AN EXPERIMENTAL INVESTIGATION OF THE RELATION BETWEEN THE EXPOSURE-TIMES AND THE INTERVAL BETWEEN EXPOSURES IN APPARENT VISUAL MOVEMENT

By

C. R. Garvey

A. B., University of Kansas, 1925.

Submitted to the Department of Psychology and the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Arts.

Approved by:

Harry Helson

Harry Helson,
Instructor in Charge

R. H. Wheeler

R. H. Wheeler - Head of Dept.

September 15, 1927

ACKNOWLEDGMENT

I wish to express my appreciation of the inspiration and guidance given me by Professor Wheeler and Professor Helson. My work on apparent maovement was started at the suggestion of Dr. Wheeler and carried out under the direction of Dr. Helson.

Dr. Harry Helson and Dr. Joy P. Guilford of the psychology department of the University of Kansas, Mr. S. Howard Bartley, assistant instructor in psychology, and Mr. Donald F. Showalter, graduate student in psychology, the subjects who observed so faithfully and gave so generously of their time during the experiments, deserve especial credit also.

I give my thanks to Dr. Guilford for many helpful suggestions, to Dr. J. W. Twente of the School of Education, for so kindly lending the foot candle meter, to Mr. George A. Kelly, graduate student in education, now of the University of Minnesota, for careful attention in making the blueprints and also for critical suggestions on the mechanical aspects of the apparatus, to Miss Laura Riley, for her competence and care in handling the copy, and to Miss Helen G. Gillis, graduate student, for her assistance in reading and correcting the manuscript, and also for many valuable and appreciated criticisms and suggestions of a grammatical and literary nature.

I appreciate all the help received from the many conscientious teachers, colleagues, associates, and friends whose interest and counsel lent considerable encouragement to the progress of the work. Here I should mention at least, Dr. Beulah M. Morrison, of the department of psychology of the University of Kansas, and Dr. Curt Rosenow, now of the Institute for Child Guidance, New York City.

To those who sent reprints of their articles on similar researches I wish to express gratitude, especially to Dr. Forrest Lee Dimmick, now of Hobart College, Geneva, New York, and to Dr. Glenn D. Higginson, of the University of Illinois, whose articles were of particular helpfulness, and have been quoted at some length.

C R Garvey

Minneapolis, Minnesota

November 21, 1927

TABLE OF CONTENTS

PART I

Problem[1].

Most of the work that has been done on the problem of apparent movement in vision has utilized a temporal interval or pause/p between the termination of the first stimulus and the beginning of the second. The notable exceptions to this fact are the works of Hillebrandt (14), Higginson (12, 9), and McConnell (21). The latter work appeared since the present work was completed, and therefore only brief mention will be made of it here beyond the fact that the stimulus situation in her work was such that p was not strictly zero but virtually less than zero, since the stimuli overlapped upon each other (cf. Koffka 18, page 226f). Hilldbrandt, and Higginson (12, page 113) conclude that in view of the fact that movement is produced where p equals 0, the movement function does not require a specific temporal course. Higginson's

---

1. The problem was set and the experiments worked out under the direction of Dr. Harry Helson in partial fulfillment of the requirements for the degree of Master of Arts in the Psychology department of the University of Kansas.

exposure-times were so long, however, (5000 sigma!) (12, pages 77 and 102) that the temporal course of the movement function may well be included entirely within the temporal course of his stimulus exposures without the necessity of an interval. Higginson says that the fact that he gets movement without interval cannot be explained in terms of the exposure-time, since he did not vary his exposure-time (12, page 103). That the required time for the movement-function does not vary, does not necessarily follow from the fact that the exposure-time was kept constant at 5 seconds, because 5 seconds, or 5000 sigma, may well be a time beyond which the movement function does not need to vary, altho it may vary widely and yet entirely within these limits. Indeed, the total time for both Higginson's exposures together was 10,000 sigma. Koffka asks (18, page 226) if Higginson used an exposure-time of 50 sigma, keeping p constant at 0. So far as the literature shows, this was not done. The question remains then, what would be the result of reducing the exposure-time, keeping p constant at 0, i.e. what is the possible relation, if any, between the exposure-time and the interval-time in the production of apparent visual movement? Does the movement-function require that the stimulus situation cover an appreciable durational course, such that when the exposure-times are reduced to a low figure, a temporal interval must be introduced between them in order that good, decisive movement may still be readily perceived? It is the particular task of the present problem to answer this question. It is a secondary task to investigate the possible relations between the temporal aspects of the stimulus situation and the particular type or stage of the movement phenomenon perceived. These relations also, Higginson has denied (12, pages 102, 103, and 113).

The results of McConnell cannot throw any light on this problem because her exposure-times were always variable with the overlap, one exposure-time always including the other and the overlap (in both her main and control series), thus complicating the situation so that the influence of the exposure-time and of the overlap can hardly be separated. McConnell's overlap is similar in some respects, both to an exposure-time and a pause, but is strictly comparable to neither.

For a summary of the work done by the configurationists on the problem of apparent movement, see Helson (8). Higginson (12) gives an excellent historical summary of the work which relates to his problem (significance of the temporal interval) except that he fails to note that Wertheimer had produced movement with temporal interval zero (24, pages 109 and 114).

PART II

Apparatus

The apparatus used in these experiments is in many respects entirely new, but at the same time employs many of the features embodied in various devices used by other investigators (4, 12, 1, 10). This device is thoroughly illustrated in the plates and diagrams submitted herein (see the following pages). It consists essentially of a milk-glass screen covered with black paper out of which the exposure areas are cut, a light-box behind a shield in which are cut corresponding areas, and between these a rotating disc with slits cut so as to allow light to pass from the openings in the shield to the areas on the screen during the time the disc is in the proper portion of its revolution. Thus the areas on the screen can be illuminated independently of each other, simultaneously, or in succession, with or without temporal interval, by using various arrangements of slits in the disc. This apparatus is especially well adapted to the purpose of varying the exposure-times while *p* is kept constant at 0, and this can readily be done without any of the objectionable complications of 'addition', 'subtraction' or 'overlapping'. The section of the light-shield, the sectors of the disc, and the portion of the paper covering for the screen, which contain the openings for transmitting the light, are removable. Any number of them may be prepared in advance of the experiment and inserted into the apparatus quickly to give different arrangements and set-ups. The exposure-times with any one particular set-up can be varied over a considerable range by varying the speed of the motor which drives the rotating disc. The interval p may also be varied directly with the exposure-time e by the same means. The ratio between e and p may be set at any value by the proper arrangement of the slits in the disc. The motor attached to the disc is a four-spring phonograph motor, which, when kept wound by the automatic self-starting winder, runs with remarkable constancy. The time readings are taken by counting a number of revolutions, recording the time from a stop-watch, and computing the average of the exposure-times from the number of revolutions counted and the angular length of the slit (in terms of a circumference on the disc) which illuminates the exposure-area. Since these counter readings are taken immediately at the time the subject gives his report, any inconstancy in the motor from time to time would not impair the value of the readings. A much needed improvement on this apparatus is a speed indicator which gives instantaneous readings of the speed of the disc at any and all times. This should be attached directly to the shaft of the disc.

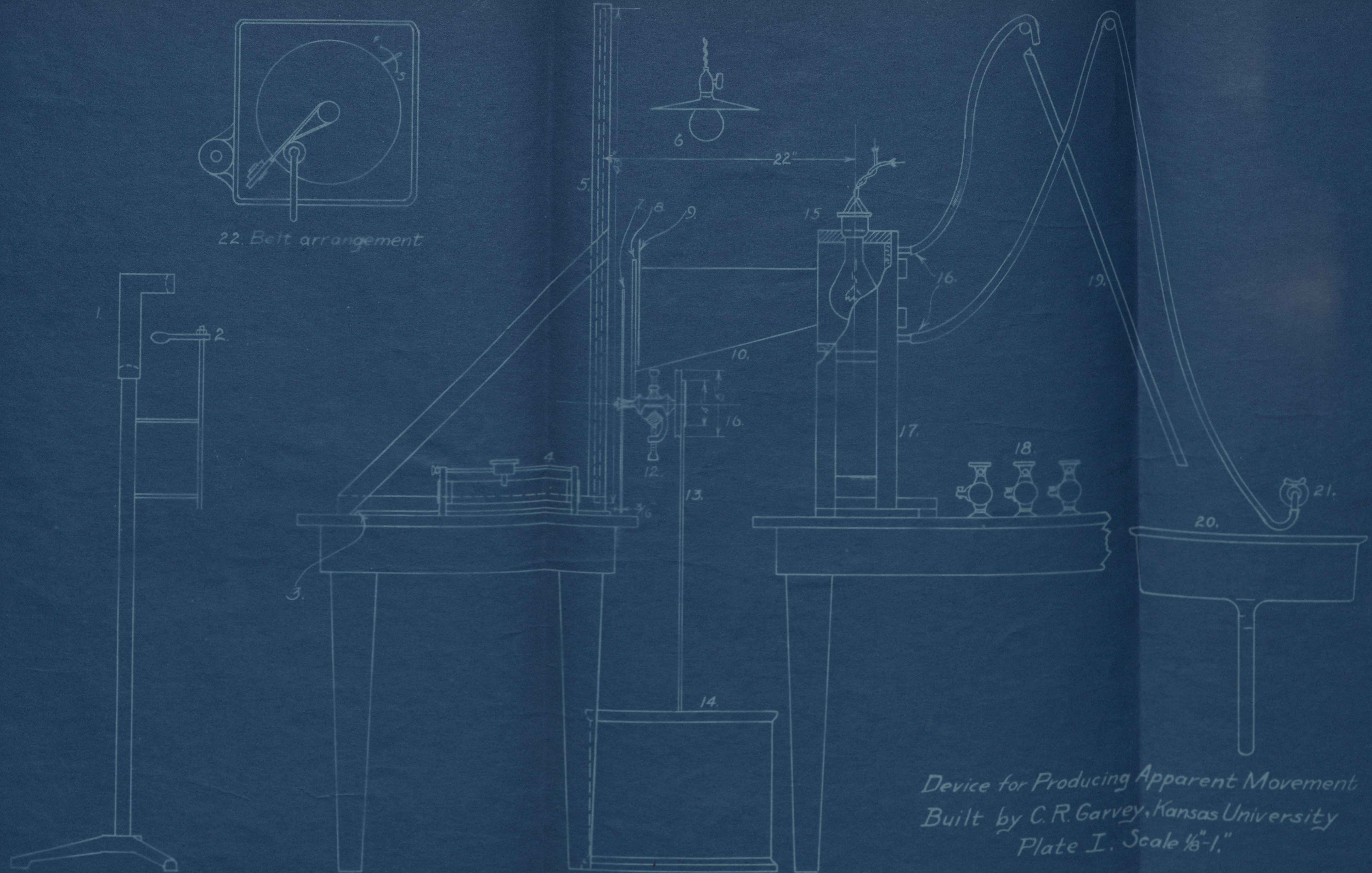
By proper arrangement of the various openings in the removalbe portions of the apparatus, any size or shape of exposure (lines, dots, squares, etc.) can be presented in virtually any directional sequence (horizontal, vertical, oblique, sliding, turning, etc.). Plate III illustrates, among other things, how the sequence can be arranged either right-to-left or left-to-right irrespective of the direction of rotation of the disc (see also the discussion on the page following this plate).

The water-jacket is necessary about the light-box to prevent over-heating by the 300 watt bulb used. This lamp provides a brighter light than has been designated by anyone in any of the previously described pieces of apparatus. Three rheostats wired in series according to the wiring diagram on Plate II permit of varying the intensity of the source light from a value which is subliminal at a distance of 3 meters, up to the highest intensity of the 300 watt lamp. See Table I for intensity readings of the various stimulus lights at 3 mēters, (the distance of the observer's seat from the screen). These readings were taken from a General Electric Company portable foot candle meter. The rheostat in circuit with the room light permits of varying the intensity of the general illumination of the room from darkness when the circuit is broken to the fullest intensity of the 200 watt lamp used.

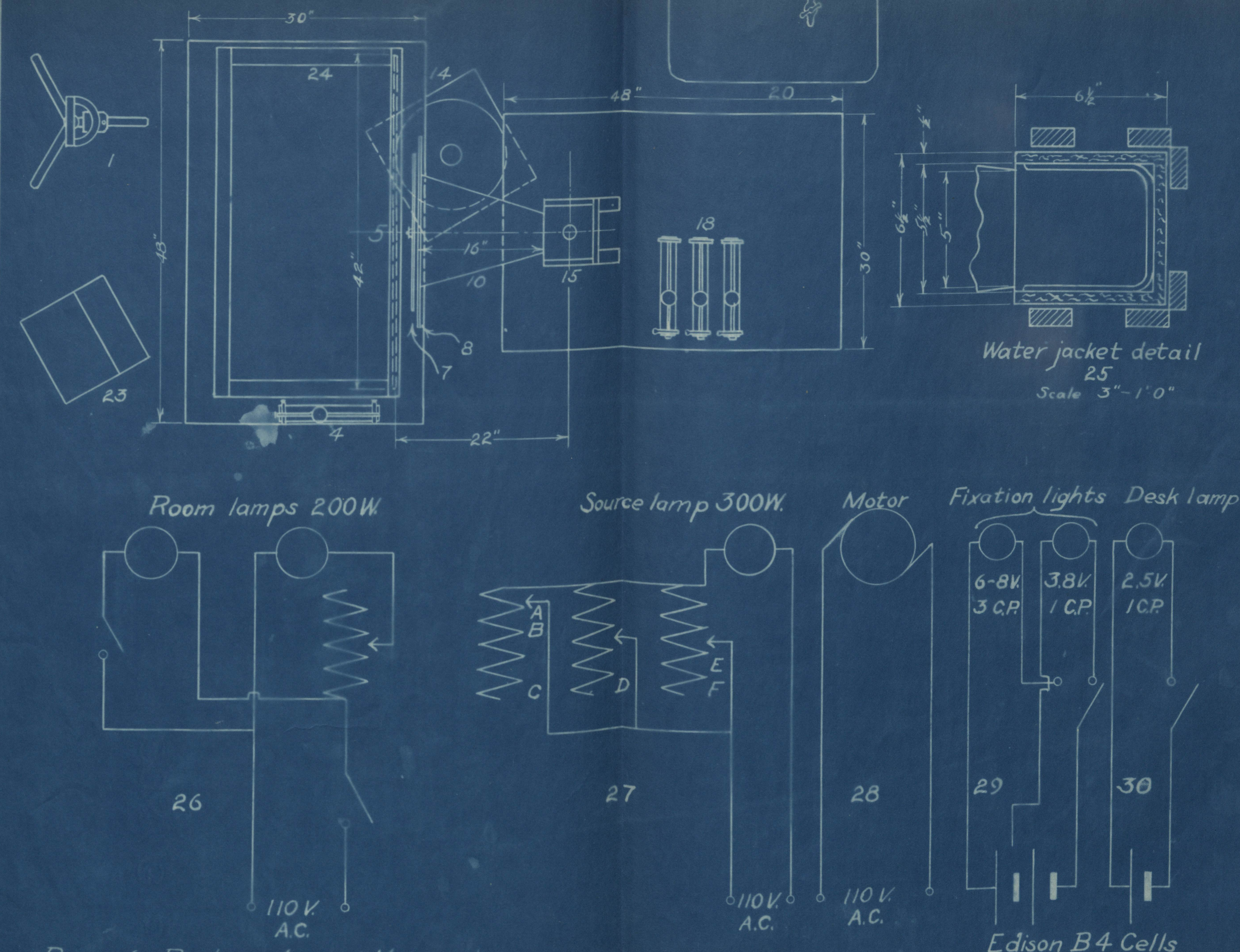
Another feature of the mechanical arrangement is the combination head-rest and biting-board. The observer sits with his head firmly but comfortably in a head-rest which has padded parts supporting the chin, forehead, and temples. His teeth grip firmly a dental impression in a wax covered metal plate. There is a separate biting-board for each individual observer. There are two fixation lights attached to the apparatus, either of which can be turned on or off independently of the other, and one of which is attached to the back of the screen by adhesive tape so that it can be attached at any point on the field. This light consists of a very small bulb inclosed in a black paper box about an inch long and half an inch square, sending out light through a cross-shaped opening in one side which is covered with a blood-red filtre. The fixation light then is a dull red cross. The fixation light is neither turned off during the exposure of the stimulus lights nor obliterated by them, but remains lighted steadily throughout the course of the experiment. This assists materially in reducing eye-movements. The fixation light is adjusted very slightly out of line with the two stimulus lights, although about half-way between them, so as not to interfere with the course of the movement.

The apparatus is in a dark-room in the laboratory. The walls and ceiling are painted black and the doors are double thickness. There are no windows. Notes are taken with the aid of a small desk having a hood which conceals a miniature light and illuminates only the area of the experimenter's note paper.

In order to assist in the dispersion of the light and make the illumination of the exposure-areas homogeneous, a bi-convex lens of 20 cm. focal length is inserted directly in front of the source light bulb.



Device for Producing Apparent Movement
Built by C. R. Garvey, Kansas University
Plate I. Scale 1/8"-1."



Device for Producing Apparent Movement
Built by C. R. Garvey, Kansas University

Plate II

Scale 1"-1'-0"

Legend of Plates I and II:

1. Head-rest with biting-board

2. Biting-board

3. Stop for sliding screen frame

4. Rheostat for room illumination

5. Milk-glass or diffusing-glass screen, covered with black paper except for a circular opening in front of the rotating disc. Double strength glass, 40" x 40".

6. Secondary room light

7. Rotating disc~~s~~ with two removable 90 degree sectors

8. Light-shield with removable section

9. Section with aperatures emitting light from the light-tube to the rotating sector.

10. Light-tube

11. Double pulley, 6" and 4"

12. Bicycle hub clamped to an optical bar

13. Drive belt

14. Columbia four-spring graphophone with automatic winder (Jones Motrola Inc. N.Y.)

15. Source lamp (300) with water-jacket cooling device

16. Water-jacket hose connections (made from gas jets)

17. Source light stand

18. Rheostats wired in parallel in source light circuit (Stoelting 1.1 ampere, 170 ohm).

19. Drain trough, to prevent water syphoning out and collapsing the water-jacket

20. Sink

21. Water jet

22. Phonograph power unit

23. Light-hood and desk for recording observations (1 cp., 2.5 volt bulb on a 1.4 volt Edison cell).

24. Sliding frame with stops, for moving glass screen into position near the rotating disc

25. Light-box with water-jacket

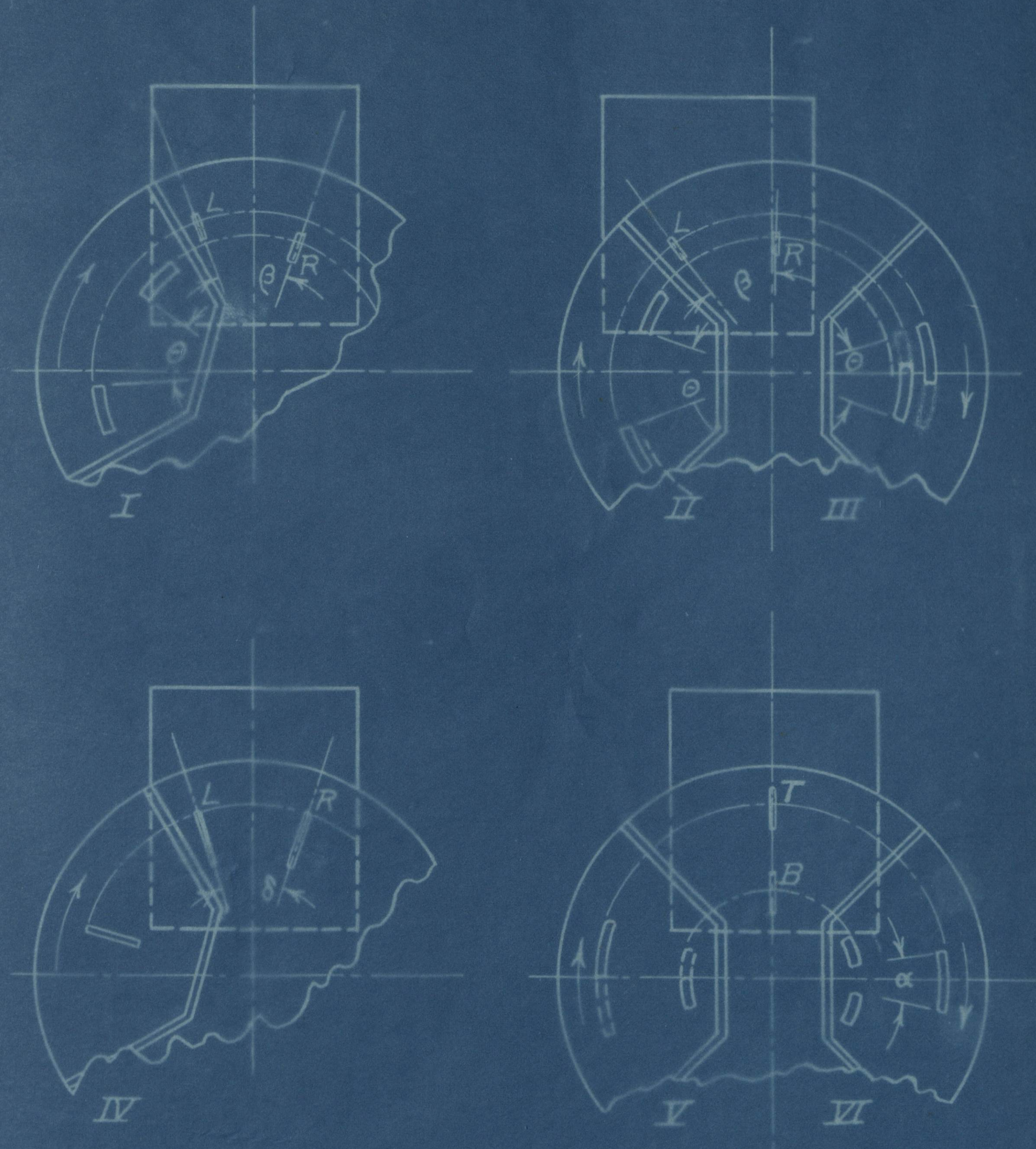


Plate III: Disc, Sector, & Section Diagrams

Legend of Plate III: Disc, Sector, and Section Diagrams

L -- Left aperature in section
R -- Right
T -- Top aperature with vertical arrangement
B -- Bottom
θ -- Angle between slits in the sector when p equals zero
ξ -- Angle between aperatures in the section
Angle θ equals angle ξ.

I, shows sector with slits arranged so that R will be exposed first, then L. Thus movement can be produced from right to left, opposed to the direction of rotation of the disc, which is left-right (clockwise).

II, and III, show how the relation of disc and section can be changed so as to make the movement absolutely horizontal.

II, shows slits which will produce an R-L sequence of exposures. If the slits are kept entirely within the angle θ as in III, rather than entirely outside it as in II, the sequence will be L-R instead of R-L. If these two sectors are used together as shown, R-L and L-R exposures will alternate repeatedly with continued rotation of the disc, and with rapid rotation can be made to produce an inverted pendular phenomenon.

If the angle θ is equal to the angle ξ, and θ marks the limits of the slits as in the drawing, the temporal interval or pause (p) between the exposure-times e1 and e2 will be zero (p equal 0), since the exposure-time e2 will start at the expiration of e1. If sectors are made in which the limits of the slits do not coincide with the sides of the angle θ, as indicated by the dotted arcs in II and III, a temporal interval may be introduced, so that p is greater than zero. The value of p can be calculated from the speed of the disc and the displacement of the slits from the angle θ.

IV, shows the method of exposing a line or bar of light in successive positions. The time p can be calculated from the distance s between L and R and the speed of the disc. The exposure-time e of each bar is regulated for any given speed of disc by the length of arc contained in the slit in the sector.

V, and VI, show vertical sequences of exposures. V is a T-B order (downward), p equals zero. The dotted arcs indicate the pattern for a sector producing B-T order of exposure. The interval p is made greater than zero by cutting the slits in the sector at a distance from the center line of the sector. The exposure-time e is increased by lengthening the slits.

VI, shows the pattern for a sector producing an exposure-order going from bottom to top and back to bottom. In this way a rocket-effect may be produced, the light shooting upward and falling back. One observer compared this to a lantern being thrown up into the air.

These are only a few suggestions as to the many possible effects which may be produced by various arrangements of slits and aperatures in sector and section. For instance, the second exposure is readily presented as two areas, equidistant from the first exposure by making slits and aperatures on the proper arcs. An actual physical movement of light across the glass screen is produced by causing a short (narrow) slit in the sector to pass over a longitudinal arc-shaped aperature in the section.

The discrete outlines of the exposed areas are cut out of jet black paper and held firmly by cleats to the front of the milk-glass screen, the cut-out areas being in line with the aperatures in the section. This is important in order to restrict to the exposed area the effects of dispersion in the glass. Thus also the two exposed areas can be varied independently in size. They can be varied independently of each other in intensity per unit area, or in color, by inserting filters of standard paper or gelatine in front of either or both areas.

The removable sectors and sections are made from 8-ply show-card, black on one side and painted black on the other. The solid portion of the disc is made of quarter inch wall-board and the light shield which receives the sections is made of quarter inch three-ply fir veneer.

PART III

Preliminary Experiments

A. Procedure:

The purpose of these preliminary experiments is to test the adaptability of a number of stimulus situations to the main task of the investigation and to secure information as to the qualitative nature of the phenomena produced without temporal interval (p equal to o).

The observer[2] was seated 3 meters from the screen, with his head in the head-rest, and asked to fixate the red cross in the center of the screen. The room light was turned off, the apparatus arranged and the motor started. The observer was given no formal instructions, but was told in very simple language to keep both eyes fixed upon the fixation light and to observe and describe as accurately as possible in his own words the appearance, disappearance, and behavior of the stimulus light or lights.

The experimenter recorded the subject's reports on plain paper, noting the stimulus situation and the number of the observation, etc. Throughout all

---

[2] Two observers were used in these preliminary experiments; Dr. Harry Helson (H), and Mr. Donald F. Showalter (S), graduate student in psychology.

these experiments the subjects used both eyes and central vision, except in some cases where monocular or peripheral vision was used in addition. The second fixation light was switched on for the peripheral experiments.

The method of continued observation (Dauerbeobachtung) was used throughout. The subject was allowed to observe the phenomenon repeatedly, till he was ready to report. Some 300 sets of serial observations were recorded during these preliminary experiments.

1. A short series of experiments was conducted in which three methods of producing a situation of zero interval were compared (Both observers, H, and S). In one method the edge of the slit in the disc, which exterminated the light of the first stimulus by passing over the first area, completed its course across that area just at the instant that the edge of the slit which was to expose the second area, started to uncover and expose the latter area. (For illustration cf. Wertheimer, 24, page 12, figure 5.) In other words, the first stimulus area was completely gone at the exact time that the second stimulus area began to

be exposed. In the second method, the second stimulus area was entirely exposed by the time the first was beginning to disappear. In the third method, the process of extermination of the first area and that of illumination of the second were simultaneous, so that both processes started at the same point of time, and both terminated at the same time. Of course, the differences between these methods are exceedingly slight, but it was not assumed that they were unimportant or ineffective.

The speed of the motor was kept only within the limits of from c. 100 sigma to c. 500 sigma. The movement was horizontal, from left to right.

2. The intensity of illumination of the stimulus areas was varied by means of the rheostats from the highest possible intensity to the subliminal state (H, S) (5 areas, see Table I).

3. Left-to-right (L-R) and right-to-left (R-L) movements were compared (H, S) (A1, A3, A5). This was done in order to determine the effect of the direction of rotation of the disc.

4. The intensities of the two stimulus lights were varied independently of each other: The

first stimulus and the second stimulus were dimmed alternately. This was done by dimming always the left stimulus and using alternately L-R and R-L movement, leaving the right stimulus at full intensity. The left stimulus was dimmed by causing it to be filtered through substance-20 white Hammermill bond paper. The various stages of dimming consisted in using 1, 2, 3, 5, 8, 11, 13, 17, 19, and 21 thicknesses of this paper (H, S) (A1, A5).

5. The speed of the motor was varied, giving various lengths of exposure-times (H) (A1, R-L, L-R).

6. Upward and downward movement was produced. Also a combined movement was used in which the second stimulus appeared above the first, and a third in the same position as the first (H) (A1, A3, A5).

7. The first stimulus and the second were independently varied in area. This was done by arranging the 10 possible combinations of the 5 areas and using R-L and L-R sequence of exposure alternately with each combination, thus producing the 20 possible combinations of the first and second stimuli (10 with R-L and 10 with L-R). A1, A2, A3, and A4 were used on the left, and A2, A3, A4, and A5 on the right (S).

8. A temporal interval was introduced (30 to 60 sigma) and the movement compared with that in which p is zero (H).(Al, R-L, L-R, Upward, Downward).

B. Summayy of Results:

1. No significant differences were found between the three arrangements calculated to produce p equal to 0. This agrees with Wertheimer's findings (24). Good decisive movement was reported in all three cases.

2. It was found with both observers that the intensity of the stimulus lights could be varied widely without destroying the movement. It was sometimes reported that the lights were just barely visible but moved decisively. The ~~special~~ spacial separation of the lights was not changed but remained constant at 9.5 cm. (see notes following Table I). Sometimes, indeed, when the lights were subliminal, the observers were asked to leave the chair and approach the screen slowly: when the lights thus became perceptible, good movement was reported (in spite of the fact that the visual angle was necessarily increased by this procedure).

3. Movement was reported in one horizontal direction as well as in the other, just as decisive movement being reported when the direction of movement was opposed to the direction of rotation of the disc as when the two directions were the same.

4. It was found that movement occurred even when the two stimuli were widely different in intensity. The second stimulus being brighter than the first was probably a little more favorable condition for good movement than the first being brighter than the second. Good movement was reported even in the latter case until the one light was dimmed with at least 11 thicknesses of paper. When the first stimulus was brighter than the second, it was often reported that the light moved to the new position and suddenly grew dim and yellowish. At other times it was said to grow suddenly dim and then jump to the new position. At still other times it was reported to fade or grow dimmer as it moved. When the second stimulus was more intense than the first the corresponding changes took place with an increase instead of a decrease in brightness. No conditions could be noted which would explain the fact that the change in brightness took place now at the beginning, now at the end, and now near the middle of the course of movement.

The lights were entirely obliterated by 21 sheets of paper, and the smaller areas by fewer sheets. When one light was very dim, movement was reported, but more infrequently and with less decisiveness.

5. With greatly increased speed of the disc the movement became partial, and with still higher speeds (smaller exposure-times) movement ceased and the two lights were reported to appear stationary and simultaneous.

Sometimes it was reported that there was movement which was not distinctly the movement of a light or specific object, but just "something moves", or 'pure movement' without a specific moving object. This pure movement was sometimes reported together with stationary simultaneity of the lights themselves, and sometimes attached to part movement of one or both of the lights. No compulsory conditions for this phenomenon were established.

6. Movement was readily reported in all four directions. Also, the double vertical arrangement gave good full movement, described as a light shooting upward and dropping back.

7. When the areas of the two stimuli were different, there was reported movement of a light which changed in size and often also in brightness as it moved. With the extreme differences in area the movement was more often only partial, with sometimes also pure movement attached.

8. When the temporal interval was introduced the movement was often described as less positive and less decisive than when p was 0. The number of cases of part movement and of no movement was also greater. At the higher speeds of the motor, however, which gave stationary simultaneity with p at 0, movement was readily reported when there was a temporal interval of from 30 to 60 sigma. Near p, 30 the movement was usually only partial, but with larger value of p, optimal movement (movement of an actual light the entire distance between the two stimuli) was more often reported.

IV. Method:

The observers[3] were seated three meters from the screen as in the preliminary experiments, using central, binocular vision. The fixation was facilitated by the use of the head-rest, biting-board, and red constant fixation light as before. Five minutes was allowed to elapse after the room was darkened before any observations were recorded. The observers were asked to fixate the red light and observe and describe carefully the appearance, disappearance, and behavior of the stimulus light or lights, but not to speculate upon the causes of the phenomena or the function of the apparatus. These instructions were given verbally and informally, and were complied with faithfully throughout the experimentation.

The method of continued observation (Dauerbeobachtung) was used throughout, the conditions always being left constant at each particular stage until the observer could observe and describe the phenomenon or phenomena produced. The observers were allowed to observe the lights while making the report, and to watch the stimuli during the time that the temporal aspects of the exposures were gradually changing from

---

3. Two observers were used throughout the entire course of these experiments. They were: Dr. J. P. Guilford (G). and Mr. S. Howard Bartley(B), graduate student in psychology.

one stage to the next. When a stage was reached at which the phenomena were reported to be significantly different, the description was recorded and the speed of the disc also recorded.

A series of observations consisted in observing the stimuli during the variation of the conditions from the highest to the lowest speed of the disc or <u>vica versa</u>. For each arrangement of the stimuli 5 series were taken ascending (length of exposure-times increasing) and 5 descending. The observers were permitted to relax and rest the eyes at the end of any series.

Three sets of experiments were performed: P0, in which the exposure-times were varied while the interval <u>p</u> was kept constant at zero; P1, in which the exposure-times were again varied over the same range, while the inter-exposure interval was also varied, the ratio between the exposure-time <u>e</u> and the interval <u>p</u> remaining constant at <u>e</u> : <u>p</u> :: 24 : 10 (see note following Table I); and P2, in which <u>e</u> : <u>p</u> :: 24 : 25.

In all three sets of experiments, both vertical sequences of exposures (upward and downward) were used. In addition to this, horizontal arrangements (R-L and L-R) were used in P0.

These experiments were all carried out by the use of the circular exposure areas A 3 (see Table I), and in addition a few observations were taken with A 1, and A 5, but these are so meager that they cannot be considered quantitatively. In these experiments the areas were always illuminated at maximum intensity.

TABLE I

Dimensions of the Exposure Areas Used in these Experiments.

Label	Diameter	Area	Maximum Illumination at 3 M
A 1	3.5 mm	9.62 sq. mm	.00088 foot candles
A 2	4.5	15.90	.00141
A 3	6.0	28.27	.00246
A 4	9.0	63.617	.00554
A 5	11.0	95.13	.00836

The exposure areas were 10 cm apart from edge to edge in all cases of vertical arrangements, and 9.5 cm apart from edge to edge in all cases of horizontal arrangement.

In experiments labeled PO, the temporal interval or pause, p, between the two exposure-times, e1 and e2, is zero. In those labeled P1, p is equal to .416$\overline{6}$ times e, or e:p::24:10, where e is either e1 or e2 (e1 equals e2). In those labeled P2, p is equal to 1.041$\overline{6}$ times e, or e : p :: 24 : 25.

V. Results:

The readings in sigma of the points in the series of observations at which the type of movement phenomenon was reported to have changed are recorded in Tables II, and III. The ascending series and the descending are shown, and the corresponding readings in the five series are averaged and the mean deviations given. In the experiments, 798 observations and readings were noted, but only those are recorded here which mark the transition point from one type of movement to another, and in addition the readings under the heading 'Same' in the tables, which do not indicate transition points, but merely the lowest readings which were taken in those series.

The data for ascending series are averaged with the corresponding data for descending series in Tables IV to XVII inclusive. The values given in these tables are, then, the limits of conditions for the various types of movement for each observer, averaged from five readings ascending and five descending in each case.

These data are brought together in more compact arrangement in Tables XVIII to XXIV inclusive (the means are shown for purposes of comparison only). They are summarized and averaged in Tables XXV and XXXI.

The ranges of conditions for the various types of movement for the different observers presented in Tables XXVII to XXX[4] are arranged from the limits shown in Tables IV to XVII without further statistical treatment. These are the averages of the ten original readings in the raw data.

Aside from the numerical data, it should be noted that various qualitative aspects of the movement experience were noted throughout the experiments. Pure movement was described, part movement of various kinds, 'return movement' or delta movement, gamma movement, and curved movement, curving out away from the fixation light. All of these phenomena have been described in the previous literature, however, and will be further considered only in the discussion of results in Section VI.

It is impossible to designate various types of movement by terms consistent with all the previous literature, so that definitions of the terms used are necessary at the outset. These definitions are not at all arbitrary, being drawn from the literature as indicated in Section VI, but are given here for use in the reading of the results.

Optimal movement is the visual perception of the apparent movement of an actual light or object across the entire phenomenal spatial distance between

---

4. Shown graphically on page 51A.

the two stimuli presented.

Part movement is the movement of such an object or objects over any part or parts but not the entire distance between the stimuli.

Pure movement is indicated when the observer reports that movement is perceived (not ~~a~~meaning or imagination of movement), but that there is no actual phenomenal object which moves.

No combination of part movement and pure movement is here included under the head of optimal movement. Such a combination may be full movement, extending over the entire distance between the stimuli, but is not optimal, as herein defined.

TABLE II

Individual Data Observer B Showing Means and Mean Deviations (in sigma)

	P0 ascending prtB	P0 ascending opt	P0 descending prt B	P0 descending sta	P1 optimal		P1 ascending part A		P1 stationary	
	e	e	e	e	e	p	e	p	e	p
A3 Upward	68	70	110	78	95	40	345	144	388	162
	79	91	104	85	81	34	380	158	552	230
	92	108	104	85	126	53	388	162	474	198
	63	92	86	85	126	52	354	147	518	216
	95	119	104	67	133	55	345	144	518	216
Mean	79.4	96.0	101.6	80.0	112.2	46.8	362.4	151.0	490.0	204.4
Mean Dev.	11.28	14.00	6.24	6.00	19.36	7.84	17.28	7.20	47.20	19.52
A3 Downward	63	78	152	86	78	33	108	45	214	89
	65	82	81	77	136	57	324	135	345	144
	64	97	86	84	81	34	107	45	432	180
	64	77	72	61	73	31	126	53	474	198
	65	93	81	59	90	37	110	46	406	169
Mean	64.2	85.4	94.4	73.4	91.6	38.4	155.0	64.8	374.2	156.0
Mean Dev.	.64	7.68	23.04	10.72	17.76	7.44	33.80	28.08	75.76	31.60
A3 Right-to-Left	78	83	102	78						
	90	104	100	78						
	78	104	104	74						
	79	104	93	83						
	90	135	102	78						
Mean	83.0	106.0	100.2	78.2						
Mean Dev.	5.60	11.60	2.96	1.92						
A3 Left-to-Right	119	189	79	67						
	95	328	78	71						
	88	102	93	74						
	93	121	105	71						
	86	112	112	75						
Mean	96.2	170.4	93.4	71.6						
Mean Dev.	9.12	70.48	12.08	2.32						
A1 Upward			158	67	164	68	274	126	423	176
A1 Downward			81	72	149	62	259	108	475	198
A5 Upward			97	71	60	25	345	144	432	180
A5 Downward			113	85	61	26	75	31	190	79

	P1 descending Part A		P1 descending optimal		P1 ascending Part B		P1 ascending Part A		P2 Sta		P2 Part A		P2 Descending Opt		P2 Same	
	e	p	e	p	e	p	e	p	e	p	e	p	e	p	e	p
A3 Upward	336	140	259	108	92	39	77	80	270	281	259	270	86	90	64	67
	302	126	259	108	102	43	190	198	298	310	276	288	135	141	73	77
	432	180	289	120	131	55	95	99	482	513	302	315	138	144	66	69
	345	144	243	101	114	47	170	177	550	575	302	315	129	135	76	79
	440	183	298	124	116	48	131	137	483	504	319	333	132	138	60	63
Mean	371.0	154.6	269.6	112.2	111.0	46.4	132.6	138.2	416.6	436.6	219.6	304.2	[illegible]	129.6	67.8	71.0
Mean Dev.	52.00	21.52	19.12	7.84	11.20	4.32	37.92	39.44	106.1	112.9	19.28	20.16	15.30	15.84	5.26	5.60
A3 Downward	388	162	237	99	124	52	113	118	259	270	302	315	141	147	59	61
	272	114	112	47	97	41	112	117	306	319	207	216	85	88	60	65
	259	108	119	49	91	38	121	126	298	310	263	274	83	87	67	70
	289	120	112	47	92	39	110	115	310	323	302	315	95	99	67	70
	345	144	93	39	85	35	142	148	483	504	285	297	79	83	63	65
Mean	310.6	129.6	134.6	56.2	97.8	41.0	119.6	124.8	331.2	345.2	271.8	283.4	96.6	100.8	63.2	65.8
Mean Dev.	44.72	18.72	40.96	17.12	10.48	4.40	11.52	9.76	60.72	63.52	29.44	30.72	17.76	18.48	3.04	3.36
A1 Upward							103	107	291	304						
A1 Downward							124	129	173	180						
A5 Upward							123	128	261	292						
A5 Downward							111	116	223	243						

The readings under each separate heading (P0, P1, and P2) are read from left to right in horizontal direction, e.g. in the first line above, e, was gradually increased till at 68 part movement began to appear. At 70 optimal movement appeared and continued as the series ascended, and also as it descended till part again appeared at 110. This continued to 78, below which they areas appeared stationary. Readings in sigma

In all cases except in case of the column labeled "same" above, the figures show the point in the series at which the phenomenon named at the head of the column begins to appear. Any reading then, marks the limiting point of, both the range of conditions which give the phenomenon named in that column, and the range of conditions which give the phenomenon which preceded it in the series; or in other words, such a reading marks the boundary line between two such ranges of conditions. For instance, the second reading in the first line under P0 above, 70 indicates the lower limit of optimal movement in that series and the upper limit of part movement; or in other words, the point at which the movement changed from part to optimal, values of e ascending.

For definitions of A1, A3, A5, P0, P1, and P2 see Table I and notes following.

TABLE III.

Individual Data, Observer <u>G</u>, Showing Means and Mean Deviations (in sigma)

	P0 ascending prt B	P0 ascending opt	P0 descending prt B	P0 descending sta	P1 optimal		P1 ascending part A		P1 stationary		P1 part A	
	e	e	e	e	e	p	e	p	e	p	e	p
A3												
	61	73	72	61	65	27	293	122	345	144	276	115
	64	65	72	57	81	34	305	127	336	140	264	110
	67	83	73	69	69	29	302	126	354	147	397	165
	74	78	77	73	66	28	319	133	483	176	319	133
	66	67	70	66	68	28	302	126	345	144	259	108
mean	66.4	75.2	72.8	65.2	69.8	29.2	304.2	126.8	360.6	150.2	305.0	126.2
mean Dev.	3.28	6.24	1.76	4.96	4.48	1.92	6.24	2.56	24.56	10.32	44.40	18.04
A3												
	70	75	76	61	61	26	259	108	432	108	302	126
	63	66	72	71	-------	-------	380	158	432	180	371	155
	69	78	72	71	-------	-------	345	144	423	176	354	147
	71	73	71	71	-------	-------	371	155	423	176	284	118
	67	71	75	67	64	27	293	122	388	162	293	122
mean	68.0	72.6	73.2	68.2			329.6	137.4	419.6	174.8	320.8	133.6
mean Dev.	2.40	3.28	1.84	3.36			42.88	13.92	12.64	5.12	33.36	11.92
A3 Right-to-Left												
	60	69	58	55								
	64	66	68	59								
	65	67	60	58								
	61	76	59	53								
	60	65	64	55								
mean	62.0	68.6	61.8	56.0								
mean Dev.	2.00	3.12	3.36	2.00								
A3 Left-to-Right												
	63	72	66	60								
	65	79	73	64								
	68	70	76	63								
	65	81	80	68								
	69	86	76	68								
mean	66.0	77.6	74.2	64.6								
mean Dev.	2.00	5.28	3.76	2.72								
A1 Upward			81	72	-------	-------	121	50	311	129		
A1 Downward			81	63	-------	-------	152	105	276	157		
A5 Upward			74	56	-------	-------	388	161	432	180		
A5 Downward			78	61	-------	-------	189	79	388	162		

	P1 descending optimal		Part B *		P2 Ascending Part A		P2 Ascending Sta		P2 Part A		P2 Descending Opt		P2 Same	
	e	p	e	p	e	p	e	p	e	p	e	p	e	p
A3 Upward														
	158	68	65	27	167	174	475	495	138	144	122	127	63	66
	183	76	64	27	194	203	216	225	164	172	126	135	60	63
	168	70	62	26	220	229	302	315	151	158	116	121	66	69
	227	94	66	28	112	117	216	225	164	171	103	108	71	74
	216	90	85	35	172	180	250	261	172	180	110	115	70	73
	190.4	79.2	68.4	28.6	173.0	180.6	291.8	304.2	157.8	165.0	115.4	121.2	66.0	69.0
	24.88	10.24	6.64	2.56	27.30	28.12	77.36	80.64	10.64	11.20	7.12	7.84	3.60	3.60
A3 Downward														
	221	92	-------	-------	227	236	475	495	158	165	82	86	65	67
	227	95	-(flutter)-		194	203	216	225	160	166	127	132	62	65
	262	109	-------	-------	187	195	288	300	136	142	93	97	62	65
	216	90	65	27	127	132	216	225	181	189	80	82	59	62
	172	72	-------	-------	172	180	242	252	172	180	88	92	71	74
	219.6	91.6			181.4	189.2	287.4	299.4	161.4	168.4	94.0	97.8	63.8	66.6
	20.48	8.48			25.52	26.56	75.28	78.48	12.08	12.88	13.20	13.68	3.36	3.12
					134	140	263	274						
					129	135	132	138						
					91	95	179	186						
					180	187	285	297						

Part B indicates the range of part movement that is intermediate between the range of stationary simultaneity and that of optimal movement; Part A, that which is intermediate between stationary succession and optimal. The column headed "Same" shows the lowest readings which were taken in each series in P2, and does not necessarily mark the lower limit of optimal, but merely shows that the movement was still optimal at this point. This note applies also to Table II and all the notes on that table apply to this one as well.

The dotted lines in the table indicate that the limits designated in that column *were* not determined for those particular series, because said limits were too low to be determined by the apparatus as it was set up for those series. The movement was and continued to be optimal through the ranges covered by the dotted lines, the limits of such movement not being reached. Since these limits were not reached, they must necessarily have been lower than those which were reached in parallel or comparable series.

The readings under A3 Upward, Part B, Descending, P1, (marked *) are not conclusively the true limits and are probably higher than the true limits, since they were given qualifiedly by G, and were succeeded by a considerable number of optimal movements. All averages, in any tables, which contain these data are also marked (*).

TABLE IV

Lower Limits of Optimal Movement, PO, Observer B.

		e
Upward	Ascending (Opt)	96.0 sigma
	Descending (Prt)	101.6
	Mean	98.8
Downward	Ascending (Opt)	85.4
	Descending (Prt)	94.4
	Mean	89.9
R-L	Ascending (Opt)	106.0
	Descending (Prt)	100.2
	Mean	103.1
L-R	Ascending (Opt)	170.4
	Descending (Prt)	93.4
	Mean	131.9

TABLE V

Lower Limits of Part Movement, PO, Observer B.

Upward	Ascending (Prt)	79.4
	Descending (Sta)	80.0
	Mean	79.7
Downward	Ascending (Prt)	64.2
	Descending (Sta)	73.4
	Mean	68.8
R-L	Ascending (Prt)	83.0
	Descending (Sta)	78.2
	Mean	80.6
L-R	Ascending (Prt)	96.2
	Descending (Sta)	71.6
	Mean	83.9

TABLE VI

Lower Limits of Optimal Movement, Pl, Observer B.

		e	p	
Upward	Ascending (Opt)	112.2	46.8	sigma
	Descending (Prt B)	111.0	46.4	
	Mean	111.6	46.6	
Downward	Ascending (Opt)	91.6	38.4	
	Descending (Prt B)	97.8	41.0	
	Mean	94.7	39.7	

TABLE VII

Upper Limits of Optimal Movement, Pl, Observer B.

Upward	Ascending (Prt)	362.4	151.0
	Descending (Opt)	269.6	112.2
	Mean	316.0	131.6
Downward	Ascending (Prt)	155.0	64.8
	Descending (Opt)	134.6	56.2
	Mean	144.8	60.5

TABLE VIII

Upper Limits of Part Movement, Pl, Observer B.

Upward	Ascending (Sta)	490.0	204.4
	Descending (Prt A)	371.0	154.6
	Mean	430.5	179.5
Downward	Ascending (Sta)	374.2	156.0
	Descending (Prt A)	310.6	129.6
	Mean	342.4	142.8

TABLE IX

Upper Limits of Optimal Movement, P2, Observer B.

		e	p
Upward	Ascending (Prt)	132.6	138.2 sigma
	Descending (Opt)	124.0	129.6
	Mean	128.3	133.9
Downward	Ascending (Prt)	119.6	124.8
	Descending (Opt)	96.6	100.8
	Mean	108.1	112.8

TABLE X

Upper Limits of Part Movement, P2, Observer B.

Upward	Ascending (Sta)	416.6	436.6
	Descending (Prt)	219.6	304.2
	Mean	318.1	370.4
Downward	Ascending (Sta)	331.2	345.2
	Descending (Prt)	271.8	283.4
	Mean	301.5	314.3

TABLE XI

Lower Limits of Optimal Movement, PO, Observer G.

		G
Upward	Ascending (Opt)	75.2 sigma
	Descending (Prt)	72.8
	Mean	74.0
Downward	Ascending (Opt)	72.6
	Descending (Prt)	73.2
	Mean	72.9
R-L	Ascending (Opt)	68.6
	Descending (Prt)	61.8
	Mean	65.2
L-R	Ascending (Opt)	77.6
	Descending (Prt)	74.2
	Mean	75.9

TABLE XII

Lower Limts of Part Movement, PO, Observer G.

Upward	Ascending (Prt)	66.4
	Descending (Sta)	65.2
	Mean	65.8
Downward	Ascending (Prt)	68.0
	Descending (Sta)	68.2
	Mean	68.1
R-L	Ascending (Prt)	62.0
	Descending (Sta)	56.0
	Mean	59.0
L-R	Ascending (Prt)	66.0
	Descending (Sta)	64.6
	Mean	65.3

TABLE XIII

Lower Limits of Optimal Movement, P1, Observer G.

		e	p	
Upward	Ascending (Opt)	69.8	29.2	sigma
	Descending (Prt B)	68.4	28.6	
	Mean	69.1 *	28.9 *	
Downward	--			

* See note on Table III.

TABLE XIV

Upper Limits of Optimal Movement, P1, Observer G.

Upward	Ascending (Prt)	304.2	126.8
	Descending (Opt)	190.4	79.2
	Mean	247.3	103.0
Downward	Ascending (Prt)	329.6	137.4
	Descending (Opt)	219.6	91.6
	Mean	274.6	114.5

TABLE XV

Upper Limits of Part Movement, P1, Observer G.

Uppward	Ascending (Sta)	360.6	150.2
	Descending (Prt A)	305.0	126.2
	Mean	332.8	138.2
Downward	Ascending (Sta)	419.6	174.8
	Descending (Prt A)	320.8	133.6
	Mean	370.2	154.2

TABLE XVI

Upper Limits of Optimal Movement, P2, Observer G.

		e	p	
Upward	Ascending (Prt)	173.0	180.6	sigma
	Descending (Opt)	115.4	121.2	
	Mean	144.2	150.9	
Downward	Ascending (Prt)	181.4	189.2	
	Descending (Opt)	94.0	97.8	
	Mean	137.7	143.5	

TABLE XVII

Upper Limits of Part Movement, P2, Observer G.

Upward	Ascending (Sta)	291.8	304.2
	Descending (Prt)	157.8	165.0
	Mean	224.8	234.6
Downward	Ascending (Sta)	287.4	299.4
	Descending (Prt)	161.4	168.4
	Mean	224.4	233.9

TABLE XVIII

Lower Limits of Optimal Movement, PO.

		e	
Upward	B	98.8	sigma
	G	74.0	
Downward	B	89.9	
	G	72.9	
R-L	B	103.1	
	G	65.3	
L-R	B	131.9	
	G	75.9	
Mean	B	105.9	
	G	72.0	
	Both	88.9	

TABLE XIX

Lower Limits of Part Movement, PO.

		e
Upward	B	79.7
	G	65.8
Downward	B	68.8
	G	68.1
R-L	B	80.6
	G	59.0
L-R	B	83.9
	G	65.3
Mean	B	78.2
	G	64.5
	Both	71.4

TABLE XX

Lower Limits of Optimal Movement, Pl.

		e	p
Upward	B	111.6	46.6 sigma
	G	69.1 *	28.9 *
Downward	B	94.7	39.7
	G		
Mean	B	103.1	41.1
	G	69.1 *	28.9 *
	Both	91.8 *	38.4 *

* See note on Table III.

TABLE XXI

Upper Limits of Optimal Movement, Pl.

Upward	B	316.0	131.6
	G	247.3	103.0
Downward	B	144.8	60.5
	G	274.6	114.5
Mean	B	230.4	96.0
	G	260.9	108.7
	Both	245.5	102.4

TABLE XXII

Upper Limits of Part Movement, Pl.

Upward	B	430.5	179.5
	G	332.8	138.2
Downward	B	342.4	142.8
	G	370.2	154.2
Mean	B	386.4	161.1
	G	351.5	146.2
	Both	369.0	153.7

TABLE XXIII

Upper Limits of Optimal Movement, P2.

		e	p	
Upward	B	128.3	133.9	sigma
	G	144.2	150.9	
Downward	B	108.1	112.8	
	G	137.7	143.5	
Mean	B	118.2	123.3	
	G	140.9	147.2	
	Both	129.6	135.3	

TABLE XXIV

Upper Limits of Part Movement, P2.

Upward	B	318.1	370.4
	G	224.8	234.6
Downward	B	301.5	314.3
	G	224.4	233.9
Mean	B	309.8	342.3
	G	224.6	234.2
	Both	267.2	288.3

TABLE XXV:

Summary of Data, Both Observers:

		e	p
Lower Limits of Optimal Movement, PO. (18)	Upward	86.4 sigma	
	Downward	81.4	
Lower Limits of Part Movement, PO. (19)	Upward	72.7	
	Downward	68.4	
Lower Limits of Optimal Movement, P1. (20)	Upward	90.3*	37.7*
	Downward	94.7*	39.7*
Upper Limits of Optimal Movement, P1. (21)	Upward	281.6	117.3
	Downward	209.7	87.5
Upper Limits of Part Movement, P1. (22)	Upward	381.6	158.8
	Downward	356.3	148.5
Upper Limits of Optimal Movement, P2. (23)	Upward	136.2	142.4
	Downward	122.9	128.1
Upper Limits of Part Movement, P2. (24)	Upward	271.4	302.5
	Downward	262.9	274.1

The data in this table are obtained by averaging the appropriate values in Tables 18, 19, 20, 21, 22, 23, and 24 as indicated in parenthesis above.

* See note on Table III.

TABLE XXVI

Summary of Data, Averaged for all Directions Used.

		e	p
Lower Limits of Optimal, P0.	B	105.9 sigma	
	G	72.0	
	Both	88.9	
Lower Limits of Part, P0.	B	78.2	
	G	64.5	
	Both	71.4	
Lower Limits of Optimal, P1.	B	103.1	41.1
	G	69.1 *	28.9 *
	Both	91.8 *	38.4 *
Upper Limits of Optimal, P1.	B	230.4	96.0
	G	260.9	108.7
	Both	245.5	102.4
Upper Limits of Part, P1.	B	286.4	161.1
	G	351.5	146.2
	Both	369.0	153.7
Upper Limits of Optimal, P2.	B	118.2	123.3
	G	140.9	147.2
	Both	129.6	135.3
Upper Limits of Part, P2.	B	309.8	342.3
	G	224.6	234.2
	Both	267.2	288.3

* See note on Table III.

TABLE XXVII

Succession of ranges of conditions for various types of movement phenomena, Observer B.

Upward Movement:

Type	P0	P1	P2
Stationary Simultaneity	e, 0(?)--79.7		
Part B	e, 79.7--98.8	e, ?--111.6 p, ?-- 46.6	
Optimal	e, 98.8--oo(?)	e, 111.6--316.0 p, 46.6--131.6	e, ?<67.8--128.3 p, ?<71.0--133.9
Part A		e, 316.0--430.5 p, 131.6--179.5	e, 128.3--318.1 p, 133.9--370.4
Stationary Succession		e, 430.5--? p, 179.5--?	e, 318.1--? p, 370.4--?

TABLE XXVIII

Succession of ranges of conditions for various types of movement phenomena, Observer B.

Downward Movement:

Type	Po	P1	P2
Stationary Simultaneity	e, 0(?)--68.8		
Part B	e, 68.8--89.9	e, ?--94.7 p, ?--39.7	
Optimal	e, 89.9--∞ (?)	e, 94.7--144.8 p, 39.7--60.5	e, ?<63.2--108.1 p, ?<65.8--112.8
Part A		e, 144.8--342.4 p, 60.5--142.8	e, 108.1--301.5 p, 112.8--314.3
Stationary Succession		e, 342.4--? p, 142.8--?	e, 301.5--? p, 314.3--?

TABLE XXIX

Succession of ranges of conditions for various types of movement phenomena, Observer G.

Upward Movement:

Type	P0	P1	P2
Stationary Simultaneity	e, 0(?)--65.8		
Part B	e, 65.8--74.0	e, ?--69.1(?)* p, ?--28.9(?)*	
Optimal	e, 74.0--∞(?)	e, 69.1(?)*--247.3 p, 28.9(?)*--103.0	e, ?<66.0--144.2 p, ?<69.0--150.9
Part A		e, 247.3--332.8 p, 103.0--138.2	e, 144.2--224.8 p, 150.9--234.6
Stationary Succession		e, 332.8--? p, 138.2--?	e, 224.8--? p, 234.6--?

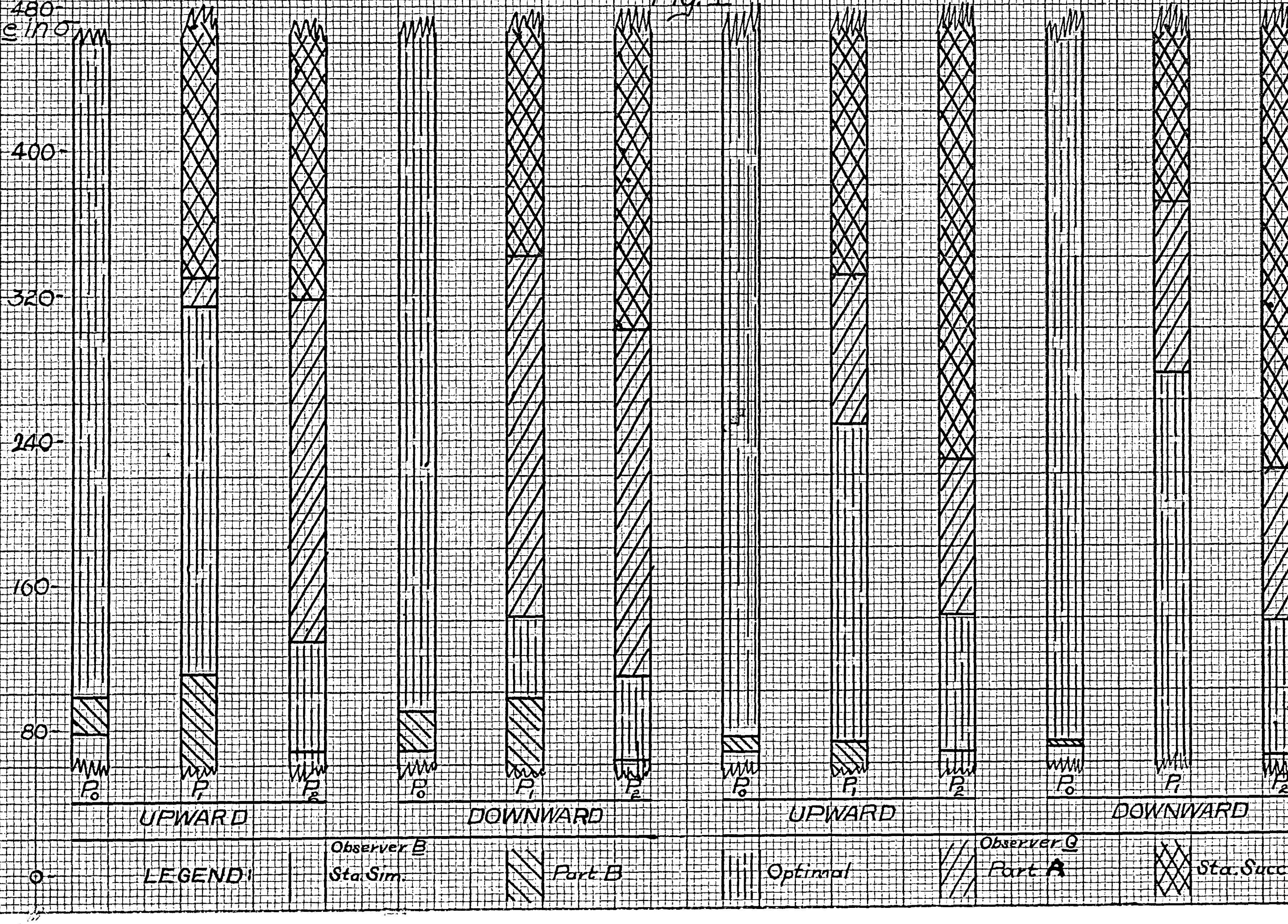
TABLE XXX

Succession of ranges of conditions for various types of movement phenomena, Observer G.

Downward Movement:

Type	P0	P1	P2
Stationary Simultaneity	e, 0(?)--68.1		
Part B	e, 68.1--72.9		
Optimal	e, 72.9--∞(?)	e, ?--274.6 p, ?--114.5	e, ?<63.8--137.7 p, ?<66.6--143.5
Part A		e, 274.6--370.2 p, 114.5--154.2	e, 137.7--224.4 p, 143.5--233.9
Stationary Succession		e, 370.2--? p, 154.2--?	e, 224.4--? p, 233.9--?

Fig. I


480
e in σ
400
320
240
160
80
0
P0 P1 P2 P0 P1 P2 P0 P1 P2 P0 P1 P2
UPWARD
DOWNWARD
UPWARD
DOWNWARD
LEGEND:
Observer B
Sta. Sim.
Part B
Optimal
Observer Q
Part A
Sta. Succ.

VI. Discussion of Results

The results show that optimal movement can be produced without temporal interval. This has been mentioned by Higginson (12), Wertheimer (24), and Hillebrandt (14). Higginson contended, however, that the temporal interval was therefore unimportant. These results also show that simultaneity can be consistantly produced with zero interval, and further, that this simultaneity can be changed to movement by a temporal separation of the exposure-times, or by an increase in the exposure-times themselves. It therefore, appears that the durational aspect of the stimulus situation is an important factor in the perception of apparent movement, and that Higginson has minimized the importance of this factor. The results of Wertheimer which show simultaneity with a temporal interval of 30 sigma indicate that the duration of the stimulus situation must be at least that, and even more if good movement is to be perceived. The results of the present experiments, showing the influence of the different temporal intervals upon the type of movement phenomena reported, are shown in Tables XXVII, to XXX. These same facts are presented graphically in Figure I. Any further work upon this point should be done with constant values, not merely of the ratio of e to p, but of p itself. That is, e should be varied with p constant throughout a series of experiments, and several values of p used, each in a different series. The functional relation between e and p could then be plotted in the form of a curve.

The values stated in these results, with the exceptions noted (those marked 'same' in Tables II and III and indicated by < in Tables XXVII to XXX) are the outer limits of the regions indicated. This means that the best conditions for optimal movement would be expected at a place intermediate between these limits (the upper and lower limits for optimal movement). These limits can readily be located on the diagrams in Figure I.

As noted under Results Section V all movements which are classified as Optimal are those in which an actual light or phenomenal object was reported to apparently move over the entire distance between the stimulus lights. This type of movement would be included under Higginson's heading of 'full movement' but it is a more restricted term than the latter (cf. 12). Hulin (15, page 306) has reversed this terminology. Part movement is of course to be mentioned as a separate class of phenomena in addition to the three main stages stressed by Koffka and Wertheimer (17, page 269). There are two regions of part movement, that which occurs between the regions of succession and of optimal, and that which occurs between the regions of simultaneity and of optimal, called herein; Part A and Part B, respectively.

Cermak (2) writes upon the relation between e and p, but the conditions of his experiments were so complicated (e and p varied together in all cases), and his apparatus so inflexible that it would be virtually impossible to isolate the influence of either e or p from the effect of the other. His fourth parallel law states that in order to retain any particular stage of phenomena, the pause must be made shorter if the exposure-time is made longer. Under the conditions of the present work, the pause *may* be made shorter if the exposure-time is made longer, but need not necessarily be so shortened. On the other hand, if the exposure-time is shortened beyond the limits which give the desired condition of movement, the pause must be lenthened to restore the phenomenon. The results of the present work agree still less with statement of Cermak's fourth law given by Helson, (8, page 512, "the greater the time of exposure, just so much the greater must the pause be between the phases if any kind of movement or any degree of fusion is to be seen"). Cermak's original statement (2, page 106) is "Je grösser die Expositionseit, um so kürzer muss die Pause sein, damit ein bestimmter Stadieneindruck, z. B. Sim, oder Verschmelzung eintritt, und je grösser die Pause, um so kürzer die Expositionszeit."

The tendency of the stage of movement phenomena to remain the same with serial observation and gradual change of conditions (as shown by comparison of the ascending and descending values in this work) should be remembered in connection with the 'zone law' of Cermak (8, page 511; 2), and also with the influence of experimental set demonstrated by Wertheimer (25) and described by Koffka (16, page 548).

In connection with the part of the preliminary work dealing with intensity cf. Thelin (22), who investigated the influence of intensity of stimuli on the accuracy of perception of relative visual motion (not apparent movement from stationary stimuli).

A word should be said about eye-movements. Itthas been assumed by Higginson and others that ocular shifts may produce, at least in part, the movements observed in stroboscopic experiments. It is not clearly stated just how these eye-movements dould possible occasion the perception of such movement, but it is indicated (11, 12) that if a second stimulus light appears below the first, the eyes will tend to follow it and thus the downward movement is perceived. See also McConnell (21, page 238). This is also illustrated by Higginson (11, page 408) by referring to mechanical manipulation of the eyeball. Anyone can verify for himself the fact that mechanical manipulation of the eyeball produces movements of objects in the field of vision in the direction exactly opposed to the direction of rotation of the eyeball. By placing the fore finger on the soft portion of the eye below the eyeball, one can soon learn to rotate (not merely move) the eyeball either upward or downward. When the eye follows the appearance of the second stimulus, it rotates downward. Then a downward sequence of exposures should, according to eye-movement, produce the perception of upward movement, or none at all (if the eye-movement and stimulus-change equaled each other), since downward rotation of the eyeball causes stationary objects in the field of vision to rush upward.

The relation between the temporal interval and the percentage of cases of optimal movement reported in Dimmick's experiments (4) is illustrated by the curves shown here in Figures II and III. It is obvious that the curves are highest near the 90 sigma interval point.

The parallel between Dimmick's process and meaning data is also demonstrated in these curves, and Higginson's treatment of these data is examined in the following table (XXXI) and discussion.

TABLE XXXI

From Higginson's treatment of Dimmick's data.

30 sigma	60 sigma	90 sigma	120 sigma	150 sigma
+12	-3	+ 2	+ 3	- 7
-25	+ 25	- 5	+35	- 5
+ 5	+15	+ 5	+ 5	+20
-25	-17	+15	0	+62
-23	- 2	+ 3	+53	+12
-20	+28	+27	+ 7	+15
+ 5	+ 5	+15	- 5	+18
-10	- 5	+ 7	+33	+ 8
+22	+73	+74	+136	+135
-103	-27	- 5	- 5	-12
-81	+46	+69	+131	+123

The above table shows the same figures which Higginson has taken from Dimmick's Table III and incorporated into his article (12) on page 109, together with, for each column, the algebraic sum, which Higginson does not show. If the reader will study Dimmick's table and Higginson's statements (page 109f), remembering that Dimmick's table is one of percentages and not of cases, he may see how grossly Higginson has misinterpreted Dimmick's data. Higginson says that "At 30 sigma there were 103 more cases of full-movement than of corresponding process-configuration (5 <u>Os</u>)". The above figures clearly show that at 30 sigma the excess of meaning over process reports is 81 instead of 103; and again it must be remembered that these figures are not <u>cases</u>, as Higginson represents them, but that they are mere aggregations of percentages. The excess of meaning over process reports can readily be obtained from the averages given in Dimmick's own Table III, and at this point (30 sigma) is obviously 11% (64 minus 53). Now, 11% of 160 cases (20 cases for each of 8 observers) is about 18 cases, rather than the 103 cases calculated by Higginson. This value can be verified by referring to the curves (Figure II) shown herewith, which were plotted from the averages given in Dimmick's Table III. What Higginson has done is to add Dimmick's data arithmatically instead of algebraically, or in other words, to select the data from those of Dimmick's observers which best suit his contention at each particular point. He considers three points (30sigma, 90sigma, and 150sigma), and at no two of these points does he consider the data from the same identical group of observers, nor even from the same <u>number</u> of observers, and at no one of these points does he consider the data from all

8 observers as Dimmick presents them. In presenting the alleged discrepancy of 103 cases between the two sorts of reports at this point, Higginson has neglected to mention the total or absolute number of cases so that one might see whether the discrepancy is considerable or negligible. The reader may well be inclined to wonder if he is expected to assume that, since 103 is a large number, as numbers go, it is therefore a serious one. As has been shown above, however, the real difference between these two types of reports at this point is about 18 cases out of a total of 160 cases for each type of report. The curves presented here, of Dimmick's data, show the differences between the two kinds of report in the number of cases of full-movement and of total-configuration, at each point, as well as the absolute amount of each, i.e. the vertical height of each curve. The parallelism between the two curves is obvious. When the data from the other part of Dimmick's table (oblique-to-horizontal movement) is also plotted (Figure III), the parallel is even more striking. The diagrams (Figures IV and V) plotted from Dimmick's Table I show that the numbers of cases of total-, unimembral-, and bimembral-experiences respectively, are virtually the same for both types of report.

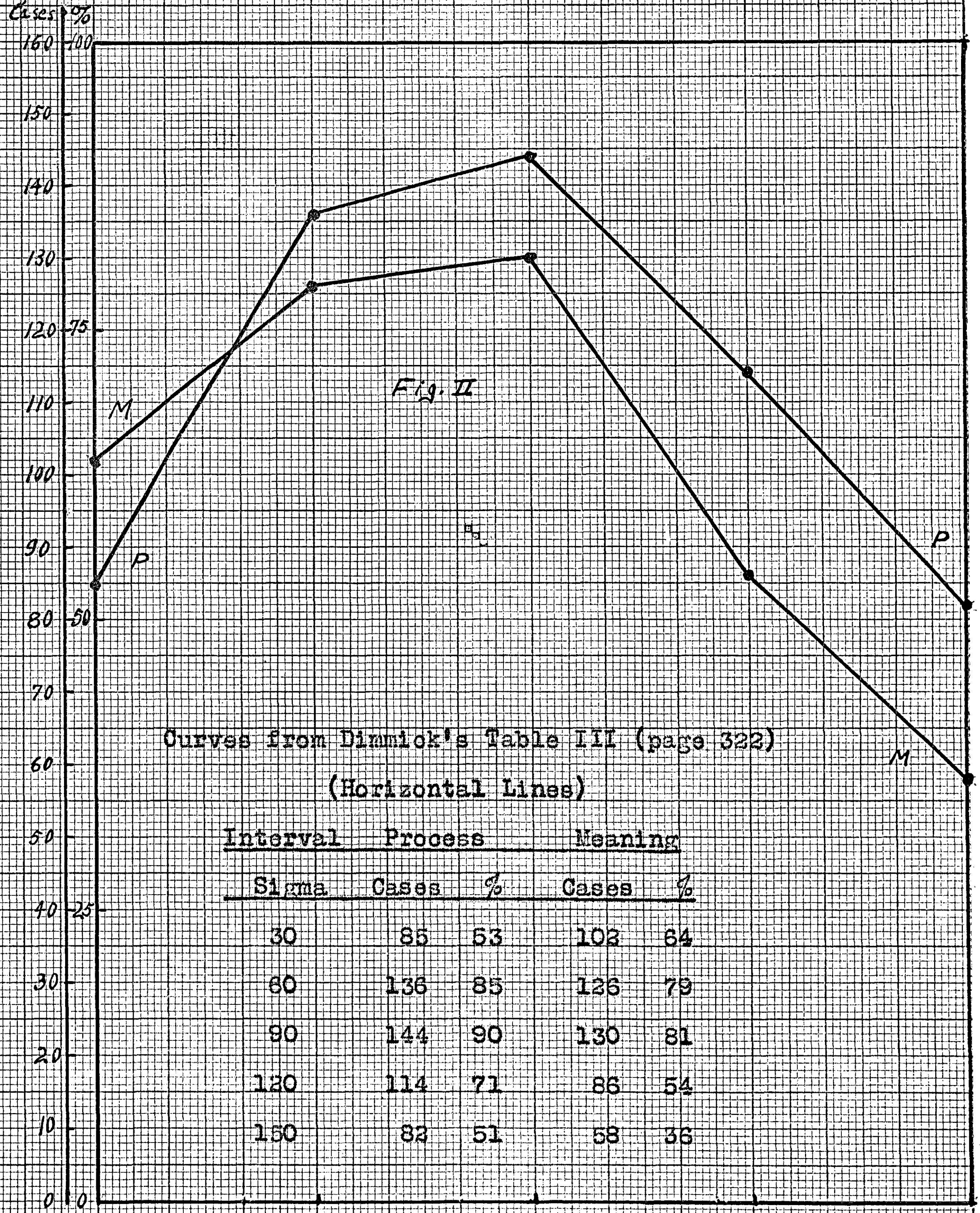


Fig. II

Curves from Dimmick's Table III (page 322)

(Horizontal Lines)

Interval	Process		Meaning	
Sigma	Cases	%	Cases	%
30	85	53	102	64
60	136	85	126	79
90	144	90	130	81
120	114	71	86	54
150	82	51	58	36

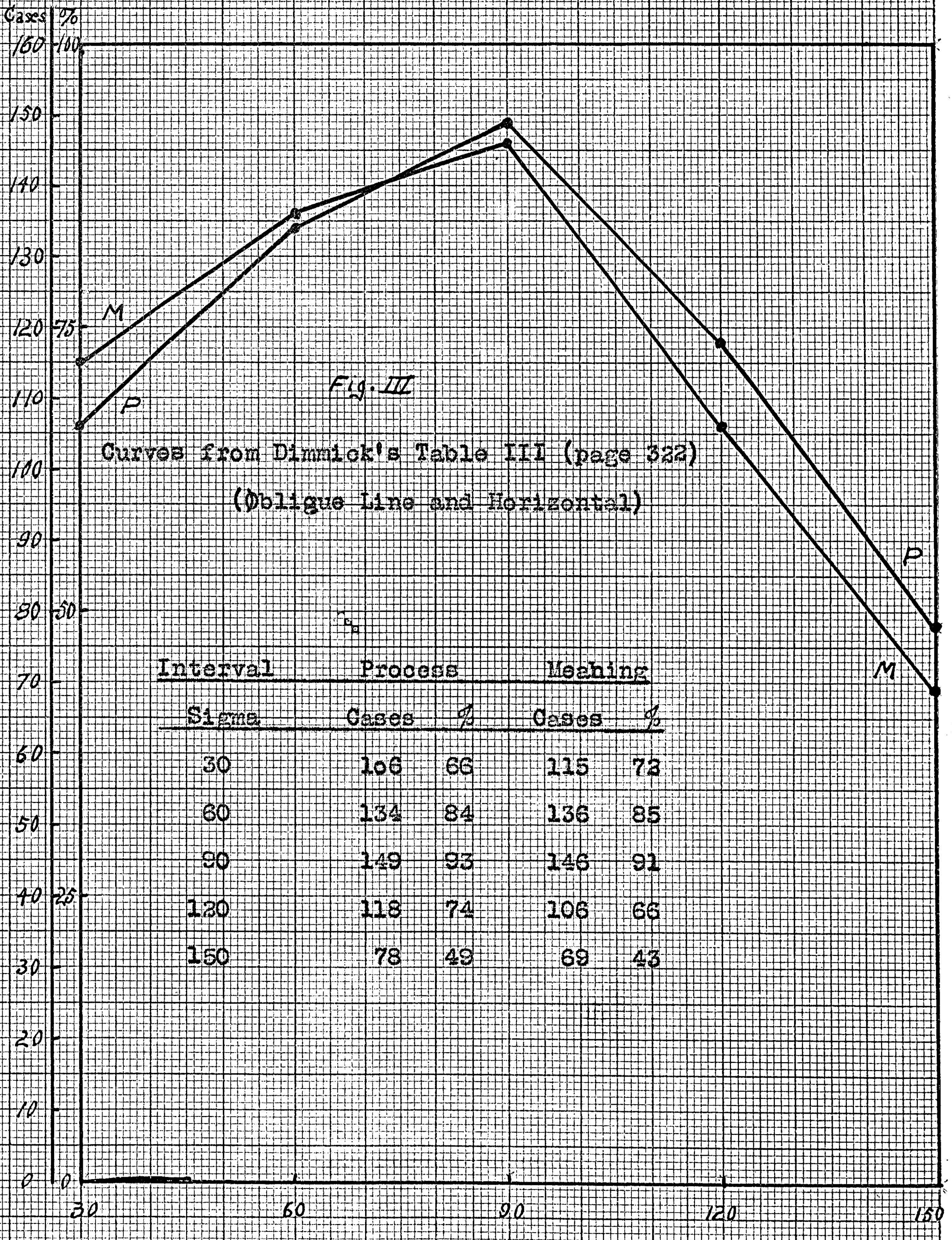


Fig. III

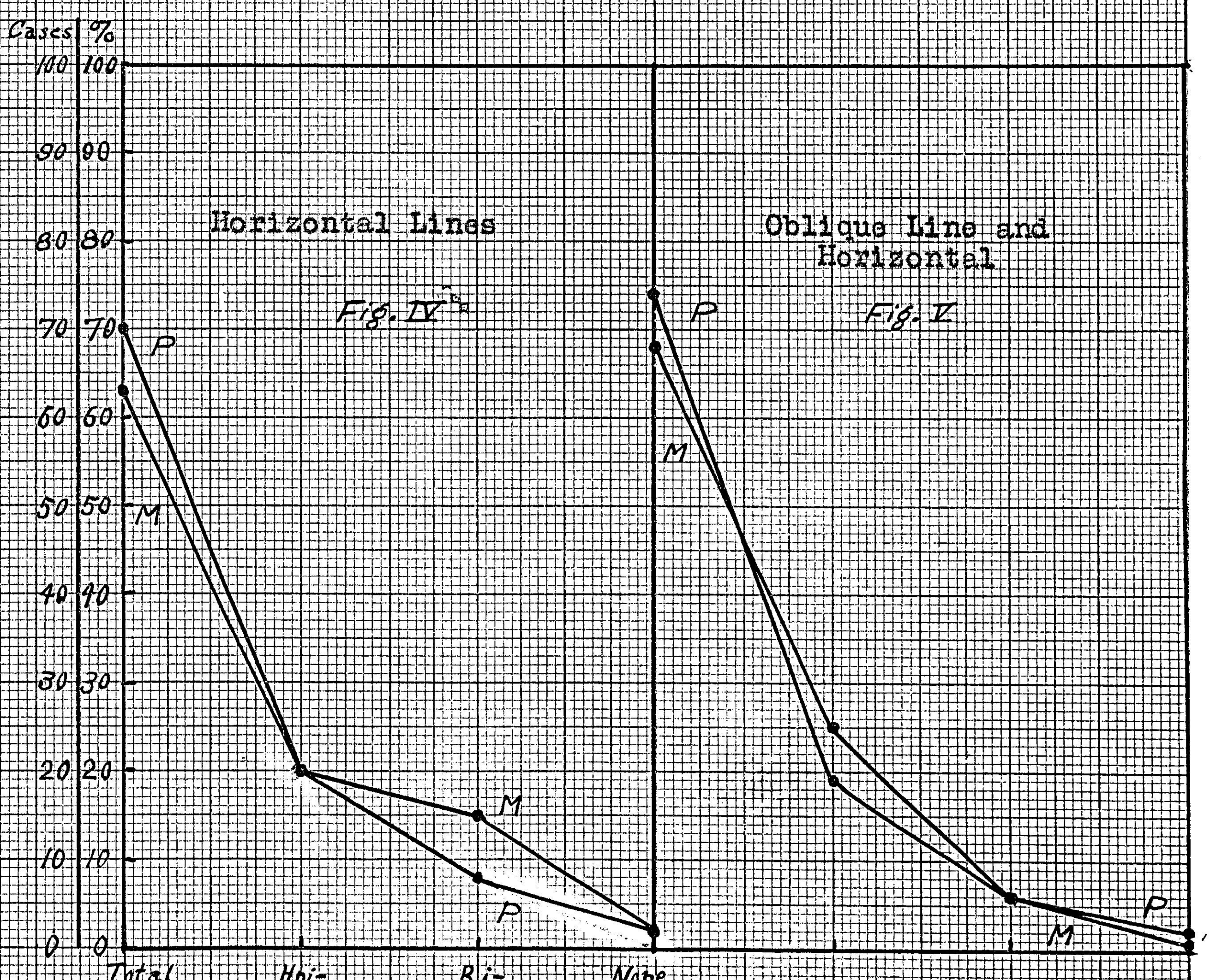
Curves from Dimmick's Table III (page 322)

(Obligue Line and Horizontal)

Interval	Process		Meaning	
Sigma	Cases	%	Cases	%
30	106	66	115	72
60	134	84	136	85
90	149	93	146	91
120	118	74	106	66
150	78	49	69	43

Diagrams from Dimmick's Table I (page 321)

	Experience Type	Process Cases	Process %	Meaning Cases	Meaning %
Horizontal Lines	Total	70	70	63	63
	Uni-	20	20	20	20
	Bi-	8	8	15	15
	None	2	2	2	2
Horizontal Line and Oblique	Total	74	74	68	68
	Uni-	19	19	25	25
	Bi-	6	6	6	6
	None	2	2	1	1



VII. Conclusions

1. Very good decisive optimal movement may be produced without temporal interval between exposures if the exposure-times themselves are long enough.

2. Very definite and consistent phenomenal stationary simultaneity may be produced under the same general conditions without temporal interval if the exposure-times are short enough.

3. Under the conditions of these experiments and for the observers used, it may be concluded that values below about 60 sigma (each exposure-time) are sufficient to produce phenomenal stationary simultaneity without temporal interval between exposures.

4. Under the same conditions, values above 100 sigma (each exposure-time) may be expected to give full optimal movement quite consistently without temporal interval between exposures.

5. It is possible to produce optimal movement with temporal interval between exposures although the exposure-times themselves are such as produce stationary simultaneity without interval between exposures.

6. Under the conditions of these experiments, the temporal interval which is sufficient to produce optimal movement with such exposure-times is in the neighborhood of 60 sigma.

7. Phenomenal stationary succession may be produced if the intervals between exposures are long enough, the length of the intervals necessary and sufficient to produce succession being different with different exposure-times.

8. When one passes gradually from the conditions which produce optimal movement to those which produce simultaneity or succession, with serial observation (Dauerbeobachtung), a region of conditions giving part movement is encountered, although it is not concluded that the conditions in this same region would produce part movement consistently if the method of single observation (Einzelbeobachtung) were used (Cf. Higginson, 12).

9. From the foregoing statements, especially, 1,2,5, and 8, it appears that the movement-function (of whatever nature) does require a temporal course, composed either of periods of stimulation or of these together with an interval between them. The phenomenal stationary

simultaneity which Wertheimer reported with 30 sigma intervals substantiates this view.

10. Dimmick's data, which have been misinterpreted by Higginson, show a relation between 'total movement' and the length of the temporal interval, under the conditions of his experiments.

VIII. BIBLIOGRAPHY

1. L. CARMICHAEL -- A Device for the Demonstration of Apparent Movement, American Journal of Psychology, Vol. XXXVI, No. 3, July 1925, pp. 446-448.

2. P. CERMAK and K. KOFFKA -- Untersuchungen über bewegungs- und Verschmelzungsphanomene. K. KOFFKA -- Beiträge zur Psychologie der Gestalt. V., Psychologische Forschung, Band I, Heft 1 & 2, August 1921, pp. 66-129.

3. H. R. De SILVA -- An experimental Investigation of the Determinants of Apparent Visual Movement, American Journal of Psychology, Vol. XXXVII, No. 4, October 1626, pp. 469-501.

4. F. L. DIMMICK -- An Experimental Study of Visual Movement and the Phi Phenomenon, American Journal of Psychology, Vol. XXXI, No. 4, October 1920, pp. 317-332.

5. F. L. DIMMICK -- The 'Visual Perception' of Movement *vs.* The 'Apprehension' of Movement from Visual Stimuli, American Journal of Psychology, Vol. XXXVII, No. 3, July 1926, pp. 461-463.

6. F. L. DIMMICK and G. H. SCAHILL -- Visual Perception of Movement, American Journal of Psychology, Vol. XXXVI,

No. 3, July 1925, pp. 412-417.

7. LUDWIG HARTMANN-- Neue Verschmelzungsprobleme.

K. KOFFKA -- Beiträge zur Psychologie der Gestalt, VIII, Psychologische Forschung, Band III, Heft 4, 1923, pp. 319-396.

8. HARRY HELSON -- The Psychology of Gestalt, American Journal of Psychology, Vol. 36, 1925, pp. 494-526.

9. GLENN D. HIGGINSON -- Apparent Visual Movement and the Gestalt, Journal of Experimental Psychology, Vol. IX, No. 3, June 1926, pp. 228-252.

10. GLENN D. HIGGINSON -- A Simple Class Demonstration of Apparent Movement, Journal of Experimental Psychology, Vol. X, No. 1, February 1927, pp. 67-68.

11. G. D. HIGGINSON -- The Place of Ocular Movements in Stroboscopic Perception, American Journal of Psychology, Vol. XXXVII, No. 3, July 1926, pp. 408-413.

12. G. D. HIGGINSON -- The Visual Apprenhension of Movement under Successive Retinal Exitations, American Journal of Psychology, Vol. XXXVII, No. 1, January 1926, pp. 63-115.

13. GLENN D. HIGGINSON -- The Visual Perception of Movement, American Journal of Psychology, Vol. XXXVII, No. 4, October 1926, pp. 629-631.

14. FRANZ HILLEBRANDT -- Zur Theorie der stroboskopischen Bewegungen, I. Abteilung, Zeitschrift fur Psychologie, Band 89, Heft 4, 5, & 6 Juli, 1922, pp. 209-272.

15. WILBUR S. HULIN -- An Experimental Study of Apparent Tactual Movement, Journal of Experimental Psychology, Vol. X, No. 4, August 1927, pp. 293-320.

16. *

17. K. KOFFKA -- The Perception of Movement in the Region of the Blind Spot. A Report of Experiments Performed in the Psychological Laboratory of the University of Giessen, British Journal of Psychology, General Section, Vol. XIV, Part 3, January 1924, pp. 269-273.

18. K. KOFFKA -- Über das Sehen von Bewegung. Bemerkungen zu der Arbeit von Higginson, Psychologische Forschung, Band VIII, Heft 1 & 2, Juli 1926, pp. 222-235.

19. WOLFGANG KÖHLER -- Zur Theorie der stroboskopischen Bewegung. (Im Anschluss an die Untersuchung Hartmanns), Psychologische Forschung, Band III, Heft 4, 1923, pp. 397-406.

20. ADOLF KORTE -- Beiträge zur Psychologie der Gestalt und Bewegungserlebnisse, 1. Abteilung, Zeitschrift fur Psychologie, Band 72, Heft 3 & 4, Juli 1915, pp. 193-296.

21. RUTH FRANKLIN McCONNELL -- Visual Movement under

* 16. K. KOFFKA — Perception: An Introduction to the Gestalt-Theorie, Psychological Bulletin, Vol. 19, No. 10, October 1922, pp. 531-585.

Simultaneous Excitations with Initial and Terminal Overlap, Journal of Experimental Psychology, Vol. X, No. 3, June 1927, pp. 227-246.

22. ERNST THELIN -- Perception of Relative Visual Motion, Journal of Experimental Psychology, Vol. X, No. 4, August 1927, pp. 321-349.

23. HERBERT G. VOGT and WILLIAM GRANT, Jr. -- A Study of the Phenomenon of Apparent Movement. H. S. Langfeld -- Minor Study from the Psychological Laboratory of Princeton University, American Journal of Psychology, Vol. XXXVIII, No. 1, January 1927, pp. 130-133.

24. M. WERTHEIMER -- Bemerkungen zu Hillebrands Theorie der stroboskopischen Bewegungen, Psychologische Forschung, Band III, Heft 1 & 2, April 1923, pp. 106-123.

25. MAX WERTHEIMER -- Experimentelle Studien über das Sehen von Bewegung, 1. Abteilung, Zeitschrift fur Psychologie, Band 61, 1912, pp. 161-265.