50 responses per background could be obtained in practice before overlapping of the exposures on the film became a problem (This limitation could have been overcome quite simply, if necessary, by superposing a low-amplitude, high-frequency A.C. signal on the steady output of the resistor chain. However, since by the time this number of responses had been attained for each of 5 backgrounds, and S was feeling the effects of fatigue, the experiment was usually terminated before this).

After the completion of the experiment, the exposed film was removed from the camera and developed, resulting in up to five rows of point exposures, each now consisting of up to 50 of the latter. Of course, the position of each individual point in relation to the time calibration line could be determined by direct measurement, enabling distribution means and variances to be found, but to do so is very tedious, even if an enlargement of the negative is prepared. Accordingly, a device suggested by Professor MacKay was constructed which enabled the distribution median to be determined very simply and rapidly. Figure A1(b) is a schematic diagram of this.

A bridge circuit was constructed, each arm of which consisted of an ORP60 photodiode in series with a resistor; into one of the arms was also inserted a small rheostat for fine balancing adjustments. The two photodiodes were mounted about 5 cm from the open end of an otherwise lightproof metal box, one on each side of a thin lightproof metal partition which extended from the closed end of the box and between the photodiodes to the open end. Thus each of the diodes was in its own separate compartment, segregated from the other. The interior of both sections was painted a matt black. A 60-volt

H.T. battery was used to supply the bridge circuit and the output, which after the bridge had been balanced was a measure of the difference in the amounts of light incident on each diode, was amplified by a small D.C. amplifier and registered on an ordinary multimeter. The bridge was balanced to a null reading by turning the open end of the box towards a field of homogeneous brightness, and adjusting the rheostat. After this had been done, it was found to be sensitive to very small luminance imbalances.

For the purposes of measurement, an inverted copy was made of the original negative so that the exposed points appeared as transparent areas on an otherwise opaque film. This copy was then placed in a suitable masking envelope, which occluded all distributions except the one or ones of interest, and was then mounted on a screw-operatered carriage. Beneath the distribution to be measured was a homogeneous light field, and above it, such that its open end was almost in contact, was rigidly fixed the metal box containing the photodiodes. The partition separating the diodes thus effectively split the distribution into two portions, one of which was presented to each diode, and any inequality of the number of spots of light present in each field, due to the homogeneous source beneath, then turned up as an imbalance of the bridge circuit. The screw could then be adjusted until balance was re-established, and at this position, the thin metal partition must be over the median point of the distribution. A reading was made of the screw position for each of four settings; since the backlash of the system was approximately nil, these readings were essentially the same.

It should be noted that i) due to the height of the photodiodes above the film to be measured, and the restricted spatial extent of the obtained distribution, each point of the latter was approximately the same distance away from a diode, and its light was incident at about the same angle. (This precaution is necessary only for a markedly skewed distribution) and ii) overlapping of images, and consequent greater 'storage' capacity can now be allowed, provided that care is taken to operate on a linear portion of the film characteristics. The sensitivity of the method is more than adequate for the purposes required; even a shift of a single light-point from one side of the partition to the other caused an easily noticeable deflection of the multimeter.

Other advantages of the methods described are:

1. The easy availability of the instruments and equipment needed, obviating expensive and complicated timers and lengthy calculations.

2. The adaptability of the method to group experiments, simply by providing each S with his individual telegraph key, the outputs of which are pooled before being applied to the Z-terminal.

3. The fact that, for particularly intensive or time-consuming studies, E can act as his own S, the experimental circumstances contriving to ensure that no regular stimulus-response rhythm is inadvertently acquired.

4. A permanent photographic record is always available for closer scrutiny, if required.

Background fields always consisted of one homogeneous bright field, one homogeneous dark field, and three fields from a selection consisting of single or multiple contours of various curvatures, white or black squares or discs, and white or black half-fields of various orientations. Ss, who in all cases fixated the position of the flash, were 8 volunteers, each of whom participated in two to four sessions at various times. E also acted as his own S for nine sessions.

Although systematic differences usually existed between the R.T.'s obtained under bright-field as opposed to dark-field conditions, and were often found between either or both of these and the rest, there was no indication that the amount or type of contour information in the field was a significant factor. Thus, as far as these studies are concerned, latency differences, if they exist, are too small to be detected.

2. Perception of simultaneity.

In an attempt to eliminate one source of the variability of the results of the reaction-time study - that which arises from the efferent or motor side of the response - it was decided to see if the effects of contours made themselves felt in the position of apparent simultaneity of a flash of light, which appeared in their vicinity, and an independently presented click or tone. It was considered desirable to use an auditory stimulus as a reference, rather than a visual one, to prevent any complications which might arise from interactions of two visual stimuli.

Early work by Exner (107), who introduced the idea of measuring the relative speeds of visual and auditory perception, and by Michotte (108), substantiated the findings of astronomers, who were aware that the appearance of subjective simultaneity of a star or planet crossing the meridian, and of the clicks of a pendulum by which the transit was to be timed, was not a true reflection of the physical temporal relationship between the two events, but was distorted by the so-called 'personal equation' of the observers. The 'complication experiment' studied by Michotte and others, however, is more involved than what is of interest here, in that Ss were required to estimate the time of passage of a moving indicator over a point on the scale.

It is generally thought (76, p.106) that perception of simultaneity depends upon simultaneity of cortical excitation, although Titchener's 'prior entry' theory (109), regarding the effects of attention, is still applicable under certain circumstances. Thus, Halliday and Mingay (110), using shock stimulation, find that factors other than conduction delays are operative.

Roufs (113), however, in a comparison of reaction-time, and perception of auditory/visual and visual/visual apparent simultaneity methods of determining the dependence of perception lag on stimulus luminance, found i) that the methods could be arranged, in order of decreasing variability, as reaction time, auditory/visual apparent simultaneity, and visual/visual apparent simultaneity ii) that, in agreement with the latency hypothesis, auditory perception occurs 20-50 ms before visual perception iii) that there existed only a weak dependence of the perceptual lag of auditory perception on auditory intensity over the ranges used, and iv) that all methods gave similar results, which could be described by the equation $T=T_o \log {}^{E_1}/_{E_2}$, where T is the perception lag between two stimuli causing retinal illuminations of E_1 and E_2 trolands, and T_o is a constant close to 10 ms.

In the present experiments, in order that Ss could be tested in small groups, the method of constant stimuli was used, that is, click/flash pairs were presented to Ss, and they were required to report which of the stimuli preceded the other; if they were not sure, they were instructed to guess. Stimuli were controlled by an electronic millisecond chronometer which was adjusted to reset itself automatically and recommence its cycle once every 2½ seconds. Output pulses were available from the chronometer at any or all of up to six preset times during the cycle.

The flash preset control was left untouched at 1.555 seconds during the experiment; relative temporal positions of the flash and click were varied by adjusting the click preset control in 20 ms steps either forward or backward from this value.

The flash stimulus itself was provided by a neon bulb placed across one of the valves of a monostable multivibrator, and was of about 150 ms. duration. The electronic timer provided the pulses to operate the multivibrator. The former also was found to produce suitable clicks when attached directly to high-impedance earphones, and this was the method most often used. If a continuous tone was required, instead of a click, a second monostable multivibrator was available which, on receipt of a pulse from the timer, operated an electronic gate between a 1000 cps source and the set of earphones worn by S.

Ganged switches were placed in the two control lines, and were closed by E after each adjustment of the click preset control. Three flash/click pairs were presented to Ss and the switches opened while E made the necessary changes for the next presentation, and S wrote down his estimate of which stimulus came first, on the sheet provided. Generally each of 7 or 9 flash-click combinations was presented 60 times, in twenty groups of 3, during the experiment, the order of presentation being randomized. The whole session lasted somewhat over one hour.

After the experiment, the number of "flash first" responses made to each objective flash lead was counted up, and these values, expressed as percentages

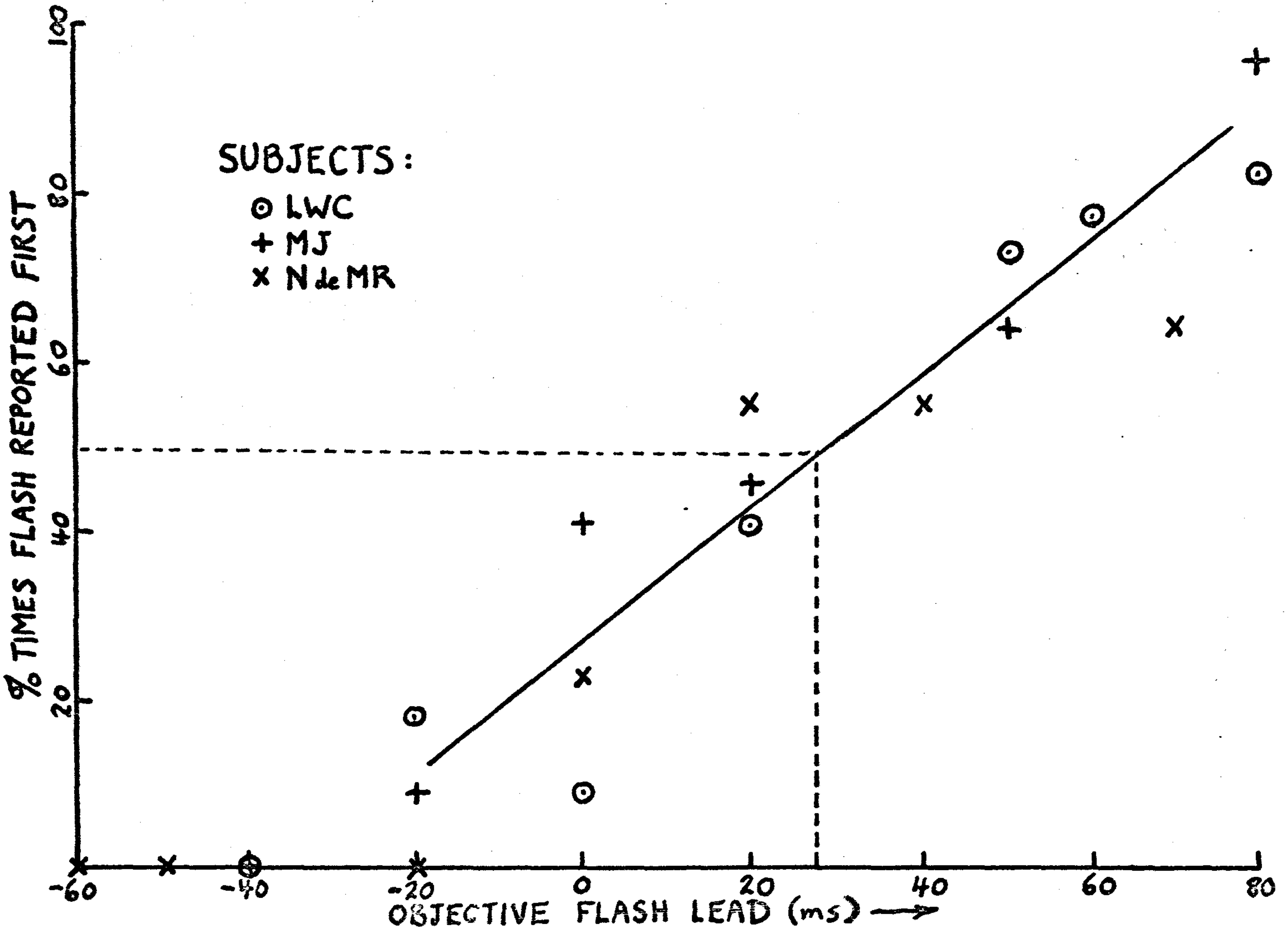


FIGURE A2: Results for 3 Ss. Apparent simultaneity occurs when the flash actually leads by about 28 ms.

of the total number of responses made for that category, were plotted against the corresponding flash leads. Some typical results are shown in Figure A2.

Of a total of 14 Ss tested, only the 3 experienced observers gave any degree of day-to-day consistency, and even with these, 10-15 ms shifts of the point of apparent simultaneity were common. There were gross changes in the results of the rest, and a feature which was common to many was a significant tendency to report "click first" even when the flash preceded it by more than 100 ms. Expectation seemed also to play a large part in their patterns of responses; for example, some Ss showed a significant tendency to 'bet', that is, if they were required to make a difficult judgement, or found themselves in a position of having to guess, they were likely to base their response on the way they had responded to the past few stimulus-pairs. Results for tones were similar.

It was realized that for Ss to adopt any consistent criterion of successiveness and simultaneity, extensive practice would be necessary. Since this was not practicable, and because of the large variability otherwise, no attempt was made to test the effects of different background configurations, and the method was abandoned.

3. Evoked cortical potentials.

If S is stimulated with a flash of light then, according to the latencies of the retinal processes and transmission times of the optic nerve and pathways, activity of the visual cortex can first be detected only after a small time has elapsed. According to Cobb and Dawson (111) the first signs of activity at the scalp appear 20-25 ms after the flash. Hereafter follows a series of alternating positive and negative waves of varying amplitudes (but never more than about 10 uv) and durations, the whole complex of which requires about 250 ms (112). A rhythmic after-discharge then starts, builds up to a maximum (of about 10 uv) and declines. The first phase, known as the 'evoked potential', reflects such changes as the intensity and frequency of the stimulating flash (111, 112, 114, 115) and the state of awareness or amount of concentration of the subject (111, 116, 117).

Differences in the form of the visual evoked potential are so marked from subject to subject as to cause Werre and Smith (118) to speculate as to their possible uses for the study of individuality. It is known that, even for the same subject, variation occurs because of habituation (119), as well as the factors already mentioned, and this fact makes the detection of small systematic changes in latency or amplitude very difficult.

Since most of the studies done on visual evoked potentials have been confined to the effects of stimuli covering a large percentage of the total visual field, there was some question as to whether a point stimulus could be measurable at all; in any case, it was anticipated that the results of a large number of stimuli would have to be averaged before any conclusions could be drawn.

Bipolar electrode configuration was always used in the present study. The reference electrode was attached on the midline about 6 cm above the external occipital protuberance, and one of the active electrodes 3-4 cms above this. The other active electrode was placed at 90° either to the left or to the right of the midline, again 3-4 cms from the reference electrode. The earth electrode was attached to S's mastoid, behind his ear.

The electrode leads were led to two standard E.E.G. amplifiers, which in turn supplied inputs to two channels of a Mnemotron Computer of Average Transients (C.A.T.); the latter performed the necessary data reductions, and the result after any number of response summations could be displayed on a C.R.T. and be photographed if required.

Flash stimulation could be provided either at equal or at random intervals, and both modes were used from time to time. Regularly-spaced flashes were controlled by the millisecond chronometer described in the last section; one channel of the apparatus was connected to the C.A.T. to trigger the summation scan, while another triggered a stroboscope at the same time. For random flashes, two methods were variously used. One of these involved attaching a white noise generator, adjusted to a suitable output amplitude, to the reset circuits of the millisecond chronometer. The latter then was reset at random intervals, and whether a flash and summation scan occurred or not was then dependent on the (random) length of time the chronometer ran before being reset. The second method, although similar, used as a source of random pulses the output of a tape recorder on which was played an endless loop of pre-recorded, randomly dispersed clicks. Both methods proved to be quite adequate, provided that not too many summations were required to be accumulated in any period of time; otherwise, since the small amount of hum pickup present biassed the voltage level at which reset occurred, the hum tended to build up, rather than cancel out, on the C.A.T. screen.

The flash tube of the stroboscope was completely masked, except for a small, circular hole about $\frac{1"}{16}$ in diameter. This hole appeared in a screen of white cardboard, adjacent to the stroboscope, upon which could be projected a variety of different background patterns (in other experiments, a halfsilvered mirror was used to combine the flash and background). A small, red fixation light could also be projected onto the screen.

Backgrounds tested were similar to those used in the reaction time experiments; in every session a homogeneous bright and homogeneous dark field were used in combination with various others, more or less structured. It generally proved necessary to summate the result of from 150-200 flashes before a well-defined evoked response was available; since flash rates used were of the order of 2/sec, this meant that each background was exposed for about 1½ minutes before being changed. Each of the 3 or 4 structured backgrounds used during the experiment was presented randomly 2 or 3 times, one of the homogeneous fields being tested between each successive pair of structured backgrounds. Thus, if D is the dark background and B the bright one, a typical sequence might have been B, S_1, D, S_2, B, S_3 ... . A few runs were also interspersed in the series to check that a response to the noticeable click made by the stroboscope discharge was not being recorded with the visual evoked potentials.

Three Ss were used, each of whom particpated in 3 or 4 separate one-hour sessions.

Results were negative as far as any effect of curvature was concerned, different degrees of curvature resulting in much the same response. Another feature of the experiments was the very long latencies of the first discernable activity on the traces; these were often of the order of 60-70 ms or longer, indicating that the initial part of the response, supposed by Ciganek (114, 120) to be due to the primary activity of the visual centres, was largely too small to rise above the noise, even if the results of 300-400 flashes were summated. In general, smaller latencies and more complex evoked responses were obtained when the flash appeared against the dark, homogeneous background than against the bright one, and intermediate results were found when backgrounds were structured - all of which did not contradict the hypothesis that contrast, rather than curvature, was the operative factor. Although latencies were not affected to the same extent, there were marked differences of the relative magnitudes of the components of the response to any given background from presentation to presentation, and day-to-day reproducibility, except for one S, was not good. To check the extent to which adaptation was occurring during a typical presentation, occasionally successive blocks of 50 responses were alternately added and subtracted from the C.A.T. storage; it was found that for more than about 200 summations, complications of this sort arose, although randomizing the flash presentations ameliorated the situation.

Various conclusions could be drawn from the negative results of the three series of experiments described. The first, and most likely, is that the effect being looked for is too small to be resolved by the methods in the form in which they were used. In the second place, even if more sensitive and better controlled extensions failed to detect an effect of curvature, this would at the best only indicate that the processing of contour information does not occur in series with the optic tracts under consideration. That for at least one stage of the production of the omega effect this is true is probably without question; the ranges over which the contours interact are greater than those usually found to be possible on a purely retinal basis, and no sex differences have been reported to occur in visual evoked potentials (D.A. Jeffreys, private communication). It seems that the question must await further direct physiological evidence before being finally resolved.

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