(From the Psychological Laboratory of Yale University.)

The Visual Perception of Velocity[1].

By

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Contents.

I. Introduction.

In the last half century of psychological investigation few specific problems of perception have elicited so many researches and have been the basis for so much theoretical controversy as the visual perception of movement. The reason for this is not far to seek. From the earliest

[1] This paper is abridged from a thesis presented to the faculty of the graduate school of Yale University in partial fulfilment of the requirements for the degree of Doctor of Philosophy. The study was started in the Psychological Institute of the University of Berlin in 1926—1927 and completed at Yale University in 1928—1929. The work at Berlin, which has been already reported [cf. *J. F. Brown*, Über gesehene Geschwindigkeit. Psychol. Forschg **10**, 84—101 (1927)] was largely exploratory in nature; that at Yale was undertaken to fill the gaps in the experimental series and to control more completely the causal factors. For clarity of exposition the previously reported data are included here so far as necessary. The writer is indebted to Professor *W. Köhler* of the University of Berlin for suggesting the problem, and to Professors *R. P. Angier*, *R. Dodge*, and *L. T. Spencer* of Yale University for many valuable suggestions. He wishes also to express his thanks to the subjects who served in the experiments.

laboratory studies to the most recent it has become increasingly clear that the inconstant correlation between the physical events in the stimulus and the phenomenal events in the perception of movement could not be explained by the ordinary psychophysical concepts.

In 1912[1], after a careful investigation of all the previously postulated explanations for the perception of real and pseudo-movement, *Wertheimer* set up his radical theory, which in its wider applications is known to all psychologists as the *Gestalt* theory. *Wertheimer*'s view of movement perception has been widely accepted, but by no means in its entirety or without criticism. Numerous investigations continue to center around *Wertheimer*'s hypothesis and there is still much controversy in the field. The latest investigation, that of *DeSilva*[2], shows there is still much confusion regarding the interpretation of the perception of movement and points out clearly that much remains to be known about this type of perception before it becomes a closed chapter in experimental psychology and any theory may be accepted as final.

This investigation aims to fill one of the most outstanding gaps in our knowledge of movement perception. In all the work that has been done, no investigation has concerned itself primarily with the functional characteristics of the perception of velocity. Various investigators, as will be shown in the historical survey, have observed lack of correlation between the velocity of the stimulating movement and the phenomenal velocity, and it is generally known that judgments regarding velocity are rarely accurate. But such scattered material as exists by no means adequately covers the field. This investigation attempts (1) to assemble the observations of previous workers that concern the perception of velocity; (2) to determine by experiment what objective factors condition phenomenal velocity (i. e. the perceived rate of movement) and in what varying degrees they operate; and (3) to discover how these factors affect the theory of the perception of movement. These three given aims will be followed out in order in the following three sections.

II. Historical.

The literature on the perception of movement has been adequately reviewed[3], consequently the present survey is limited to the studies concerning the perception of velocity.

[1] *Max Wertheimer*, Experimentelle Studien über das Sehen von Bewegung. Z. Psychol. **61**, 161—265 (1912).

[2] *H. R. De Silva*, An analysis of the visual perception of movement. Brit. J. Psychol. **19**, 268—305 (1929).

[3] The reader is referred to *De Silva*, op. cit., 293—295, for the latest material on the perception of movement and references to the older investigations. The material up to 1923 is also admirably summarized by *J. Fröbes*, Lehrbuch der experimentellen Psychologie **1**, 395—413 (1923).

The earliest observations on the perception of velocity known to the author are contained in *Porterfield*'s treatise published in 1759[1]. *Porterfield* made the first determinations for the threshold of movement. His calculations, however, have since been shown to be inaccurate. He also reported that objects moving at a constant velocity, varied in their phenomenal velocities inversely as their distances from the observer. This conclusion was not based upon experimental evidence; it was nothing but a logical deduction derived from physiological optics.

Czermak, in 1857, published a paper suggesting extended investigations upon the perception of time in which he pointed out the importance of the perception of velocity[2]. Unfortunately he did not carry out his plans and his program, strangely enough, never stimulated anyone to attack the problems he outlines. The studies that have been made upon the problems seem not to have been influenced by him. His only empirical observation on the visual perception of velocity is that movement observed in the periphery is phenomenally slower than the same movement observed in the center of the field of vision. He observed this by comparing successively the velocity of the second hand of a watch, fixating first the center of the minute hand, then the center of the second hand itself. The difference is reported in terms of subjective estimate.

In 1882, *Fleischl* observed that movement seen while fixating a stationary point is phenomenally faster than the same movement followed by the eye[3]. He noted that velocity could be perceived by three different modes of observation: by pursuit eye-movements; by the unmoved eye; and by an intermediate mode in which both pursuit eye movements and fixations occurred. He found that phenomenal velocity was about twice as fast when observed with fixation as when it was observed with pursuit movement. He also corroborated *Czermak*'s observation that the velocity of movement in peripheral vision is phenomenally slower than that in central. *Fleischl* did no further experimenting and the rest of his paper is concerned chiefly with the attempt to decide which mode of observation gave the correct perception.

In his paper of 1886, *Aubert*[4] classified the work of previous investigators and calculated the threshold for movement centrally and peripherally observed, in homogeneous fields, and the difference threshold

[1] *W. Porterfield*, A Treatise on the Eye **2**, 416 (1759).

[2] *J. Czermak*, Ideen zu einer Lehre vom Zeitsinn. 1857. Published in his Ges. Schriften **1**, 421 (1879).

[3] *E. Fleischl*, Physiologisch-optische Notizen. Sitzgsber. Akad. Wiss. Wien, Abt. III, **86**, 17—25 (1882).

[4] *H. Aubert*, Die Bewegungsempfindung. Pflügers Arch. **39**, 347—370 (1886); **40**, 459—480 (1887).

for movement. *Aubert* found that the velocity at which objects could be perceived as moving depended on such factors. He also measured the difference in phenomenal velocity conditioned by the mode of observation as observed by *Fleischl,* and obtained results in agreement with those of *Fleischl.* This difference in phenomenal velocities was hence called the *Aubert-Fleischl* paradox.

At about this time *Bourdon* observed that the threshold for movement with large objects was greater than that with small[1]. He found the difference threshold only roughly approximated *Weber*'s law. *Exner*[2] and *Meumann*[3] also determined the threshold for movement; the latter observed the difference in phenomenal velocity between central and peripheral observation.

Stern[4], in 1894, published a monograph on the visual perception of movement. He was the first investigator to devote a section to the perception of velocity. He summarized all the work on the problem that had been done up to his time, and attempted to explain all the known facts. He repeated the earlier experiments but made no new observations concerning velocity.

Dodge, in 1904, investigated the part played by eye-movement in the perception of motion[5]. His results show that the role of kinaesthesis had been over-estimated by previous investigators. He also studied the *Aubert-Fleischl* paradox and believed that it could be explained by different rates of displacement on the retina.

Hamann, in 1907, considered the psychological basis of movement and devoted a section of his paper to the perception of velocity[6]. Besides some logical theorizing he made one new observation, viz. a rider crossing a field seems to double his velocity as he enters a wood.

In 1911, *Grim* attempted to measure the threshold under conditions making it impossible to deduce the movement from a changed position of the stimulus[7]. She found that the threshold for movement depended on the curvature of the track in which the objects moved. The greater the curvature the lower the threshold.

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[1] *B. Bourdon,* La perception visuelle de l'espace. 1902.

[2] *S. Exner,* Über optische Bewegungsempfindung. Biol. Zbl. **8,** 437—452 (1889).

[3] *E. Meumann,* cited by *Fröbes,* op. cit. 396.

[4] *L. W. Stern,* Die Wahrnehmung der Bewegung vermittelst des Auges. Z. Psychol. **7,** 321—385 (1894).

[5] *R. Dodge,* The participation of eye-movements in the perception of motion. Psychologic. Rev. **11,** 1—14 (1904).

[6] *R. Hamann,* Über die psychologischen Grundlagen des Bewegungsbegriffes. Z. Psychol. **45,** 231—254, 341—377 (1907).

[7] *K. Grim,* Über die Genauigkeit der Wahrnehmung und Ausführung von Augenbewegungen. Z. Sinnesphysiol. **45,** 9—27 (1911).

In his 1912 paper, *Wertheimer* observed that in apparent movement the phenomenal velocity varied greatly under different conditions[1]. He points out that the problem of velocity for apparent movement is a special one as yet uninvestigated.

Richardson, in 1916, attempted to determine the accuracy of estimations of the speed of automobiles[2]. Her conclusions were that velocity was rarely judged with accuracy, and that numerous factors influenced the judgment.

In 1922, *Filhene* investigated the *Aubert-Fleischl* paradox[3]. He observed that when a movement was perceived with pursuit eye-movements there was an apparent movement of the background in the opposite direction, which he believed caused the phenomenal difference involved.

Lau and *Gehrke*[4], in 1923, and *Metzger*[5], in 1927, investigated the velocity at which the moving objects increase in apparent number and flicker commences. Both observers found that this threshold was not constant and that it depended largely on the structure of the visual field. *Metzger* also suggested that the same factors that affected the increase in number would affect the phenomenal velocity. He found several cases where this was true. He observed that the phenomenal velocity for a continuous series of figures that move past the resting eye was greater than when only three figures moved by, although the physical velocity was identical. A comparable difference was found in the threshold for increase in number for these variations. He observed that broad figures seem to move faster than narrow figures at like physical velocities. Here again a comparable difference was found in the threshold for increase in number[6].

Granit, dealing primarily with the after-effects of seen movement, noted that phenomenal velocities showed little correlation with the velocities of the projection of the moving object on the retina[7]. On this basis he assumed a transformation of phenomenal velocity directly correlated with the apparent constancy of visual size (Sehgrößenkonstanz).

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[1] *Wertheimer*, op. cit. 15, 35.

[2] *F. E. Richardson*, Estimations of speeds of automobiles. Psychol. Bull. 13, 72 (1916).

[3] *W. Filhene*, Über das optische Wahrnehmen von Bewegungen. Z. Sinnesphysiol. 53, 134—145 (1922).

[4] *E. Lau* a. *E. Gehrke*, Versuche über das Sehen von Bewegungen. Psychol. Forschg 3, 1—8 (1923).

[5] *W. Metzger*, Über Vorstufen der Verschmelzung von Figurenreihen. Psychol. Forschg 8, 114—221 (1926).

[6] *Metzger*, op. cit. 196.

[7] *R. Granit*, Über eine Hemmung der Zapfenfunktion durch Stäbchenerregung beim Bewegungsnachbild. Z. Sinnesphysiol. 58, 95—110 (1927).

Dembitz, in 1927, also showed there is little correlation between phenomenal velocities and retinal velocities[1]. He found a high apparent constancy of visual velocity that is not deducible from the apparent constancy of visual size.

This historical survey would not be complete without mention of the velocity of the movement after-image. It has been shown by various investigators that the velocity of the after-image varies under numerous stimulus conditions. An excellent review of this topic up to 1910 is to be found in *Wohlgemuth*[2]. Later papers on the after-image with its velocity are those of *Hunter*[3], *Granit*[4], and *Thalman*[5].

In the above review only the empirical results of the different investigators are given. Such of their theoretical conclusions as are important for this investigation will be included in Section IV.

III. Experimental.

A. Method.

One of the principal defects of the earlier experiments was the lack of quantitative results. Most of the differences in the phenomenal velocities observed in the studies reviewed above were subjectively estimated. We sought to escape this limitation and to obtain an objective measure of the differences. We used two moving stimulus-objects; a standard, the velocity of which was constant, and a variable, the velocity of which could be varied by the subject. These moving objects were presented to the subject and he was instructed to bring the velocity of the variable to that of the standard. When this had been done the physical velocities of the two stimulus-objects were measured. We were thus able to obtain a direct measure of the difference and to quantify our results. The experimental procedure will be treated in more detail after a description of the apparatus.

Two light-tight wooden boxes (20 cm. × 20 cm. × 150 cm.) each enclosing two 15 cm. drums were prepared. The lower drum in each box was on an adjustable axle, so that it could be lowered or raised at convenience. In each box the upper drum was connected to an outside drive wheel, which was rotated by a motor on the outside of the case. The boxes were mounted on iron stands to allow rotation in the

[1] *A. Dembitz*, Beiträge zu experimentellen Untersuchungen der Bewegungswahrnehmungen durch das Auge. 1927.

[2] *A. Wohlgemuth*, On the after-effect of seen-movement. Brit. J. Psychol. Monog. Suppl., **1**, 1—117 (1911).

[3] *W. Hunter*, The after-effects of visual movement. Psychologic. Rev. **21**, 245—277 (1914).

[4] *Granit*, op. cit. 108.

[5] *W. A. Thalman*, The after-effect of seen movement when the whole visual field is filled by a moving stimulus. Amer. J. Psychol. **32**, 429—441 (1921).

vertical plane. The front surfaces of the boxes were cut out (75 cm. × 20 cm.) and replaced by adjustable diaphragms of black cardboard. A roll of white paper (200 cm. long) on which figures of black or colored paper were pasted, ran over the drums. Each box was lighted by a 25-w. shaded globe placed between the front and back surfaces of the paper rolls. Hence in the dark room only the diaphragm aperture and the section of band plus figures immediately behind it were visible.

The standard stimulus was driven by an Ediphone electric motor, and the variable by a Pathé phonograph motor. Gross changes in the objective velocity for both standard and variable were obtained by pulley combinations. Finer adjustments were obtained for the Ediphone motor through rheostats in the circuit, and for the Pathé motor by the brake on the governor. This brake was used for the experimental adjustments. The total range of velocity that could be given on the combined apparatus was from 4 to 60 cm./sec. For any given pulley combination the velocity could be varied over a range that allowed tripling or cutting to one-third the initial extreme velocity (e. g. 5 to 15 cm./sec.).

The most easily available measure of the stimulus velocities was to measure them after adjustment by a stop watch. Such a measurement is subject to two sources of error, variation in the experimenter's reaction-time and variation in the speed of the motors. Care was taken in the tests and experimental series to keep the reaction-time as constant as possible. The motors were known to approach constancy[1].

At Berlin the influence of knowledge of the problem and of practice were carefully controlled and it was found that both were without influence on the experimental results[2]. Hence at Yale only two regular subjects were used for all of the experiments. These were H, one of the regular subjects used in Berlin, and the author, B. Since neither of these subjects was completely disinterested the results throughout the experimental series were controlled by using one or more new subjects for each new experimental situation. For these control subjects various under-graduate and graduate students were used, who were ignorant of both problem and the mode of attack. The results show no significant differences between the regular and casual observers.

In the early part of the study at least five subjects were used for every experiment. From everyone of these at least five measurements, often more, were taken. Since it was clear that the distribution of individual differences and fluctuation of differences in the individual were small against the magnitude of absolute differences measured this

[1] The reliability of such a measurement method is easily determinable. Using the method employed throughout the experimentation 50 measurements each were made for the extreme velocities and the most frequently used velocities for each motor. The maximal observed error of measurement was 2% for the extreme velocities and 1% for the most frequently used velocity. Since the differences in physical velocities found in the experimental results are never of a magnitude of less than 10%, the measurement error is negligible.

[2] *Brown*, op. cit., 86.

rule was not strictly adhered to in the later experimentation. Occasionally when an experiment dealt with no new factor and in some control experiments only two subjects were used.

The subject was seated in the dark room midway between the stimuli at the distances and positions noted in the results. The experimenter then instructed, "You will see one moving object to your right and afterwards one to your left. Please observe them carefully and tell me which is moving faster. Don't count or try to judge by breathing or any secondary criterion." This limitation was added as a control of a factor discussed later (p. 211). The room was darkened and the apparatus set in motion. Then under direction of the subject the experimenter stepped the variable apparatus upwards or downwards until the subject reported identity. Frequently the change was made against the direction of the report, as a check on experimenter and subject alike. Usually about five steps were necessary for identity, but in some cases many more were taken. The only rule adhered to was that the experimenter varied the stimulus under the subject's direction until the subject was sure of his judgment. Suggestion on the part of the experimenter was controlled in that during dark room experimentation he knew only crudely the actual velocity of the stimulus. An additional control was had when the experimenter acted as subject, as then the operator was completely ignorant of the relationship between the regulating dial on the apparatus and the velocity except for direction.

Time and space errors were controlled throughout the early experimentation by variation in the presentation order. Here no differences of a significant order were found in the results. The variable stimulus was presented ascending and descending in random order throughout the experimentation.

The accuracy with which velocities can be judged by the successive comparison method must be known before conclusions may be drawn from the data. Under identical stimulus conditions such a comparison was shown to succeed almost exactly.

At Berlin the diaphragm apertures measured 40×5 cm., the figures were black circles of 1.6 cm. diameter placed at 5 cm. intervals on the bands. In Berlin free observation, that is without fixation, was used. At Yale the diaphragm aperture measured 15×5 cm. and the figures were irregularly placed black squares of 1.6 cm. At Yale the subject fixated a red glass strip 5×1 cm. placed at the top of the diaphragm aperture. In each case the stimuli to be compared were identical. The observation was monocular.

Our experiments indicated that under identical stimulus conditions two velocities can be adjusted to equality with a high degree of accuracy which is a further test of the reliability of the measurement method. Four subjects made two adjustments each at Berlin, three subjects made two adjustments each at Yale. In terms of percentage difference the greatest difference obtained was 5%, in many cases there was no difference at all, and the average difference was but 1%[1]. These figures should be kept in mind in considering the data presented in the following results.

B. Results.

1. Effect of Increasing the Distance of the Moving Field from the Observer.

If, with a stationary eye, a definite objective velocity is observed first at the distance of 2 m. then at the distance of 4 m. the velocity projected on the retina in the first case is double that of the second. That is, in any given period of time the retinal image of the object traverses twice as much space at 2 m. as it does at 4 m. Since velocity is defined as space divided by time, $V = S/T$, in doubling space S, with time T constant, V must also double. If, however, an objective velocity such as that of an automobile is observed first at a distance of 10 m. then at one of 20 m. it is obvious that no such change occurs in the perception of the velocity. It is known that there is an apparent constancy of visual size (Sehgrößenkonstanz) and it might be suspected that there is an apparent constancy of visual velocity that is directly deducible from this. Experiments were made to test for this constancy and to see if it is deducible from the apparent constancy of visual size.

The Berlin apparatus was arranged exactly as described in the test series. A, the standard apparatus, was placed at varying intervals from the observer from 3.3 m. to 10 m., and run at the constant velocity of 10 cm./sec. B, the variable apparatus, was placed at 1 m. from the subject. In these experiments the subjects fixated the upper edge of the diaphragm aperture for both units of apparatus. The experiments took place in daylight illumination so that the subjects saw the surrounding field as well as the diaphragm and aperture. Table 1 gives the results of these experiments on five subjects. The relative velocities of the projection on the retina vary between 1 and 10. As is shown in the V_A/V_B quotient the phenomenal velocities vary only between 1 and 1.25. Hence it can be said that there is an apparent constancy of visual velocity, constancy denoting the "Konstanz" of modern German psychology.

The second question; is the apparent constancy of visual velocity fully deducible from the apparent constancy of visual size, must be answered in the negative. All the subjects reported the moving fields

[1] For complete raw data of this and other experiments where for brevity a table is omitted see *Brown*, The Visual Perception of Velocity, Dissertation, Yale, 1929, for the Yale material or *Brown*, op. cit., for the Berlin material. In the following exposition the general rule is to give in tabular form the results of the experiments first undertaken in Yale, with a sufficient summary of the Berlin results, to make the argument clear.

(i. e. aperture and figures) to appear identical in size for the distances used. This was also more thoroughly controlled in the following manner. Two *Aubert* diaphragms placed respectively at 1 m. and 10 m. were compared successively. That at 10 m. was constant with a diagonal dimension of 16 cm., that at 1 m. was stepped up or down to phenomenal identity of size for the subject. The results showed exact apparent constancy of visual size for the distances used. Four observations on four subjects gave a range for the ratio of the size of *A* to that of *B* of 0.97—1.03. If the constancy of velocity were a mere consequence of constancy of size, velocity ought to be quite as constant as size is. Table 1 shows that the constancy of velocity is obviously reduced at a distance of 10 m. Therefore apparent constancy of velocity is not deducible from apparent constancy of size.

Table 1[1]. *Showing the effect of distance (Velocity of A, 10 cm. per sec.; distance of B, 1 m.).*

Subject	Distance of A	V_B	V_A/V_B
M	10.0	8.3	1.20
	6.6	8,7	1.15
	3.3	9.1	1.10
Y	3.3	9.1	1.10
	6.6	8.7	1.15
	10.0	8.3	1.20
A	10.0	8.3	1.20
	6.6	8.7	1.15
	3.3	8,7	1.15
C	10.0	8.3	1.20
	5.0	9.1	1.10
H	10.0	8.0	1.25
Average at the distances:	10.0		1.21
	6.6		1.15
	3.3		1.12

At Yale it was attempted to answer the same question by an experiment in the dark room. The experiment was not wholly successful in that the long laboratory hall used could not be darkened to the extent that had been expected and there were some disturbances which made the subjects acquainted with the distances. The results of these experiments on three subjects, however, support the findings at Berlin. The set-up was the same as in an earlier experiment (p. 206) except that *A* was at the varying distance shown in table 2, while *B* was always at 1 m. The observation was monocular.

Comparison of tables 1 and 2 shows that the V_A/V_B quotients run a little higher in the Yale series than in the Berlin experiments. This is to be expected on account of to the more homogeneous surrounding fields at Yale. At 20 m. the constancy of visual size had greatly diminished so that the sudden rise in V_A/V_B is to be expected on this basis.

[1] In all tables V_A represents the velocity of the standard apparatus, V_B that of the variable apparatus for each subject. V_B/V_B represents the number of times *B's* velocity is contained in *A* for identity of velocity.

Table 2. *Showing the effect of distance in an approximately dark room.*

Subject	$A = B$ Distance of $B = 1$ m.			
	Distance A in m.	V_A	V_B	V_A/V_B
H	20	11.8	7.1	1.66
	10	11.0	9.1	1.21
	5	11.0	9.4	1.17
J	20	11,8	7.9	1.50
	10	11.0	9.3	1.18
	5	11.0	9.2	1.20
B	20	11.8	7.7	1.53
	10	11.0	8.3	1.33
	5	11.0	10.4	1.06
Average at the distances:	20			1.56
	10			1.24
	5			1.14

The following conclusions may be drawn from the above data. Phenomenal velocity diminishes as the distance of the movement from the observer increases. There is however a remarkable "relative constancy" of visual velocity and the visual perception of velocity is by no means immediately correlated with the rate of displacement of images on the retina. Secondly, if one operates with apparent size rather than with retinal s ze it is still impossible to deduce observed phenomenal velocity solely on this basis.

That is to say, phenomenal visual velocity is not to be immediately equated to S/T whether S be measured in terms of space traversed on the retina or in terms of phenomenal space. This discovery led to the experiments which follow in an attempt to find the factors that condition phenomenal velocity. Further investigation of the apparent constancy of visual velocity was postponed because it seemed more desirable to show the most essential functional properties of visual velocity in general. In the meantime the publication of a dissertation by *Dembitz*[1] makes projected experimentation on this constancy unnecessary in that his results confirm those of this investigation so far reported.

2. *Effect of Enlarging the Moving Field.*

Apriori, it should make no difference in the phenomenal velocities if the sizes of the moving fields are so transposed that for given distances the retinal images are identical. Apparatus A at 4 m. from the subject presented behind a diaphragm aperture (15 cm. $\times$ 5 cm.) black circles of 1.6 cm. diameter regularly at 4 cm. intervals. Apparatus B at 2 m.

[1] *Dembitz*, op. cit.

from the subject presented behind a diaphragm aperture (7.5 cm. × 2.5 cm.) black circles of 0.8 cm. regularly at 2 cm. intervals. Hence all the linear dimensions of A are double those of B. The experiment was conducted monocularly in the dark room. The subject was led blindfolded into the dark-room. Some light escaped from the apparatus but so little that the subjects only distinguished the two moving fields A and B, which, despite retinal identity as to size, seemed of different size. Table 3 gives the results of this experiment on 5 subjects.

Table 3[1]. *Showing the effect of linear transposition of all dimensions of the field.*

Subject	*lin* $A/B=2$ A at 4 m. B at 2 m.			
	V_A	V_B	V_A/V_B	A.M. of V_A/V_B
W.	10	5.0	2.00	
	10	5.0	2.00	
	10	5.4	1.85	
	10	5.4	1.85	
	10	5.3	1.90	1.92
M.	10	4.8	2.10	
	10	5,3	1.90	
	10	5.3	1.90	
	10	5.0	2.00	
	10	5.1	1.95	1.97
L.	10	5.5	1.80	
	10	5.4	1.85	
	10	5.3	1.90	
	10	5.7	1.75	
	10	5.3	1.90	1.85
S.	10	4.8	2.10	
H.	10	5.0	2.00	
Average			1.92	

In all cases V_B must be reduced to approximately one-half of V_A in order that phenomenal identity of velocity results. V_A/V_B ranges from 1.80 to 2.10, a range which allows no doubt as to the reliability of the measurement. Formally, since B is at one half the distance of A, one might say that phenomenal velocities are equal when the velocities of the retinal projections are approximately equal.

However that this statement is misleading was clearly shown by the following experiment. A and B were both placed at 2 m. from the subject, all other conditions remaining as in the last experiment. The results of observations on seven subjects gave again a range of $V_A/V_B = 1.80-2.10$ with an average of 1.90. Here the velocity

[1] *lin* A/B in all tables indicates the amount of enlargement of the linear dimensions.

of the projection on the retina varies, approximately as 2 : 1 showing that the essential condition for our result in the case of unequal distance is not given in the retinal projection velocities but in the difference in size of the moving fields, because in this respect the two experiments are alike.

The conclusion from the last two experiments can be expressed in the following law: If a moving field in a homogeneous surrounding field is transposed in its linear dimensions as 1 : 2 the stimulus velocity must be transposed by a like amount in order that the phenomenal velocity in both cases be identical. In the following pages this is called the velocity transposition phenomenon[1]. The next experiments are concerned with a further investigation of this phenomenon. So far it is clear that the processes which determine phenomenal velocity are not immediately correlated with the rate of displacement of retinal images but are at least as much conditioned by the size of the field in which the movement takes place.

Further experiments at Berlin[2] showed that the transposition phenomenon held for *lin* $A/B = 4$, for *lin* $A/B = 1/0.5 = 2$, and for objective velocities of the standard apparatus ranging from 5 cm./sec to 25 cm./sec. That the subjects reacted to velocity, not the rhythm with which the objects entered the field was also demonstrated by presenting moving fields, where an irregular succession of objects excluded any definite rhythm. The V_A/V_B quotient for such an experiment is practically identical with those so far reported.

With the exception of experiments on the apparent constancy of velocity where the subjects were instructed to fixate the upper margin of the diaphragm aperture, the preceding results were obtained by a free observation method i. e. without fixation. In judging, the subject moved both eyes and head. These movements belong to the pattern of the reaction and can only be inhibited with constant conscious effort. It was clear from the first experiments that no direct correlation was present between the length of the pursuit eye movements and the phenomenal velocities. For example, the two experiments on the transposition phenomenon with A at respectively 2 m. and 4 m. give almost identical results, while the distance followed by the eye in observing apparatus A at 2 m. must be twice the distance followed in observing the same apparatus at 4 m. Also in the experiments on constancy of velocity the distance traversed by the eye varied as 1 : 10, while the V_A/V_B quotient varied only between 1 and 1.25[3].

[1] Transposition is used as the equivalent of "Transponieren" as this concept is understood in the Gestalt theory. [2] *Brown*, op. cit., 91—94.

[3] It is supposed in all the above cases that exact pursuit movements occur, which of course is not the case.

Throughout the experiments reported, occasional fixation experiments were performed[1]. Fixation proved difficult to hold but it was possible to get adjustments on the basis of fixation by spending more time on each individual adjustment. The subjects were introspectively satisfied with such fixation and the experimenter could detect no eye movements by unaided observation in these cases. In no case was a significant difference observed between the method of fixation and that of free observation. Certainly considerable inhibition of the natural eye movements remained without effect on the given results.

At Yale more thorough inhibition of eye movements was attempted by an after-image control. The subjects were seated in a swivel chair upon which a chin and mouth rest were built. By adjusting the height of the chin and mouth rest, the head movements were completely inhibited. The observation in all the Yale experiments was monocular. Fixation boxes were prepared by placing electric bulbs behind milk and red glass and a tin diaphragm cut out so that the subject saw a thin red line. These boxes were arranged at the height of the subject's eye alongside the moving fields with the red line horizontal. The subject was instructed to fixate this line and always to make his judgment on the basis of distinct contour of the fixation line. A short practice period was held before each new experimental observation. Apparatus A had a diaphragm aperture (15×5 cm.) behind which black squares of 1.6 cm. at varying intervals were exposed. Only one figure was in the field at any interval of time. Hence the rhythm factor was controlled from the first in the Yale experimentation. Apparatus B was equal to half A in all linear dimensions. The fixation line for A was 4 cm. $\times$ 1 cm. placed 2 cm. to the left of the diaphragm aperture edge, for B 2 cm. $\times$ 0,5 cm., 1 cm. to the right of the diaphragm aperture edge.

With the fixation lines to one side of the moving field, fixation was not particularly difficult and the results may be considered reliable. Table 4 gives the results of this experiment for fixation and for free observation of the type used in Berlin. The results show that for the averages of the methods, as well as for individual cases V_A/V_B is nearer 2. for fixation. Furthermore this difference is reliable. Therefore the following conclusion may be drawn. The transposition phenomenon is not dependent on eye movements.

The difference in the results by the two methods of observation was later found out to be due to the fact that during fixation both A and B are peripheral to the fixation point and that A is more so. In later experiments it is shown that phenomenal velocity decreases at a considerable rate as the moving field becomes peripheral. The illu-

[1] The subject fixated the upper margin of the diaphragm aperture or a fixation cross in the middle of the diaphragm aperture.

Table 4. ***Showing control of eye movements for the velocity transposition phenomenon.***

Subject	*lin* $A/B=2$			(Fixation lines to side)		
	Fixated			Not Fixated		
	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B
H	11	5,6	1,97	11	5.8	1.90
H	11	5.1	2.16	11	6.2	1.77
B	11	5.3	2.08	11	5,7	1.93
F	11	5.3	2.08	11	5,9	1.86
F	11	5.4	2.04			
R	11	5.9	1.86	11	6.2	1.77
Q	11	5.7	1.93	11	6.7	1.64
Q				11	6.6	1.67
Average			2.02			1.80

mination of the fields in this experiment was by 25 watt unshaded lamps which caused the surrounding field to be slightly visible. This accounts for the comparatively low V_A/V_B in the case of free observation[1].

Since a reliable control of fixation gave no difference in the results that could be attributed to an influence of fixation itself, the following experiments at Yale used another fixation method. The subject fixated a strip of red glass, attached to the upper edge of the diaphragm aperture. This gave no after-image control of fixation but proved satisfactory in that it kept the conditions comparable to those of Berlin and removed the influence of peripheral observation. Fixation was further controlled by the following fact. During fixation any movement is phenomenally faster than when the eyes pursue the moving object[2]. This of course does not affect the transposition phenomenon if both fields are observed by the same method. It furnishes, however, an additional check on fixation. The subjects were instructed to judge while fixating and they knew that they were fixating, when the respective fields were phenomenally the fastest.

Table 5 gives a distribution of 22 cases when this fixation method was used. The illumination of the apparatus was dimmed by the addition of wax paper shades to the 25 watt globes, so that the surrounding field was nearly homogeneous. Diaphragm apertures and rolls remained as in the last experiment except for the red glass fixation lines as described above. (Fixation line on A, 5×1 cm. on B, 2.5×0.5 cm.)

For 22 cases the range of V_A/V_B is 1.80—2.04, one fourth of the absolute difference involved.

On the Yale apparatus it was possible to transpose the linear size relationships to considerably greater *lin* A/B ratios than was possible

[1] See the experiments on these factors, p. 217. [2] See p. 223.

Table 5. *Showing a distribution of 22 judgements with fixation.*

Subject	lin $A/B=2$			Subject	lin $A/B=2$		
	V_A	V_B	V_A/V_B		V_A	V_B	V_A/V_B
H	10	5.1	1.96	B	10	5.2	1.92
	10	5.2	1.92		10	5.1	1.96
	10	5.3	1.88		10	4.9	2.04
	10	4.9	2.04		10	5.0	2.00
	10	5.5	1.80		10	5.3	1.88
	10	5.1	1.96		10	5.0	2.00
	10	5.0	2.00		10	5.1	1.96
	10	5.1	1.96		10	5.0	2.00
	10	5.3	1.88		10	5.2	1.92
	10	5.0	2.00		10	5.4	1.85
	10	5.1	1.96		10	4.9	2.04
Average			1.94	Average			1.95

in Berlin. The ratios chosen were as follows: *lin* $A/B=$ respectively 2, 3, 4, 5, 10. Actually instead of the ratio *lin* $A/B=10$, the ratio *lin* $A/B=5/0.5$ was used, which, for comparison purposes is equivalent to 10. The actual diaphragm apertures in these cases were the transposed equivalents of those given in the preceding experiment. In all cases the fixation glasses were also transposed in the given ratios.

Table 6 gives the results of these experiments. For all transpositions beyond *lin* $A/B=2$, V_A/V_B falls considerably behind the theoretical expectancy. It was impossible to increase the size of A through this series (except in the *lin* $A/B=5/0.5=10$, where of course A was not further increased) without enhancing the inhomogeneity of the surrounding field, due to increasing illumination of the dark room. For the case where *lin* $A/B=5$ this decrease in homogeneity was so great that the room appeared dimly lighted. Later experiments[1] showed that the transposition law holds only for fields in homogeneous surrounding fields. If we suppose the decrement from the theoretical expectancy in the last experiment is really due to increasing illumination of the surrounding field, under constant illumination the increase in V_A/V_B through the *lin* A/B series may be expected to be linear function. Hence these experiments were repeated in daylight illumination for two of the above subjects. The apparatus was placed in an evenly lighted laboratory room, so that the bands behind the apertures were phenomenally even in brightness. In daylight illumination i. e., with the moving fields in the inhomogeneous surrounding field of the average laboratory room, the ratio *lin* $A/B=2$ gives an average V_A/V_B ratio $=1.60$ as the starting point of the series under these conditions.

[1] See p. 217.

Table 6[1]. *Showing the effect of increasing the ratio of the linear transposition in the dark room.*

Subject	lin $A/B=$ 2			3			4			5			5/0.5 = 10		
	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B
H	10.5	5.3	1.98	15.4	5,7	2.70	18.5	6.2	3.00	20.4	5.6	3.64	35.7	5.5	6.50
	10.5	5.6	1.88	15.4	5.8	2.65	18.5	5.8	3.20	20.4	5.8	3.52	40.0	5.8	6.90
B	10.5	5.6	1.88	15.4	5.6	2.75	18.5	5.7	3.25	20.4	6.1	3.35	40.0	6.2	6.45
	10.5	5.6	1.88	15.4	5.9	2.60	18.5	6.0	3.10	20.4	5.9	3.46	40.0	5.6	7.14
X	10.5	5.3	1.98	14.8	6.0	2.48	18.5	6.3	2.95	20.4	5.9	3.46	40.0	5.6	7.14
	10.5	5.6	1.88	14.8	6.0	2.48	18.5	6.1	3.05	20.4	5.9	3.46	40.0	5.8	6.90
Average			1.91			2.61			3.09			3.48			6.83

[1] Subject X represents a different subject in each column. The limitations of our apparatus made it impossible to hold the velocity of A at 10 cm./sec. throughout this series. However this does not make our results less reliable (cf. p. 217).

Table 7. *Repetition of Table by daylight illumination.*

Subject	lin $A/B=$ 2			3			4			5			5/0.5 = 10		
	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B
H	9.1	5.7	1.60	13.3	6.0	2.22	16.1	5.6	2.88	20.4	6.0	3.40	34.5	5.9	5.85
	9.1	5.8	1.57	13.3	5.8	2.29	16.1	6.6	2.44	20.4	6.2	3.29	34.5	5.5	6.27
B	9.1	5.8	1.57	13.3	6.6	2.02	16.1	6.1	2.64	20.4	6.2	3.29	34.5	5.5	6.27
	9.1	5.9	1.54	13.3	5.8	2.29	16.1	5.6	2.88	20.4	6.6	3.09	34.5	5.5	6.27
Average			1.57			2.21			2.71			3.27			6.17

Table 7 gives the result of this series and shows this assumption to be correct. Plate I plots the results of all observations of the two methods and also gives graphically the result of the transposition experiments in Berlin and the theoretical expectancy. In curve *b* there is negative acceleration in all the ratios up to five due to the increase in illumination. In the transition to *lin* $A/B = 10$ however there is no negative acceleration, because in this case there is no increase in the illumination of the room from the case where *lin* $A/B = 5$. Furthermore for the ratio *lin* $A/B = 4$ under the Berlin experimental conditions, where there was less decrease in the homogeneity of the surrounding field than at Yale, experiment yielded $V_A/V_B = 3.7$ as over and against $V_A/V_B = 3.15$ for Yale. The total evidence supports the conclusion that, were the experiments conducted in a homogeneous surrounding field, the law for the transposition phenomenon would hold up to the ratio *lin* $A/B = 10$.

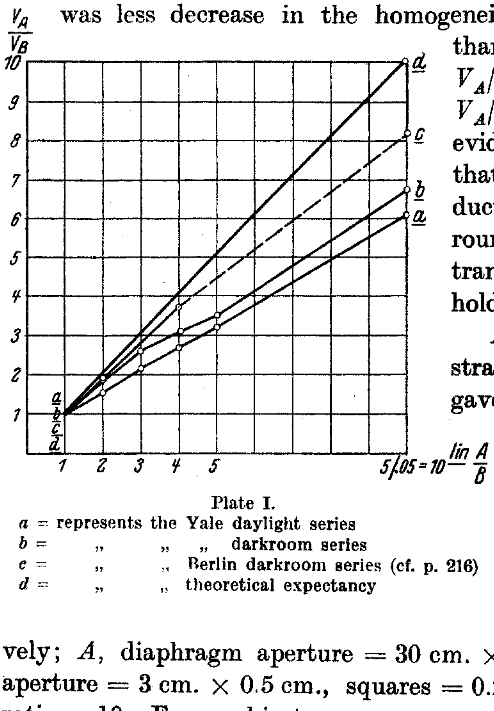

Plate I.

a = represents the Yale daylight series
b = „ „ „ darkroom series
c = „ „ Berlin darkroom series (cf. p. 216)
d = „ „ theoretical expectancy

An attempt at a direct demonstration of the above conclusion gave results that may be considered satisfactory. The illumination of both fields was cut down considerably so that the surrounding fields approached homogeneity. The transposed fields measured respectively; A, diaphragm aperture $= 30$ cm. $\times$ 5 cm., squares $= 2$ cm., B, aperture $= 3$ cm. $\times$ 0.5 cm., squares $= 0.2$ cm. Hence, the *lin* A/B ratio $= 10$. Four subjects gave an average V_A/V_B quotient of 8.22 with a V_A/V_B range of 7.6—9.1. It must be pointed out however, that at such high *lin* A/B ratio as ten, the subjects see the discrepancy between the directly phenomenal and the stimulus velocities, due to secondary clues, such as time and distance. The phenomenal velocity is still shown by the V_A/V_B ratio, when the subjects naively judged by the impression of speed alone. The result of the direct demonstration of our last conclusion is shown on Plate I, as the continuation of *c* beyond the ratio *lin* $A/B = 4$.

That fixation makes the transposition phenomenon more striking was indicated again here. After making adjustment under fixation the subject was instructed to regard A and B without fixating and report if the velocities were phenomenally identical. For *lin* $A/B = 2$ the report was always yes, for *lin* $A/B = 3$ the report in about half the cases was "A slightly faster," for *lin* $A/B = 4$ the report in all cases was "A slightly faster." This procedure was not carried beyond *lin* $A/B = 4$. Here A is larger and hence more peripheral than B *during fixation*, which accounts for this difference. At all events this qualitative experiment shows that eye movements are not essential for the transposition phenomenon.

At Yale it was also possible to vary the stimulus velocities over a greater range than at Berlin. The ratio *lin* $A/B = 2$ was used with stimulus velocities for A at 52.6 cm./sec., 33.3 cm./sec., 20 cm./sec., 10 cm./sec. Two subjects made two adjustments each for each velocity. The V_A/V_B range was 1.83 to 2.10. At the two higher velocities some flicker and increase in number of stimulus objects was noted[1].

3. *Effect of Decreasing Homogeneity of Surrounding Field.*

The effect of decrease in homogeneity of the surrounding field has been mentioned in the preceding results. An experiment was performed for monocular observation, binocular observation, and binocular observation by daylight illumination at Berlin with the *lin* $A/B = 2$ transposition[2]. The results of this experiment on three subjects show a marked decrease in the V_A/V_B quotient as the homogeneity of the surrounding field decreases in A and B. The average V_A/V_B ratio decreases for the three steps as follows: 2.03, 1.77, 1.60. The difference between binocular and monocular observation may be due to a decrease in the homogeneity resulting from the increased size of the total visual field, or to the inherent greater acuity of binocular vision. Phenomenally the surrounding field during binocular observation was less homogeneous, which is the interesting factor in this connection. A similar experiment for the ratio *lin* $A/B = 4$ in Berlin gave the following result. The ratio V_A/V_B fell from an average of 3.7 to an average of 2.8 for daylight illumination.

A similar experiment, monocular with fixation, gave comparable results at Yale. The *lin* $A/B = 2$ set-up was used, the fields being illuminated first with unshaded 50 watt globes, secondly with unshaded 25 watt globes, and lastly, as usual at Yale, with the 25 watt wax paper shaded-globes. Phenomenally for the first step in the above series the room was dimly lighted, for the second step some contours were faintly visible and for the third step the room was nearly homogeneous. The average V_A/V_B quotients for the respective steps were 1.76, 1.87, 1.98. Two subjects each made two adjustments.

At daylight illumination however at both Yale and Berlin the immediately surrounding fields on both A and B were homogeneous i. e.

[1] cf. *Lau* u. *Gehrke*, op. cit., a. *Metzger*, op. cit.
[2] *Brown*, op. cit., 94.

black cardboard. The following experiment shows the results caused by decreasing the homogeneity of this immediately surrounding field as well. At Berlin the ratio *lin* $A/B = 4$ was used in daylight illumination. In case I the outer bands of the diaphragm of both pieces of apparatus were covered with a simple wall paper pattern made up of 10 cm. squares, so that a small section of black cardboard remained about each aperture. In case II the entire diaphragm up to the aperture was covered by the wall paper. The V_A/V_B quotients for three subjects averaged 2.33 for case I, 1.92 for case II[1].

Comparison of these figures with those of the experiment for *lin* $A/B = 4$ in the dark room shows that with decrease in the homogeneity of the surrounding field to the point where the surrounding field is clearly structured the V_A/V_B quotient falls from 3.7 to ca. 2. Here also is a complete control of the rhythm factor spoken of previously, since the same bands with equidistant objects were used.

The effect of the surrounding field in itself was next investigated. The Berlin *lin* $A/B = 1$ was used with the above wall paper pattern covering the diaphragm of B to the aperture. On A the diaphragm was uncovered, and so remained homogeneous black. The average V_A/V_B quotient for six judgments from four subjects was 1.24 i. e. V_A had to be increased by 25% in order to appear equal to V_B, which appears faster on account of the inhomogeneity of the surrounding field[2]. Fixation was not controlled in this case. After so many controls a repetition seemed superfluous.

The effect of presenting A and B in the same visual field was next investigated. The lighting of the Berlin apparatus was so arranged that by a single switch either A or B could be presented or both simultaneously. The two pieces of apparatus were placed so close together that the distance between the aperture edges was 2.5 cm. The ratio *lin* $A/B = 2$ was used, observation being binocular in the dark room. By presenting the stimuli successively so near to each other any possible difference caused by moving the head is controlled. By presenting the two stimuli simultaneously the effect of transposition in the same visual field is measured.

For successive presentation, the results were entirely comparable with those for the regularly used comparison method in which the subject turned head or body 90° or 180°. For simultaneous presentation V_A/V_B sinks to average 1.18. If however subjects were instructed to follow definite circles in the two fields simultaneously the difference disappeared entirely[3].

When A and B are given together in the same visual field and compared with a field of the properties of B alone, we gain an impress-

[1] Op. cit., 94. [2] Op. cit., 95–96. [3] Op. ci., 96.

ion of the effect which A and B exert upon each other. For the following experiment we shall call A and B, as given in the last experiment (i. e. with the distance between the aperture edges at 2.5 cm.), $A + B$. The illumination of the dark room was such that $V_A/V_B = 1.60$ resulted from the ordinary *lin* $A/B = 2$ experiment. When four subjects compared $A + B$ in one visual field with a field B alone in another visual field, the average V_{A+B}/V_B ratio was 1.32, with a range of $V_{A+B}/V_B = 1.27-1.37$. This experiment indicates that the phenomenal velocity of $A + B$ is the resultant of the phenomenal velocities of A and of B as seen alone. A in the combination $A + B$ tends dynamically to lower the ordinary phenomenal velocity of B, while B tends to raise that of A. The result is that B alone appears to be moving equally as fast as $A + B$ at a velocity considerably less than that of $A + B$.

4. *Effect of the Component Elements in the Moving Field.*

The next experiments attempted to analyse the transposition phenomenon and to answer the following question. In the equation $V_A/V_B = 2$, $= 4$, etc., is it possible to assign a certain percentage to the diaphragm aperture itself (or its width and length) and a certain percentage of the difference to the sizes of the figures themselves, so that arithmetically we can account for the whole difference by superposing such amounts?

First the Berlin *lin* $A/B = 4$ ratio was used except that the diaphragm aperture widths in both cases were put at 5 cm. With all dimensions transposed except the width of the field the V_A/V_B quotient falls from average 3.7 to average 2.24[1].

Similarly if in the Berlin *lin* $A/B = 4$ ratio all dimensions are transposed except length of aperture the quotient V_A/V_B falls to around 2.

At Yale these experiments were repeated monocularly with fixation. For the ratio *lin* $A/B = 2$ with the exception of widths (which was 5 cm. for both A and B) two judgments each on two subjects gave a V_A/V_B range 1.31 to 1.49 with an average $V_A/V_B = 1.41$.

For the ratio *lin* $A/B = 2$ with the exception of length (which was 15 cm. on both A and B) two judgments each on two subjects gave a V_A/V_B range of 1.25—1.37 with an average $V_A/V_B = 1.31$.

Next, the effect of transposing the diaphragm apertures in the *lin* $A/B = 2$ ratio without transposing the figures (the figures were circles 0.8 cm. in diameter at intervals of 4 cm.) was investigated. The observation was binocular without fixation. The linear transposition of field alone with figures constant forces the V_A/V_B quotient down from around 2 to an average of 1.38[1].

[1] Op. cit., 97.

Similarly in Berlin the effect on V_A/V_B of transposing the figures without the fields was investigated. (*Lin* $A/B = 2$ was given for the figures alone, while both diaphragm apertures were 15 cm. × 5 cm.) This change forces the V_A/V_B quotient down to an average of 1.20[1].

At Yale the effect of a difference in the aperture width alone was investigated. *Lin* $A/B = 1$ was used except for the width of aperture in B which was reduced first from 5 cm. to 4 cm. and then in another experiment from 4 cm. to 2 cm. The results of these experiments are given in Table 8. The observation was monocular with fixation.

Table 8. *Showing the effect of field width.*
Lin $A/B = 1$ except for the width of B which is:

Subject	4 cm			2 cm		
	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B
B	13.3	11.8	1.13	13,3	10.3	1.30
B	13.3	12.1	1.10	13.3	10.0	1.33
H	13.3	12.5	1.06	13.3	10.3	1.30
H	13.3	12.1	1.10	13.3	10.1	1.32
Average			1.10			1.31

This table shows that identical figures moving through identical objective lengths vary in their phenomenal velocity if the field varies in width. Within the investigated limits the narrower the field the greater the phenomenal velocity.

The preceding data show conclusively that variation in the size of the field in which figures move as well as variation in the size of the figures themselves conditions variation in phenomenal velocity. Variation in the size of the field evidently causes greater difference than does variation in the size of the figures. The data also show that the complete transposition phenomenon can not be accounted for by adding the difference caused by variation in the size of the field alone to the difference caused by variation in the size of the figures.

Furthermore in this experiment reliable control is given for another factor which might be supposed to cause the transposition phenomenon. It might be suspected that if the essential factor is not rhythm it might still be the time. That is to say when in the case *lin* $A/B = 2$, V_A/V_B is found to be 2, the time necessary for any figure to move through the length of the diaphragm aperture on A is the same as that for any figure on B. The subject's judgments might be based not on an absolute perception of velocity but on a time perception. The velocities in fields of different sizes might appear equal when the objects took the

[1] Op. cit., 97.

same time to move through them. That this is impossible is shown in all the experiments where a decreasing homogeneity of the surrounding field forces the V_A/V_B quotient downwards. But even more clearly is this shown in our last experiments. In the experiment with *lin* $A/B = 2$ with the exception of equal width in A and B, if the time factor alone conditioned the perception we should expect V_A/V_B to remain at 2; in the experiment with *lin* $A/B = 2$ with the exception of equal length in A and B we should expect it to fall to 1, neither of which happens.

5. *Effect of Size and Orientation of Moving Objects.*

At Yale an attempt was also made to find the relationship between increasing phenomenal size of the objects and decreasing phenomenal velocity[1]. The apertures remained 15 cm. × 5 cm. through the series, the figures on A were 1.6 cm., 2.4 cm., 3.2 cm. respectively, on B the figures remained 0.8 cm. Table 9 gives the results of this experiment on three subjects.

Table 9. *Showing effect of the size of the figures. A and B with same aperture (15 cm. × 5 cm.).*

Subject	2			3			4		
	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B
H	11.4	8.9	1.27	11.4	8.3	1.37	11.4	7.9	1.44
	11.4	9.1	1.25	11.4	8.5	1.34	11.4	8.3	1.37
B	11.4	9.1	1.25	11.4	8.9	1.28	11.4	8.3	1.37
	11.4	8.8	1.29	11.4	8.7	1.31	11.4	8.6	1.32
X	11.4	9.3	1.23	11.4	8.5	1.34	11.4	7.7	1.48
	11.4	9.3	1.23				11.4	8.3	1.37
Average			1.25			1.32			1.39

It is evident from these figures that the relationship between size and phenomenal velocity is not a linear function. This may be due to the fact that increase in size of the figures decreases the relative width of the moving field[2].

Size of the figure is not to be taken to mean absolute size of the black surface as compared with the white background, but upon the area in the stimulus that has a figural character. It is "figure" as the term is used by *Rubin*[3] and the Gestalt theorists. This was shown experimentally in Berlin. A exposed two lines drawn in India ink 4 cm. long and 4 cm. apart. B exposed two lines 4 cm. long and 1 cm. apart. No difference existed in the relative amount of black

[1] As indicated previously in the Berlin experiments, op. cit., 97.
[2] cf. Table 8.
[3] *Rubin, E.*, Visuell wahrgenommene Figuren. Kopenhagen 1921.

and white. Still in every case the V_A/V_B quotient was greater than 1, because from the standpoint of *Rubin* the figures on A are larger[1].

Besides relative size of the stimuli the relative position of objects with reference to the direction of movement was investigated. On A black lines in India ink were drawn so that they were at right angles to the direction of the movement, on B black lines of the same dimension were given, the length of which lay in the direction of movement. The results of these observations on five subjects showed a V_A/V_B quotient with an average of 1.21[2].

Oblongs of paper (2×4 cm.) arranged as above were tried with like results. The orientation of the figure in the field of movement is important for the phenomenal velocity, those oriented with the movement being phenomenally faster.

These findings regarding size and orientation were checked in the following experiment. On A a rectangle of 2×6 cm., the 6 cm. dimension in the direction of the movement, was presented; on B a rectangle 2×4 cm., the 4 cm. dimensions at right angles to the direction of movement. From our findings A should be phenomenally faster than B through its position and slower through its size. The expectancy that these factors will compensate for each other is verified in that the V_A/V_B quotients were not greater than 1 by a reliable amount[3].

That other things being equal larger figures are phenomenally slower was also demonstrated purely qualitatively. On one apparatus a series of figures of one size (0.8 cm.) was followed by a series of twice that size (1.6 cm.). Four subjects were instructed to watch the movements and report any change in velocity. All agreed that when the smaller circles were observed after the large ones the velocity increased. The inverse of this was only noted by two of the subjects.

In all the above experiments movements are compared in which different figures move through definite space areas. At Berlin on a different apparatus it was demonstrated that size and orientation of the moving objects influence phenomenal velocity even if nothing is visible except the objects and they move through the whole visual field[1].

Experiments were performed at Yale to find out whether color differences in the stimuli would cause differences in the phenomenal velocities. Squares of different color were used for the ratio *lin* $A/B = 1$ but no reliable difference was found. Triangles as figures were compared of which on A the base came first into the field of vision and on B the apex. Here again no reliable difference was found.

6. *Effect of Direction of Movement.*

The influence of the direction of the movement itself was investigated at Yale. A and B were identical except that A ran horizontally in reference to the subject, B vertically. A was also presented at 45° between the horizontal and vertical. Table 10 indicates that a difference is present between horizontal and vertical and between vertical and

[1] Op. cit., 99. [2] Op. cit., 100. [3] Op. cit., 101.

Table 10. *Showing the effect of the direction of the movement. A horizontal and 45% diagonal. B vertical.*

Subject	*A* 45°				*A* horizontal		
	V_A	V_B	V_A/V_B		V_A	V_B	V_A/V_B
H (a)*	14.3	13.3	1.08	(a)	16.7	13.3	1.25
	14.6	13.3	1.09				
(d)**	15.4	13.3	1.16	(d)	17.4	13.3	1.31
	14.7	13.3	1.10		17.4	13.3	1.31
B (a)	14.1	13.3	1.06	(a)	16,7	13.3	1.25
	14.3	13.3	1.08				
(d)	14.9	13.3	1.12				
	14.7	13.3	1.10	(d)	18.0	13.3	1.35
Average			1.10				1.30

* (a) = Ascending. ** (d) = Descending.

diagonal to a less extent. Although both subjects attempted to fixate here neither of them was completely satisfied with the fixation and it should not be considered absolute. There was, notwithstanding, great inhibition of the normal pursuit movements.

7. *Effect of Field Brightness.*

That the intensity of the illumination of the movement field has an influence on velocity was shown at Yale. Ratio *lin* $A/B = 1$ was used. In the circuit lighting *B*, resistances as follows were introduced, 0, 200, 400, 600, 800 ohms. The effect was to change the field brightness of the respective fields from identity to the point where *A* was much brighter than *B*. At 800 ohms the contours of *B* were beginning to fade. The results of this experiment on three subjects are given in Table 11. (Here *B* was the standard apparatus as to velocity, *A*, the variable.)

Increase of phenomenal brightness decreases phenomenal speed. This experiment is not equivalent to that in which the homogeneity of the surrounding field was decreased because no such decrease was noted.

8. *Effect of Mode of Observation.*

Finally the results of earlier investigators[1] concerning the differences in phenomenal velocity caused by fixation in contrast to observation with pursuit movements, and those caused by peripheral in contrast to central observation, were checked and found correct so far as direction and approximate amount of influence were concerned. The results of an experiment in which the subjects followed the velocity on *A*

[1] See Section II of this investigation.

Table 11. *Showing the effect of field brightness.*

Subject	Resistance added to B														
	0			200			400			600			800 ohms		
	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_B	V_B	V_A/V_B	V_A	V_B	V_A/V_B
H (a)*	13.3	13.3	1.00	14.1	13.3	1.06	15.4	13.3	1.16	15.2	13.3	1.14	16.0	13.3	1.20
(d)**	13.5	13.3	1.01	14.3	13.3	1.08	14.9	13.3	1.12	15.5	13.3	1.16	16.7	13.3	1.26
B (a)	13.2	13.3	0.98	14.6	13.3	1.10	15.2	13.3	1.14	15.9	13.3	1.19	16.1	13.3	1.21
(d)	13.5	13.3	1.01	14.7	13.3	1.10	16.1	13.3	1.21	16.3	13.3	1.23	16.7	13.3	1.26
P (a)	13.5	13.3	1.01	14.3	13.3	1.08				15.2	13.3	1.14	16.1	13.3	1.21
(d)	13.9	13.3	1.03				14.7	13.3	1.10						
Average			1.01			1.08			1.15			1.17			1.23

* (a) = Ascending. ** (d) = Descending.

with pursuit movement and fixated B gave the following results. In four judgments each from two subjects a V_A/V_B range of 13.3—1.66 was found with an average of 1.43[1]. This experiment is difficult to perform due to the constant change in "Aufgabe" in turning from A to B, which may account for the comparatively wide range in the distribution. Still in all cases the apparatus observed with fixation must be slowed down by a considerable amount in order that phenomenal identity ensue.

The difference in phenomenal velocity which is produced by increasingly peripheral stimulation was measured experimentally by two methods. Table 12 gives the result when both moving fields were in the same field of vision. That is, the subject fixated B, while A was peripheral to B by the distances given. Distances indicate midpoint of one diaphragm aperture to midpoint of the other. Distance of subject from apparatus was, as usual, 2 m. In the next experiment the subject was again in the midline between the two fields. B was fixated directly, A was observed while fixating a red line respectively at 10, 20, 40 cm. from A. Table 13 gives the results of the experiment.

[1] *Aubert*, op. cit., **40**, 463, found a ratio V_A/V_B = ca. 2. His experiments, however, were conducted under daylight illumination.

Table 12. *Showing the effect of peripheral as opposed to foveal vision. Both fields seen simultaneously.*

Subject	24 cm			48 cm		
	V_A	V_B	V_A/V_B	V_A	V_C	V_A/V_B
B	10	8.3	1.20	13.3	8.0	1.66
	10	7.7	1.30	13.3	8.3	1.60
	10	7.5	1.33	13.3	7.9	1.68
H	10	7.5	1.33	13.3	7.6	1.75
	10	6.9	1.45	13.3	6.9	1.89
	10	7.1	1.40	13.3	7.1	1.87
Average			1.34			1.74

Table 13. *Showing the effect of peripheral as opposed to foveal vision. Fields seen successively.*

Subject	10 cm			20 cm			40 cm		
	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B	V_A	V_B	V_A/V_B
B	12.5	10.5	1.19	12.5	9.1	1.37	12.5	7.3	1.74
B	12.5	10.6	1.18	12.5	8.9	1.40	12.5	7.6	1.65
H	12.5	9.4	1.33	12.5	8.1	1.54	12.5	7.0	1.79
H	12.5	9.4	1.33	12.5	7.8	1.61	12.5	7.3	1.74
Average			1.25			1.48			1.73

The results seem to indicate that the difference in phenomenal velocity caused by peripheral placement of the stimulus differs with simultaneous and successive comparison. This would probably be due to the fact that during simultaneous comparison both stimuli are in the same visual field and that under these conditions the fields influence each other[1]. This is further substantiated by the fact that as *A* becomes more peripheral the differences between the two methods decrease. In any case it is clear that velocities peripherally observed are phenomenally much slower than the same velocities centrally observed.

C. Summary of the Experimental Results.

Under varying stimulus conditions two moving fields were adjusted to phenomenally identical velocity by the subject. The differences that the varying stimulus conditions cause in the phenomenal velocities may be indicated by the quotient V_A/V_B which is the number of times one stimulus velocity is contained in the other for identity of phenomenal velocity. Hence $V_A/V_B = 1$ indicates that both stimulus and phenomenal velocities of *A* and *B* are identical, $V_A/V_B = 4$ that *B* is phenomenally faster than *A* and must be made four times as slow in order that its velocity be phenomenally the same.

[1] *Brown*, op. cit., 96.

The following factors were found to condition phenomenal velocity:

1. Distance of moving field from the observer.

As the distance of the observer from the moving field increases the phenomenal velocity decreases. As the distance varies from 1 to 20 m. V_A/V_B varies from 1 to 1.56.

2. The size of the visual field in which the movement occurs.

A. With homogeneous surrounding field.

If in a homogeneous surrounding field one transposes a moving field in all its linear dimensions one must transpose the stimulus velocity by a like amount in order that phenomenal identity of velocity result. As the linear dimensions of one field are changed from 1 to 10, the V_A/V_B quotient tends to change from 1 to 10.

B. With inhomogeneous surrounding field.

Any decrease in the homogeneity of the surrounding field decreases the V_A/V_B quotient for transposed moving fields. For example, in daylight illumination the V_A/V_B quotient for the $^2/_1$ transposition falls to 1.60.

3. The structure of the surrounding field.

If the surrounding field is inhomogeneous the phenomenal velocity is faster.

4. Width and length of the moving field.

Increase in the width of the field alone, decreases phenomenal velocity, as does also increase in the length of the moving field.

5. Size of the moving objects.

Increase in the size of the moving figures decreases the phenomenal velocity.

6. Orientation of the object with reference to the direction of movement.

Objects oriented in the direction of movement move phenomenally faster.

7. Direction of the movement relative to observer.

Vertical movements are phenomenally faster than horizontal ($V_A/V_B = 1.30$), while movements diagonally between vertical and horizontal fall phenomenally between these two ($V_A/V_B = 1.10$).

8. Brightness of the field in which the movement occurs.

Decrease in the illumination of the field in which the movement occurs increases the phenomenal velocity. $V_A/V_B = 1.23$ for considerable decrease in brightness.

9. Mode of observation.

A. Movements observed while fixating a stationary point are phenomenally faster than when the eye follows the moving object. $V_A/V_B = 1.43$.

B. Movements projected on the fovea of the retina are phenomenally faster than on the periphery.

Of the above observations all except 1 and 9 are first reported in this or the previous investigation. 1 and 9 are confirmations of the results of previous investigators.

IV. Theoretical.

A. Conclusions.

The factual conclusions have been reported along with the experiments that uncovered them. This section will deal with conclusions of a more general theoretical nature, repeating only those of the findings necessary for illustration.

Examination of the explanations offered by the earlier investigators for the previously known facts about perception of velocity shows such types of explanation wholly inadequate to deal with the phenomena before us. For these physiologists and psychologists the physical world as investigated by the physicist was the real world, psychological phenomena were epiphenomena. Sensory processes were mechanical processes through which knowledge of this real world was obtained. When the epiphenomenal events in the conscious world correlated with the real events in the physical world there was not much to explain. But they often did not, and an important function of the psychologist working on the theory of perception was to explain away these discrepancies. The history of the investigation of the so-called geometric-optical illusions is illuminating to this point. Previous experience, errors of judgment, and eye movements were among the factors postulated to explain why the originally correct sensation was modified by psychological processes so that it became illusory in perception. The hypotheses by which investigators tried to explain the lack of simple correlation between the velocity of the stimulus and the phenomenal velocities perceived under different conditions belong to the above category. All the investigators with the possible exception of *Aubert* and *Dodge* supposed that there must be one correct phenomenal velocity to correspond with any given stimulus velocity. Any other phenomenal velocity observed for this constant stimulus velocity was illusory in nature and must be explained as such. Differences in phenomenal velocity when the projection on the retina was peripheral rather than central seemed to allow an explanation in terms of retinal structure and in so far not to furnish a particular problem. But the *Aubert-Fleischl* paradox proved more difficult. *Fleischl*[1] himself was forced away from psychological to logical considerations. *Aubert*[2] attempts

[1] *Fleischl,* op. cit., 25. [2] *Aubert,* op. cit., **40,** 163.

no explanation. *Stern*[1] gives two explanations not closely related. First, experience teaches us that the longer a moving object is in the field of vision the slower is its velocity, hence we underestimate the velocity of objects that we follow with the eye. Second, during pursuit movement there are also movements of the head and trunk which cause us to underestimate the movements of the eye and consequently when the eyes move phenomenal velocity is slower. *Wundt*[2] explained the paradox even less satisfactorily. We often move our eyes in judging the size of objects, hence when we move our eyes in pursuing a moving object, the amount of this usual movement is "mentally" subtracted from the total eye movement and the velocity seems slower. *Dodge*[3] showed that the kinaesthetic moment postulated by earlier observers was of relatively little importance. He supposes the difference to be due to rates of retinal displacement. *Hamann*[4] believed that the phenomenal velocity is determined by the number of perceived changes divided by the time. The number of changes was less during pursuit movements, hence so was the phenomenal velocity. The explanation was more valuable than those of previous investigators; but through the experiments of this investigation it is shown to be quite untenable. *Filhene*[5] believed that both velocities are correctly perceived but that during pursuit eye movements there is a relative movement of the background in the opposite direction which is „mentally" subtracted and hence the velocity is less. But the difference occurs without any background that might be seen as moving in the opposite direction as is shown in this investigation.

Explanations of the type given above are proved to be untenable when it is considered that there are not two nor four but a multiplicity of factors that condition the phenomenal velocity. Which then is the correct perception, any deviation from which is illusory? It is quite obvious that the whole mode of attack must be different.

The futility of attempting to set up any phenomenal velocity as the correct epiphenomenal correlate of any given stimulus velocity is indicated by the following fact. By varying the size and structure of the visual field in which a given stimulus velocity occurs the phenomenal velocity may be varied over a large continuous range. There is not a single criterion that may decide that any one of these phenomenal velocities is more correct than any other. It may be concluded that the physical velocity of the stimulus alone conditions the phenomenal

[1] *Stern*, op. cit., 380—382.
[2] *W. Wundt*, Physiologische Psychologie, 4. Aufl., 2, 158 (1893).
[3] *Dodge*, op. cit., 14.
[4] *Hamann*, op. cit., 362—368.
[5] *Filhene*, op. cit., 143—144.

velocity only when all the properties of the visual field are kept constant.

Neither is there a simple relationship between the velocity of the projection of the moving object on the retina and the phenomenal velocity. At varying distances of the objective movement from the subject the retinal velocity may vary as 1 to 10 while the V_A/V_B quotient will vary only from 1 to 1.25. Again it may be concluded that phenomenal velocity is constantly correlated with the velocity of the projection on the retina only when all the other conditions for phenomenal velocity are kept constant.

What, then, does determine the phenomenal velocity? It has become quite obvious that the phenomenal velocity of a moving object is dynamically determined by the structure and the general properties of the visual field in which the movement takes place.

The objection might still be raised that velocity is not perceived directly, but is deduced through secondary psychological mechanisms operating on originally "correct" sensory data. However such an explanation would necessitate the introduction of even more concepts than the psychologist is at present burdened with. That existing concepts are not capable of dealing with the phenomena will be clear through examination of the controls used in our experiments. Certainly the data do not allow explanation on the basis of "error of judgment", attention, rhythm, time perception, or eye-movements.

Since Dodge's investigation (1904) the fact that the eyes move in one case and not in the other was realized to be no adequate explanation for the *Aubert-Fleischl* paradox. One observation is scientifically worth much theoretical argumentation. It can be demonstrated on any pulley arrangement on which a knotted cord is driven at a constant velocity that the same objective velocities can be perceived simultaneously as different phenomenal velocities which also have different directions. Several knots can be simultaneously perceived of different velocity and in different directions. If the perception depended on the modification of originally correct sensory data by psychological mechanisms or by eye-movements, such simultaneity of different "correct" perceptions would be hard to explain. From all the evidence it may be concluded that the velocity of moving objects is perceived directly and does not depend upon indirect judgments.

Concerning the underlying physiological processes the following general conclusion may be drawn. Phenomenal velocities are determined in a dynamical field, the essential nature of which can not be described as a sum of independent local events. They correspond to dependent events in the functional whole. Therefore the whole functional structure of the excited field, not the excitation present at any given point within the field, must be considered in order that one understand the physiology of the visual perception of velocity.

Since velocity of movement is perceived as a property of movement the laws that determine the visual perception of *velocity* must be the same in nature as those that determine the visual perception of *movement*. Hence it may be concluded that *Wertheimer* was essentially right in his 1912 paper concerning the physiological basis for the perception of movement, in that both his investigation and this point to the fact that the processes underlying dynamic events in sensory fields are determined by the structure and the properties of the total field in which they occur.[1] A more definite physiological theory can not be given at this time.

B. Implications.

In the nineteenth century determinations of the absolute threshold for movement gave such inconstant results that the attempt to measure it was largely abandoned. *Aubert*[2] pointed out that various factors in the stimulus situation condition the movement threshold, but he remained incognizant of what this implied. *Grim*[3] as late as 1911 attacked the problem believing the inconsistent results due to faulty technique. It is interesting to note that the factors reported by *Aubert* as raising the threshold, are among the factors reported in this investigation as decreasing the phenomenal velocity. It is entirely likely that all those factors that determine the visual perception of velocity determine the threshold for movement too. *Hence* the concept of an absolute threshold for movement would become meaningless.

The investigations of *Lau* and *Gehrke*[4] and *Metzger*[5] concerning the velocity at which the flicker phenomenon first appears are not less interesting in connection with our results. In fairness to these investigators it must be stated that they were not concerned with the absolute threshold for this phenomenon. *Metzger* whose work is the more thorough lists a multiplicity of factors that determine the velocity at which the phenomenon under consideration occurs. The following fact is of extreme interest. Of all the factors reported by *Metzger*, those that have been subjected to experiment in this investigation have influenced the phenomenal velocity in a manner which corresponds to *Metzger*'s results. Those factors that decrease the flicker threshold increase the phenomenal velocity. In one case in this investigation flicker and

[1] The writer believes that the experiments reported here are very convincing in support of the essential ideas of *Wertheimer*, since the results given here are completely independent of introspection, and concerned with „real“ rather than „apparent“ movement.

[2] *Aubert*, op. cit., 39, 353—365.

[3] *Grim*, op. cit., 11—12.

[4] *Lau* u. *Gehrke*, op. cit., 1—8.

[5] *Metzger*, op. cit., 216—221.

increase in number of figures were noted (p. 217). The reader will remember that this occurred for identical phenomenal velocities of the two fields. It seems reasonable to suppose that the same factors determine the upper and lower thresholds of movement that determine its phenomenal velocity.

Numerous investigators as reported by *Wohlgemuth*[1] have noted that the velocity of the movement after-image varies with different structural properties of the excitatory stimulus. The duration of the after-image is also said to vary with the velocity of the objective movement. In both of these cases the correlation is not a very close one. None of the investigators except *Granit*[2] have realized that phenomenal velocities are not directly correlated with the objective stimulus velocities. There is some indication that a simplification of the problem of the movement after-image would result, if the facts concerning phenomenal velocities were considered. A more detailed report concering the movement after-image would require more developed experimental data.

Gelb[3] has reported experiments wherein the place in which an object appears was conditioned by the time interval between its appearance and that of other objects. To a certain extent he was also able to influence phenomenal time by spatial conditions. In our experiments it was introspectively noted several times by both of the regular subjects at Yale, that the phenomenal time necessary for objects to move through the diaphragm apertures was the same when the phenomenal velocities were the same, although marked differences were present in the physical time. Also it was noted that, when a given objective velocity was observed first centrally and then peripherally, the phenomenal time necessary for a given figure to move from the bottom of the diaphragm aperture to the top was longer in the second case. Theoretical and experimental investigation of the perception of time has of late been much neglected. A modification of the method of this investigation could possibly throw some light on phenomenal time[4].

C. Summary[5].

In this section it is concluded that velocity is perceived directly and is dynamically conditioned by the structure and general properties of the visual field in which the movement occurs. The visual perception of velocity follows dynamic laws that are not immediately deducible from the velocity of the stimulus as physically defined. No physio-

[1] *Wohlgemuth*, op. cit., Historical Section. [2] *Granit*, op. cit.

[3] *A. Gelb*, Versuche auf dem Gebiet der Zeit und Raumanschauung. Bericht über den VI. Kongreß für experimentelle Psychologie. Leipzig 1914, 36—42.

[4] Since this paper was written the author has read *Guilford*'s paper on time perception and eye movements. *Guilford* observed cases of distortion of perceptual time similar to the ones reported here. (cf. *J. P. Guilford*, J. of Exper. Psychol. **12**, 259—267 (1929).]

[5] Theoretical summary only. For summary of experimental results see Section III, C.

logical theory is offered but it is pointed out that the theory of physiological *Gestalten* is essentially correct in its basic assumptions concerning the perception of movement.

The investigation has bearing on the problems of movement thresholds, movement after-images and the perception of time.

Zusammenfassung.

Von den zahlreichen Untersuchungen über gesehene Bewegung hat kaum eine sich in erster Linie mit dem Problem der gesehenen Geschwindigkeit beschäftigt. Diese Arbeit soll zur Kenntnis dieses Problems beitragen. Sie gliedert sich in drei Teile. Im ersten, historischen Teil wird versucht, sämtliche von Psychologen und Physiologen mitgeteilten Beobachtungen über gesehene Geschwindigkeit zusammenzustellen.

Im zweiten, experimentellen Teil wird untersucht, welche Faktoren im Bewegungsfeld einen Einfluß auf gesehene Geschwindigkeit ausüben. Dieser Einfluß wird so gemessen, daß der Versuchsleiter die Versuchspersonen zwei ungleichartige Bewegungsfelder auf phänomenale Gleichheit der Geschwindigkeit einstellen läßt; der Unterschied der objektiven Geschwindigkeiten der zwei Felder, bei welchem gleich schnelle Bewegung gesehen wird, dient als Maßstab der Stärke des Einflusses. Folgende Faktoren haben sich als ausschlaggebend erwiesen: 1. Die lineare Größe des Bewegungsfeldes und lineare Größe seiner einzelnen Teile d. h. Breite und Länge des Feldes und lineare Größe der bewegten Figur. 2. Die Struktur des Umfeldes. 3. Die Richtung der Bewegung relativ zur Versuchsperson. 4. Die Richtung der längeren Dimension der Figur in bezug auf die Felddimensionen. 5. Die Beleuchtung des Bewegungsfeldes. Von anderen Autoren schon beobachtete Faktoren wurden nachgeprüft.

Im dritten, theoretischen Teil werden auf Grund des experimentellen Teiles folgende Schlüsse gezogen: Die Geschwindigkeit eines bewegten Objektes wird direkt wahrgenommen. Die gesehene Geschwindigkeit ist von der Struktur des Bewegungsfeldes und des Umfeldes dynamisch bedingt und hält sich an Gesetze, die nicht unmittelbar von der Geschwindigkeit des Reizes oder von der retinalen Geschwindigkeit deduzierbar sind. Eine physiologische Theorie wird nicht aufgestellt, doch sprechen die Resultate für die Theorie der physiologischen Gestalten. Die Untersuchung hat Berührungspunkte mit den Problemen der Bewegungsschwellen, der Bewegungsnachbilder und der Zeitwahrnehmung.

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