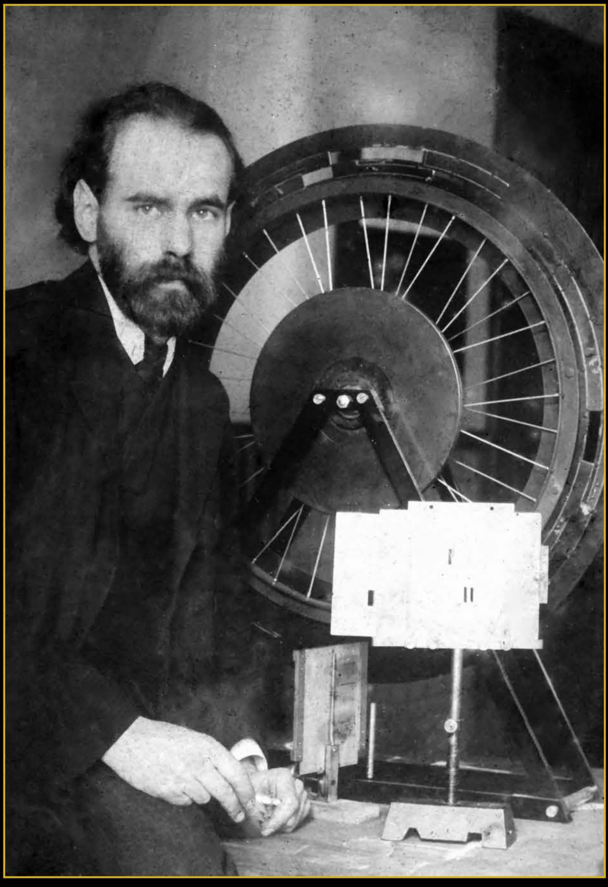
MAX WERTHEIMER

On Perceived Motion and Figural Organization



edited by LOTHAR SPILLMANN

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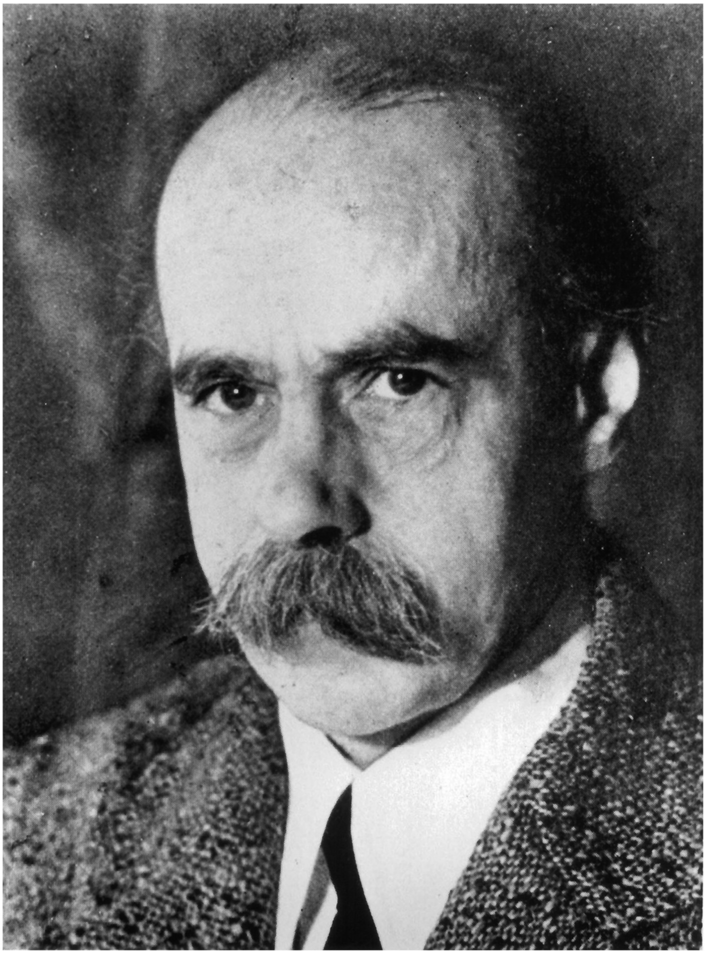

Max Wertheimer

1880–1943
Photo: Frankfurt am Main, 1930

On Perceived Motion and Figural Organization

Max Wertheimer
edited by Lothar Spillmann

with contributions by Michael Wertheimer, K. W. Watkins, Steven Lehar, Robert Sekuler, Viktor Sarris, and Lothar Spillmann

The MIT Press
Cambridge, Massachusetts
London, England

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This book was set in Sabon on InDesign by Asco Typesetters, Hong Kong. Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Wertheimer, Max, 1880–1943.
[Selections English 2012]
On perceived motion and figural organization / Max Wertheimer ; edited by Lothar Spillmann ; with essays by Viktor Sarris, Robert Sekuler, and Lothar Spillmann ; with contributions by Michael Wertheimer . . . [et al.].
p. cm.
"This work by and about Max Wertheimer collects together new translations of his two most important articles and places them in both historical and contemporary contexts with contributions by Michael Wertheimer . . . [et al.]"—Provided by publisher.
Includes bibliographical references and index.
ISBN 978-0-262-01746-6 (hardcover : alk. paper) 1. Perception. 2. Motion perception (Vision). 3. Gestalt psychology. I. Spillmann, Lothar. II. Sarris, Viktor. III. Sekuler, Robert. IV. Title.
BF203.W4413 2012
153.7—dc23 2011042099

10 9 8 7 6 5 4 3 2 1

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Prefatory Note

It is gratifying that the MIT Press has issued this complete translation of two of my father's major articles, together with several essays dealing with their impact. I thank Lothar Spillmann for having initiated this project and bringing it to completion, Viktor Sarris for his many efforts to keep Max Wertheimer's work in psychology and philosophy in the limelight (including his substantial participation in the preparation of the present volume), the various other individuals and foundations that have helped make this project possible, and my daughter K. W. Watkins (who earned a B.A. with highest honors in English from Swarthmore College and a Ph.D. in English from Yale University) for her wordsmithing skills in rendering the translations of the two articles (which in the original German contain many complex grammatical convolutions typical of the scientific writing of the time—and typical of this sentence) into readable modern English. I am deeply grateful to all who have played a part in the project that culminated in this volume. May it help make Max Wertheimer's work more accessible to researchers and readers in the English-speaking world and continue to inspire research in visual neuroscience, cognitive psychology, and perception well into the twenty-first century.

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Preface

This book is a tribute both to Max Wertheimer, the founder of the Gestalt school of psychology, and the importance of his work to current research in the field of visual perception. There are few articles in science that remain relevant over a span of 100 years. Wertheimer's pioneering studies on perceived motion (1912) and figural organization (1923) are notable examples. Through the English translations presented here, Max Wertheimer's seminal articles are now available to a wider international readership. There have been several partial translations in the past (Ellis, 1938, 1955; Beardslee & Wertheimer, 1958; Shipley, 1961), yet full-length translations have never before been published. The two translations presented here are largely original.

"One sees motion: An object has moved from one location to another." These sentences by Max Wertheimer at the opening of his seminal article of 1912 set the stage for a revolution in motion research that continues to this day (see the review by Burr & Thompson, 2011).

The motion elicited by two stationary stimuli presented successively in different locations is not the continuous motion that we see when a bird flies by. Rather, we see an object seemingly moving from *a* to *b* without stimulation of the intervening space. How could an inconspicuous phenomenon like this—a common event in today's cinema and even then—cause a revolution in experimental psychology and beyond?

Apparent motion of an object or *optimal* motion had been described before (Exner, 1875), but Wertheimer was the first to study it systematically and discuss it within the theoretical framework of a *Gestalt* (see Sarris's synopsis of the 1912 article in this volume). He thereby became the founder of Gestalt psychology. Apparent motion includes pure or *phi* motion, when no object is seen to move in the motion field, i.e., objectless motion. This condition occurs between optimal motion and simultaneity of *a* and *b* (Steinman, Pizlo, & Pizlo, 2000).

Optimal motion has been termed a sensory illusion (*Sinnestäuschung*), a motion that has no correlate in the physical world. Yet Wertheimer's experiments demonstrated that it can be perceptually indistinguishable from real motion when both are presented simultaneously next to each other. Something new, a phenomenon *sui generis*, had emerged that is irreducible and cannot be analyzed any further. He concluded that the two phenomena are based on the same physiological mechanisms (since confirmed by Grüsser-Cornehls, 1968, in the frog).

To account for the perception of apparent motion (optimal and *φ*), Wertheimer postulated a short-circuit-like transverse process (*Querfunktion*). Radial excitations caused by stimuli *a* and *b* propagate laterally and interact (much like the concentric waves spreading out when one throws two stones into a pond) and in this way produce the brain substrate for the perceived motion. This idea posits directional propagation of a motion signal (*gerichtetes Hinüberfluten*) on the cortical surface, the direction of which depends on the temporal sequence of stimulation. Practice and attention increase the probability for seeing motion, but they are not determinative.

Wertheimer calls his short-circuit hypothesis a heuristic sketch (p. 75): "If this hypothesis treads on difficult and still unknown territory, it is because of our current state of knowledge." His postulate that the processes underlying apparent motion are capable of bridging the unstimulated interspace anticipates the concept of a *perceptive field* for motion.

He writes, "Aside from these temporal conditions, this effect appears to depend primarily on the distance between the two objects" (p. 63). And he continues, "The closer the two places *a b* are to each other, the more favorable the conditions for the emergence of the *φ* event" (p. 76). Retinal eccentricity as a limiting factor was not studied. We now know that the extent of spatial interaction between two discrete stimuli is larger in the periphery due to larger receptive fields (Jung & Spillmann, 1970).

In a systematic study, Korte (1915) investigated the dependence of apparent motion on interstimulus interval, spatial separation and stimulus intensity, formulating the three laws that bear his name. These laws (or rules) specify that in order to maintain optimal motion, a change of one stimulus parameter requires that another stimulus parameter be changed in the same or opposite direction: The relationships between these stimulus variables are critical to any explanation of apparent motion, including the correlation-type motion detector by Hassenstein and Reichardt (1956), which is considered the most parsimonious explanation of Wertheimer's phenomenon (see Sperling, van Santen, & Burt, 1985).

Where in the brain do the cells that mediate this kind of apparent motion reside? The observation that apparent motion is more compelling with monocular than binocular stimulation (Shipley, Kenney, & King, 1945) suggests that spatial interaction of the two stimuli may occur already in the retina via low-level neuronal integration. On the other hand, apparent motion is also observed with interocular stimulation (Smith, 1948), suggesting a cortical contribution. Furthermore, apparent motion crosses over unresponsive retinal areas, including the physiological blind spot and retinal scotomata (Stern, 1926; Teuber & Bender, 1950), and thresholds for the individual motion stages are significantly altered in patients with certain cerebral lesions (Teuber & Bender, 1948). These findings are consistent with a higher-level origin.

This book, for the first time, enables English-language readers fully to appreciate Max Wertheimer's visionary thoughts in the field of perceived motion and figural organization. It also bridges the years between their first publication and modern research by providing essays that tie the phenomenological descriptions to the underlying neuronal mechanisms.

Two essays complement the translations. Robert Sekuler's essay relates Wertheimer's 1912 principal findings to the results of subsequent investigations of motion perception, including currently active lines of research. Paul Kolers, Michael von Grünau, Alan Pantle, Oliver Braddick, Bruno Breitmeyer, Christopher Tyler, Stuart Anstis, Vilayanur Ramachandran, and Takao Sato, among others, are some of the researchers in our time who picked up and continued the study of optimal and phi-motion.

My own essay reviews the many ramifications in the field of *grouping* and *figure–ground* perception that can be traced, in part, to Wertheimer's 1923 paper. This field also has blossomed and continues to do so as is evidenced by a special issue in a major journal dedicated to perceptual organization and neural computation (Gepshtein, Elder, & Maloney, 2008). Thus, this book not only commemorates the work of Max Wertheimer but also brings his work into the current arena of vision science, where it can foster further research by experimental phenomenologists, psychophysicists, cognitive neuroscientists, computational modelers, and historians of science.

A recent paper (Vezzani, Marino, & Giora, 2012) looking at the early history of the Gestalt factors, especially the contributions by F. Schumann, G. E. Müller, and E. Rubin, concludes that although there were forerunners, it was Max Wertheimer who was "the first to formulate [the factors of figural organization] with a full realization of their fundamental importance" (Köhler, 1938, p. 251). The authors continue: "It was Wertheimer who set in motion the *Gestalt* revolution and offered a theoretical framework capable of accounting for the facts of perceptual organization. An impressive amount of work, even at the current frontiers of research, derives from his [1923] article and testifies to its pivotal and seminal role in vision science."

In October 1988, the Deutsche Gesellschaft für Psychologie (the German Society of Psychology) bestowed its highest honor, the Wilhelm Wundt medallion (which has been presented to only about a dozen people in the society's long history), posthumously on Max Wertheimer "in recognition of his exceptional services toward the founding of psychology on a Gestalt-psychological basis and his trailblazing experimental investigations which opened new avenues for research."

This book follows a special issue honoring Max Wertheimer in the journal *Psychological Research* (Sarris, 1989) and a major exhibit on his work displayed at the University of Frankfurt, the New School for Social Research in New York, the University of Würzburg, the 36th Congress of the Deutsche Gesellschaft für Psychologie in Berlin, and the 25th International Congress of Psychology in Brussels (1992). Both the special issue and the exhibit were prepared by Viktor Sarris, who also established the Max Wertheimer Lecture Series at the University of Frankfurt.

Allison Sekuler, Alexander von Humboldt-Fellow, and Wim van de Grind, DFG-Mercator Guest Professor, both in the Freiburg laboratories, inspired and encouraged the translation of Wertheimer's two articles; and Steven Lehar issued a draft translation of the 1912 article before Michael Wertheimer and K. W. Watkins assumed responsibility and subsequently also translated the 1923 article.

Rendering Max Wertheimer's prose into contemporary English allows his articles to be read not just by historical scholars but by researchers, students, and educated laypersons interested in the field. There is never a satisfactory middle ground, so we decided in favor of keeping an eye on authenticity, readability, and flow without adhering too closely to the exact German wording and sentence structure.

Heiko Hecht, Steven Lehar, Zygmunt Pizlo, and Dejan Todorovic kindly read all or parts of the 1912 translation while Steven Lehar and Dejan Todorovic read all or parts of the 1923 translation. Their advice, comments, and suggestions are much appreciated.

We are indebted to the late Dr. Walter Ehrenstein and Prof. Heinz Wässle for initial guidance, the Hertie Foundation for a generous grant, the Stiftungsinitiative Johann Gottfried Herder and China Medical

University (CMU) for support, and the MIT Press for their great care in the publication of this book.

CMU President Prof. Jong-Tsun Huang, Dean Chang-Hung Chou, Prof. Yuk-Man Leung, and Prof. Li-Chuan Hsu kindly provided an atmosphere of hospitality, enthusiasm, and encouragement conducive to the book. Ms. JingTing Huang of CMU's Graduate Institute of Neural and Cognitive Sciences offered dedicated editorial assistance and inspired help. The librarians of the Medical Library, Freiburg University, and National Taiwan University, Taipei, supplied books and articles, and Dr. Franz Aiple, Neurocenter Freiburg, provided technical support.

I thank them all.

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On leave of absence from Freiburg University

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On Perceived Motion and Figural Organization

I. Abt. Zeitschr. f. Psychologie. *Bd. 61. Heft 1.*

Zeitschrift
für
Psychologie und Physiologie der Sinnesorgane

begründet von
Herm. Ebbinghaus und **Arthur König**
herausgegeben von
F. Schumann und **J. Rich. Ewald.**

I. Abteilung.

Zeitschrift für Psychologie.

In Gemeinschaft mit

S. Exner, J. v. Kries, Th. Lipps, A. Meinong,
G. E. Müller, A. v. Strümpell, C. Stumpf, A. Tschermak,
Th. Ziehen

herausgegeben von

F. Schumann.

Leipzig, 1912.
Verlag von Johann Ambrosius Barth.
Dörrienstraße 16.

Jährlich erscheinen 3—4 Bände, jeder zu 6 Heften. Preis des Bandes 15 Mark.
Durch alle Buchhandlungen sowie direkt von der Verlagsbuchhandlung zu beziehen.
(*Ausgegeben im April 1912.*)

[p. 161] (From the Psychological Institute of the Academy at Frankfurt am Main.)

Experimental Studies on Seeing Motion

by Max Wertheimer

Zeitschrift für Psychologie, Vol. 61, No. 1, pp. 161–265

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[p. 162] One sees motion: an object has moved from one location to another. One describes the physical facts: Until time t_1, the object was in position p_1. From time t_n on, it was in position p_n. In the interval between t_1 and t_n, the object was successively, continuously in space and time, in the intermediate positions between p_1 and p_n, through which it arrived at p_n.

One sees this motion. It is not that one merely sees that the object is now somewhere else than before, and therefore one knows that it has moved, as one knows that the slow hand of a clock has moved.[1] Rather, one actually sees the motion. What is psychologically *given* here?

By simple analogy with the physical events, one might say that seeing motion consists of the seen object, the psychological visual object, progressing from seen position p_1 through the continuum of intermediate positions to seen position p_n. One sees motion because that succession of intermediate positions is psychologically given.

If seeing motion is due to an "illusion"—if physically there was actually only a stationary event, and later a different stationary event at a certain distance from the first—then, based on the two sensations of stationary events, a subjective completion must somehow have occurred along with them, subjectively including the intermediate positions.

[p. 163] The following investigation deals with impressions of motion that can be achieved by presenting two such successive events, even with considerable distance between them.

* * *

It is well-known that "illusions of motion" can arise from appropriately exposed, successive stationary presentations of an object.[2] This is how

1. S. Exner (Über das Sehen von Bewegungen. Sitzungs-Berichte der Wiener Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Classe 72, Abt. 3. 1875) stated principally that the seeing of motion is a property of peripheral perception [and described] quantitative relationships.

2. See the abundant literature on the "stroboscopic illusion," largely summarized in, for instance, Ebbinghaus, *Psychologie*, 3rd edition, pp. 531f. etc., and in individual works such as Fischer, *Philosophische Studien* Vol. 3 and elsewhere; Linke, *Psychologische Studien* Vol. 3. Cf. Marbe, *Theorie der kinematographischen Projektionen*. Leipzig 1910.

the cinematograph produces motion, much like the older stroboscope (though in that case the conditions are complicated by the rotation of the strip). Exner[3] achieved the perception of motion by successively igniting two sparks; Marbe,[4] in experiments successively illuminating small stationary lamps. Schumann[5] observed a rotational flip produced by successive tachistoscopic presentation of a vertical line followed by a horizontal one.

Many works on various other illusions of motion are scattered in the literature,[6] as well as elementary quantitative investigations of the conditions for seeing motion.[7]

There are numerous theoretical views on seeing motion. One extensive discussion considers whether seeing motion "might be derived and deduced solely from some kind of unified interpretation of space and
[p. 164] time perception"[8] or might be "an immediate and particular sensory interpretation."[9] Others ask whether it might be based on a special type of sensation[10] or dependent on a higher psychological process.[11] Naturally, these theoretical analyses of seeing motion consider the problem of illusions of motion.[12] Among the proposed theories, the following deserve mention:

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3. Exner, op. cit.

4. Marbe, op. cit. pp. 61f., 66.

5. Schumann in II. Kongress für experimentelle Psychologie. Bericht, Leipzig 1907, p. 218.

6. See, for instance, Ebbinghaus, op. cit., p. 534; Helmholtz-Kries, *Handbuch der physiologischen Optik*, p. 226f.; and others. Cf. more recently the compendium by H. Hanselmann, Über optische Bewegungswahrnehmung, Zürich, Dissertation 1911.

7. Aubert, Die Bewegungsempfindung, *Pflügers Archiv* **39**, **40**. See also the citations in the preceding footnote.

8. Ebbinghaus, *Grundzüge der Psychologie*. Leipzig 1902. pp. 466f. Cf. Dürr in the new edition of Ebbinghaus's *Psychologie*, 3rd edition. pp. 531f.

9. Ebbinghaus, ibid.

10. Exner, *Entwurf zu einer physiologischen Erklärung der psychischen Erscheinungen*. Leipzig-Vienna; Stern, *Psychologie der Veränderungsauffassung*, Breslau 1906; Cornelius, *Psychologie*, p. 132.

11. See footnotes 17 and 18.

12. Cf. the numerous works of S. Exner; Mach, *Analyse der Empfindungen*, Leipzig; Hamann, Die psychologischen Grundlagen des Bewegungsbegriffes, *Zeitschrift für Psychologie* **45**, pp. 231, 341. etc. Cf. footnote 6.

• the sensation theory[13] mentioned above;
• the afterimage theory,[14] which seeks to explain the essence of seeing motion through the rise and fall of excitation in neighboring locations on the retina;
• the eye-movement theory,[15] which derives impressions of motion from sensations of eye movement;
• the sensation-of-change theory,[16] which derives the impression of motion from a more elementary, specific sensation of change in sensory impressions;
• the fusion theory,[17] which proposes a kind of perceptual fusion;
• finally, the Gestalt, or complex-quality, theory.[18]

Some of these theories explain seeing motion by drawing on peripheral processes; others, by drawing on higher processes beyond the periphery. [p. 165] Exner,[19] and also Marbe[20] and Linke,[21] have recognized that one must base the explanations of certain impressions of motion on central events [*that is, brain processes—Tr.*]. Schumann[22] has gone so far as to say that such explanation must involve centrally generated conscious content [*Bewußtseinsinhalt*], whether characterized as Exner's sensation of motion or as Ehrenfels's Gestalt quality.

§**1.** On the object strip [*Objektstreifen*] in a stroboscope, one draws two simple objects: a horizontal line 3 cm long at the beginning of the strip, and a second such line in the middle of the strip, about 2 cm lower. When the stroboscope rotates very slowly, first one line appears, and then the other, clearly emerging as two in succession. At very high speed, one

13. See footnote 10.

14. Cf. Marbe, *Zeitschrift für Psychologie* **46**, pp. 291, 345; **47**, p. 321 and elsewhere.

15. Cf. Wundt, *Physiologische Psychologie*, Vol. 2, p. 577.

16. Cf. Stern, op. cit. Cf. Exner, *Zentralblatt für Physiologie* **24**, p. 1169.

17. Cf. Wundt, op. cit., pp. 578f., 580f.; Linke, op. cit., p. 544 and elsewhere.

18. Ehrenfels, Über Gestaltqualitäten, *Vierteljahresschrift für wissenschaftliche Philosophie* **15**, pp. 263f.; Cornelius, Über Verschmelzung und Analyse, **17**, pp. 45f. Also, as I discovered after I finished this paper, Witasek, *Psychologie der Raumwahrnehmung des Auges*. Heidelberg 1910; in particular, the theory of producing representations [Vorstellungsreproduktionstheorie].

19. Exner, *Entwurf*.

20. Marbe, *Philosophische Studien* **14**, 1898. p. 400. Cf. p. 74 of this paper.

21. Cf. p. 66f. of this paper.

22. Schumann, op. cit.

sees them simultaneously, one above the other: The two are there together, at the same time. At an intermediate speed, one sees definite motion: One line clearly and distinctly moves back and forth between the upper and lower location.

Or one draws a slanted line, ⁄ at the beginning of the strip, and a horizontal one, — in the middle. At the extreme successive stage, one first sees the slanted line and then the horizontal. At the extreme simultaneous stage, both lines appear together; one sees an angle. ∠. In the motion stage between the two extremes, a single line is seen to rotate around the vertex, from the slanted position to the horizontal and back. The same holds true with other objects, shapes, and positions.

With a suitably adjusted diaphragm, one can confirm that at any given point in time, only one slit of the stroboscope is visible.

Starting from the notion that one sees the actual passage of the objects, it is easy to conceive of this as a matter of the seen up-and-down motion, rotation, or rest, according to the direction given by the relative positions of the two objects. The stroboscope presents additional complications, but one can observe the three distinct stages—succession, optimal motion, and simultaneity—just as easily in other experimental arrangements
[p. 166] where there is no actual passage of the objects at all. This was the case in the principal experiments here: with exposure of two successive stationary stimuli using the Schumann tachistoscope[23] (see p. 13f.), and also with projection using a focal-point tachistoscope in the slider experiments (p. 7f.), with and without projection (p. 8f.).

This clear and distinct sensory impression of the motion of a single object is psychologically puzzling. What is psychologically *given* when one sees motion here?

Can one, by posing a series of appropriate experimental questions, approach an understanding of what happens psychologically to produce these impressions?

To begin with, the observations with the stroboscope suggested to me the technical experimental question: How does the optimal motion stage arise? How does it develop out of the simultaneous and successive stages? How does it decompose into them? What is perceptually given in the interstices among these three stages? Are there qualitatively distinct,

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23. *A tachistoscope consists of a viewer through which one looks at a screen, with a wheel occluding the view of the screen. Two slits in the rim of the rotating wheel expose the stimulus on the screen for two brief intervals. The exposure and inter-exposure intervals are determined by the arc-length of the slits and the distance between them on the wheel rim, respectively.—Tr.*

characteristic impressions of intermediate stages that might shed light on the qualitative development and psychological nature of the optimal impression of motion?

Furthermore, what is going on in the field of motion?[24] Is it possible to establish what is *given* in the space between the first and second position, such as the angular space between the two lines in the angle experiment?

Are peripheral conditions or eye movements inherently fundamental?

Are conditions of attention or comprehension critical? Do different foci of attention[25] play a role? If so, what role?

What are the event's modes of appearance? What are its effects?

[p. 167] Asking such questions prompted the following specific variations of the experimental conditions:

1. Observations during the transition from one of the three main stages to another, with variation of the time interval *t* between the exposures of the two objects, and variation of the exposure times.
2. Appropriate variations in the arrangement of the two objects, such as their position and distance from each other, their shape, color, and other variations of the objects themselves.
3. Variations in the observer's behavior: fixation, attention, and set [*Einstellung*].
4. Introduction of additional objects into the field of exposure, with complicating factors to be eliminated through appropriate control experiments.
5. Finally, investigation of aftereffects.

* * *

We are concerned here with the impression of motion that occurs when one presents two stationary stimuli in succession. Yet the impression of motion is psychologically puzzling not only here, but also when seeing actual motion. If one wants to understand actual motion, isn't it backward to start from "apparent motion"?

One might say: I know what it looks like when something moves; and I am now experiencing an "illusion," which can happen only if I indeed believe that I saw motion and I subjectively completed the missing part—the passage through the intermediate positions—from past experience. It is on the basis of and consistent with previous direct experience of perceived actual motion that subjective

24. Schumann's account, op. cit., p. 218, already addresses this question.

25. On the role of different conditions of attention, cf. Schumann, Beiträge zur Analyse der Gesichtswahrnehmungen, Heft. 1; v. Aster, *Zeitschrift für Psychologie* **43**, p. 161; Karpinska, *Zeitschrift für Psychologie* **57**, p. 1; Jaensch, *Zeitschrift für Psychologie* supplementary Vol. IV; and others.

completion occurs: The apparent motion is something simply secondary, more complex. So only backward, by studying the perception of real motion, can one understand how apparent motion comes about.

Now, if it were really true that the nature of apparent motion consists only of a subjective completion of intermediate positions based on past experience, then it would be all the more important to study how these compelling "illusions" come about and by what laws they are governed. But how should one study them? Can it be said that the experimental results advance our understanding of seeing motion in general? What if, here under the technically simplest of conditions, one could experimentally tease out the constituent elements of seeing motion, perhaps even the *one* constituent element that underlies the genuine, saliently given experience of motion?

To this end, one must above all avoid a certain definition of the word "illu-
[p. 168] sion": One must not deal with this as an illusion concerning the actual physical situation. Rather, the investigation must strive to describe and study what is *psychologically given*.

However that may be—and only further study can come to decisive conclusions—in what follows, I deal with motion phenomena that occur with successive presentation of two stationary stimuli in spatially separate positions.

The aim is to study these phenomena and their constituents under these simple, precisely variable conditions, and to obtain experimental building blocks to resolve theoretical problems. The hope is that the experiments will yield unequivocal answers, which arise directly from the observations and, if possible, resolve experimentally the question of what constitutes the impression of motion.

§**2.** Before the report of the main experiments, let us consider one more question: In presenting two successive, spatially separated stimuli, is it even possible to achieve the psychological impression of motion in its fullest optimal form, exactly as would be experienced when viewing an object that actually moves from one location to another?

In the experimental arrangement described below, two stationary stimuli are presented successively at a certain spatial separation and time interval, alternating with real motion. In a variation of the experiment, actual motion and two stationary objects presented successively are shown simultaneously, next to or below each other, rather than one after the other. The observers who did not know which of the stimuli were actually moving and which were only successively presented were asked to report what they saw: where apparent motion was given, and where physical motion actually occurred.

This experiment can be done at any time simply with the help of a slider (figure IV, p. 88), even without any special auxiliary equipment.

Initially I used one of the well-known wooden slider frames that serve in a projector to hold two transparencies. To project first one transparency and then the other, one need only push the frame farther into the mechanism. It is necessary to use a slider that slides smoothly, so that it [p. 169] does not accidentally eject the transparency. Instead of a transparency, a metal sheet was inserted in one frame of the slider, with a rectangle 3 or 4 cm high by 7 mm wide cut out of the middle. Attached to the external, fixed part of the sliding mechanism and so as to cover the frame was a sheet of cardboard, in which two rather thin, somewhat shorter vertical slits were cut a certain distance apart: 1, 1.5, or 2 cm.

When the slider frame was pushed in all the way (to the right), the rectangle allowed light to pass through only one of the two slits; when the frame was pushed out by approximately the distance between the slits, only through the other (figure I, p. 88). One simply rests a finger on one of the side rails that guide the slider frame when it is pushed out, as a stop. This mechanically fixes both exposure positions: one through the mechanism itself, with the frame pushed all the way in, and the other with the frame pushed out until it stops against the finger (which can easily be replaced, of course, by a mechanical stop).

The slider frame prepared in this way is now placed in the beam of a projector.

The slits must be narrow, to ensure that sudden movement of the slider between the fixed stops produces only momentary illumination, so that the observer cannot see from which direction the slit is uncovered, i.e., guess in which direction the slider is moved. The fact that the direction of exposure was undetectable was easily ascertained; see p. 9.

Moving the slider rhythmically back and forth, one soon finds an appropriate timing (where t is the time between the two exposures in succession, and α and β are the pauses at the stops, that is, the durations of the exposures) at which the observer, whether by continuous or one-time observation, sees not two stationary projected images, but a single line that *moves* from one place to the other. After some practice by the experimenter, manual operation fully suffices for this experiment. For the determination and magnitude of the times, cf. §3 (p. 13).

[p. 170] One can also project light through a slit that is actually moving, most simply by inserting into the slider frame a card with a single slit, analogous to the card with two slits previously attached to the mechanism. The slider need only be moved back and forth as before (this time without the fixed card), thus moving the slit itself. This presents the image of the slit in actual motion in the projection field.

To enable a simultaneous comparison between the two types of display, actual motion and successive stimulation, the different slits and lines were arranged as follows: The card affixed to the front face of the mechanism has two vertical slits for successive exposure in the lower half, and a larger cutout in the upper half. The movable card in the slider has a single slit above, and the exposure rectangle below; see figure II (p. 88). Thus the upper half exposes a single line in actual motion; the lower half, two lines successively. An analogous arrangement allows side-by-side comparison; see figure IV (p. 88).

One might argue that the direction of illuminating the individual slit images, which occurs here in the direction of the seen motion, might contribute to the impression of perceived motion. The first line disappears as the slider is pushed from left to right, the second line lights up from left to right, and the seen motion has the same direction. Yet, by covering one slit and pushing the slider back and forth, it was not apparent from where the exposure occurred. The illumination was subjectively instantaneous. Moreover, any doubt was more definitively resolved by means of a technical modification. One can arrange for the opening and closing of the slits to occur in the opposite direction to that of the successive exposure of the slits. Even under these conditions, optimal motion was observed, although the exposure and occlusion of the slits occurred in the opposite direction from that of the seen motion.

To achieve this, instead of a single exposure rectangle, there were now two, the distance between which (and thus the sliding distance of the frame) was greater than the distance between the two slits. For instance, if the slits in the fixed card, 1 mm wide by 3 cm high, were 1 cm apart,
[p. 171] then the corresponding, somewhat broader exposure rectangles in the slider were 2 cm apart; see figure III (p. 88).[26]

If the slider is pushed in all the way to the right, then in the configuration in figure III (p. 88), the left slit is exposed and the right is not. If the slider with the exposure rectangle is pushed to the left by a distance equal to the separation between the slits, then the right slit is exposed while the left is not, and so on. Thus the left slit is occluded from right to left, while the right slit is illuminated from right to left. Yet the succession and the seen motion go from left to right. This produces optimal motion of one line, often "more energetic" or "stronger" than when the illumination and occlusion occur in the same direction as the seen motion.

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26. Enlarging the distance between the exposure rectangles, or the width of the rectangles, also makes it possible to vary the interval *t* between the two exposures independently of the speed of the slider. See figure V, p. 88, in which two adjacent pairs of successive exposures have different time intervals.

Figure IV (p. 88) combines

- simultaneous exposure of real motion, in the upper right of the exposure field;
- successive stimuli with same-directional exposure, in the upper left and lower right;
- successive stimuli with reverse-directional exposure, in the lower left.

One can also set up the slider observations without a projector, using the same wooden slider frame or a similar device. It is technically advantageous to work with a small distance between the fixed and the moving cards. Slits 0.5 mm wide, in cards or sliders separated from each other by 3 mm, work well.

Or, simpler yet, one can use the handy slider in figure VII (p. 88). It is best to place the slider in the dark in front of oneself, so that one cannot see the two exposure slits in front of the equally dark, moving card. Beyond that, say 50 cm away, one sets up either a white surface illuminated by a hooded lamp off to the side or a translucent surface illuminated from behind.

Or one can install the slider in the doorway between a light and a dark room or point it through a window at the bright sky.

One can also hide the slider behind a screen that conceals the external [p. 172] motion from the observer. In each fixed position of the slider, only one slit is illuminated.

To demonstrate the phenomena in the simplest way, one can hold a slider in the form of figure VII up to the bright sky, or a lampshade, while rhythmically pushing the movable part back and forth between the fixed positions.

I have chosen these slider arrangements because they allow for easily carrying out the experiment and clearly demonstrating the phenomena. Note, however, that accurate sliding does make some demands on the dexterity of the experimenter. For further experimentation, and to allow exact time settings, one can use a purely mechanical procedure, which is easy to set up.

First one seeks an appropriate rhythmic speed, which is readily found as an optimum between "imperfect" impressions of motion that result from sliding the frame too slowly or too fast. Then, keeping this rhythm, one lets the subject observe. While one seeks the appropriate speed, an assistant blocks the beams to the field that is visible to the observer.

One can also do this experiment by showing a succession only once, but this makes it more difficult to achieve both the appropriate exposure times for each slit and the interval between the exposures. Furthermore, this requires concentration of attention on the moment of exposure, and practice in tachistoscopic observations. Under these conditions, it soon becomes clear that even with prolonged, careful, and repeated observation, it is quite difficult to distinguish between impressions arising from actual slit motion and those arising from successive exposures. It is more comfortable, for procedural reasons (see §7, p. 32), to allow the observer to look at leisure at the back-and-forth motion of the strips resulting from the continuously alternating exposure.

For the way in which seen motion depends on various factors, see the following sections:

- for the time interval between stimuli: §3 (p. 13f.)
- for subjective factors: p. 26f. and §11.
- [p. 173] for conditions during continuously alternating exposure: §7 (p. 27).

Other factors can also come into question:

- the distance separating the lines (or strips) from each other; cf. §3 (p. 15), among others.
- the selected brightness.
- the duration of the interval relative to the duration of the slit exposure; a very short slit exposure with extreme brightness appears unfavorable.
- effects of accommodation; under unfavorable conditions, inadequate accommodation can be favorable.
- the Gestalt configuration (cf. p. 43).

Since this research is qualitative by its nature, the aim is to find the most suitable conditions for reaching a conclusion. For the current experiment, see the size conditions and the durations on p. 17, which sufficed to decide the issues in question.

With regard to the catch trials discussed here, care must be taken to avoid experimental errors that, for the question under study, can arise from the subject's knowledge of the experimental setup. Likewise the exposure conditions should be as optimal as possible because certain phenomena (see §7, §9, and §16) are so rare that one could deduce the actual stimulus arrangement from *any* qualitative difference. Indeed, sometimes highly practiced observers can definitively confirm such differences if, instead of focusing on the question of seen motion, they focus on whether an object is visible in the field of motion, which is quite a different matter from the impression of seen motion itself (see §16).

Despite all these various factors, the selected experimental conditions turned out to be suitable and appropriate. The experiment proved to be sufficiently robust to produce conclusive results, even when performed with unpracticed observers and also without projection.

This was the result: In most cases, the actual and the "apparent" motions were entirely indistinguishable, even to observers practiced in meticulous observation of momentary exposures in various tachistoscopic experiments performed over a span of months. In some cases, after many exposures of a particular stimulus arrangement and long observation of the resulting motions, the two types could finally be correctly distinguished from each other, not by designating one as motion and the
[p. 174] other as nonmotion, but by stating a qualitative difference in the kind of motion perceived. Specifically, the observer experienced a different impression of motion (§7), or a difference in the visibility of the object (see §16). Very often there were statements like, "One motion looked different from the other in that it was so strong, energetic, the best motion of all," and this with regard not to actual motion, but the apparent motion produced by two successive stationary stimuli.

The strength of the "illusion" was occasionally also experienced in other ways. In the dark, the beams of light that go from the projector to the projection screen are seen to describe definite back-and-forth motions like the objects themselves. Likewise, for the circular disk of light visible on the projector's lens, when the slits are exposed, often one had to convince oneself repeatedly that no actual objective motion had occurred, by moving the slider *very* slowly, so that first only one slit allowed light to pass, followed by a dark interval, and then by light coming through the other slit.

There are various ways to observe each of these arrangements. The observer can try to follow the "motion" by eye, or the gaze can be fixed on one particular spot. One can alternate the type of observation during continuous back-and-forth exposure. In all cases, a good impression of optimal motion was achieved (cf. §4).

Analogously, other kinds of impressions of motion could be obtained through different types of arrangements: by positioning the slits diagonally to each other (see figure VI, p. 88), by angular rotations, rotations of curves (see figures VIIIa, VIIIb), and so forth.

Regarding the speed of the seen motion, one might mention that the perceived speeds are not so extraordinarily fast as one might assume at first glance from the time interval of the succession (see §3, p. 19), such as $t = 50\ \sigma$ (thousandths of a second). Similar speeds are often observed when seeing actual motions in everyday life. They correspond with those of a person walking rapidly, not running, or of a pacing horse. Moreover, [p. 175] it was observed (see §7) that under certain circumstances even much slower motion could be achieved: "colossally slow, but optimal" (cf. p. 31).[27]

§3. I first made numerous observations of the transitions among the three principal stages using a simple stroboscope:

• with accelerating and decelerating speeds, and selecting a particular speed;
• with variations: introducing a diaphragm (aperture), maintaining one's gaze, directing the attention to particular locations;
• with various simple objects and appropriate variations of them;
• with introduction of third particular stimulus objects;
• employing objects of different shape, color, and size, and position.

Observations by Dr. W. Köhler confirmed the results collected under these conditions.

Professor Schumann was kind enough to make available his well-known tachistoscope, with a special addition that he devised for the purpose of studying the effects of two successive exposures, thus enabling me to conduct my experiments under technically more exact and precisely measurable conditions.[28] The experiments presented here were performed in the autumn and winter of 1910 at the Psychological Institute at Frankfurt am Main. What follows is primarily a report on the results of the principal investigations with the Schumann tachistoscope. Essentially the same results were observed with other experimental arrangements as well (see p. 18).

The Schumann apparatus, which permits selecting even a single successive exposure under exactly measurable conditions, has a prism close to the tachistoscopic wheel, beyond the distal lens of the telescope one looks through. This prism blocks the lower half of the lens, so that rays come [p. 176] into the upper half of the lens directly, while entering the lower half from the side. One exposure slit on the wheel exposes the upper half, whereas

27. Incidentally, the apparent speed of this kind of "illusory" motion is easily distinguished from the objective physical speed. The factors that play a role in apparent speed (as also in apparent size and apparent distance) constitute a special problem in themselves.

28. Cf. the reference in II. Kongress, citation 1, p. 218.

a second slit exposes the lower half. If the distance between the lens and the prism is small, then the whole circular surface of each momentary exposure field is seen at each of the two exposures. When the tachistoscopic wheel rotates, it exposes first one and then the other stimulus field.

It proved advisable to work with black exposure fields, to which white or colored strips or other objects were affixed, to counteract the change of brightness in the visual field and any possible contribution of the edge of that field.

The duration of the exposures α and β could be varied by adjusting either the slit lengths or the rotational speed of the wheel. The duration of the interval between the two successive exposures could likewise be varied by either the rotational speed or the distance between the exposure slits. In general, I worked with exposure slits whose length was between 6° and 12° of the wheel's circumference, with distances of 3°, 6°, 12°, and 16° between them. In the course of the investigation, slits much closer to one another, and even overlapping, were also used (see §15:2).

In tachistoscopic experiments, it is generally advisable to use fast rotation of the wheel and relatively long slits, to achieve instantaneous appearance and disappearance of the stimulus. Here, there is another reason besides: Slow passage of the slit edges produces apparent motions of a different kind.[29]

The two assistants at the institute, Dr. Wolfgang Köhler and Dr. Kurt Koffka, and later also Frau Dr. Klein-Koffka, were kind enough to make themselves available as regular observers.

On a number of occasions, especially in slider experiments under comfortable observation conditions, I also used other observers, including some who were completely naïve with respect to psychological observations.

The essential experiments were all made without observers knowing the purpose of the experiment, and the experimental results were always
[p. 177] revealed to the observers only after they had each spontaneously reported their results.

It turned out that a large number of observers was not necessary since the characteristic phenomena were altogether unequivocal, spontaneous, and compelling.

I thank Professor Schumann, to whom I am much indebted for introducing me to tachistoscopic experimentation and instructing me in it years ago, for graciously making available the equipment of the Frank-

29. *Such as partial motion; see p. 28ff.—Tr.*

furt institute as well as for his kind interest. I also heartily thank my observers for their active participation and unflagging patience.

* * *

The distance of the exposure fields from the prism was about 80 cm. Both exposure fields were black or dark, each illuminated from the side by a lamp. The strips and other objects (see p. 89f.), were generally 1 × 6 cm, larger or smaller, in white or another color. They were attached to the exposure fields and their positions set for simultaneous exposure, through identical slit openings. Equal brightness was produced by the placement of the two lamps.

Factors such as the brightness, shape, and size of the objects, and the distance between them (their relative positions), are of some relevance.[30] For instance, it was found that the range of the time interval[31] *t* between exposures within which the impression of optimal motion occurred was much greater, both longer and shorter, with small distances than with large ones. If one wishes—by starting from the optimal motion stage—to reach the extreme stage of simultaneity (by shortening the interval *t*), or of succession (by lengthening *t*), the shortening or lengthening of *t* must be much more extensive for smaller distances than for larger ones. Correspondingly, when using the configuration in figure V (p. 88), designed especially for this purpose, keeping speed and *t* the same, a change of stage occurred with larger distances, when the time interval between stimuli was increased beyond the optimal condition; whereas with smaller separations [*and the same time interval—Tr.*], optimal motion persisted. The influence of spatial separation was also apparent in another sense:
[p. 178] The smaller of two distances from one line to the other generally facilitates the impression of motion (see p. 50).

I used distances of 1, 3, 5 cm and more between parallel and slanted objects (cf. p. 34).

Under the given conditions, optimal motion was perceived with an interval *t* between the two exposures of about 60 σ; simultaneity with a t = approximately 30 σ; and succession with about $t = 200\ \sigma$.

To illustrate these time values, I present below some tables of the results from the three main observers, who were about equally practiced in

30. Cf. for this Marbe, op. cit., p. 65 and Linke, op. cit., p. 494; cf. in this paper p. 50.

31. *In today's terminology, these are called interstimulus intervals.—Tr.*

tachistoscopic observation and given the same specific instructions. In some experiments, especially in the beginning, individual differences played a role (see p. 31); and in §9 and §11, we will see how various other factors may have an influence. In general, however, all tachistoscopic experiments yielded time values similar to those illustrated in the tables below.

We will also see in §9 ff. that, qualitatively, different phenomena occur in between the three main stages. In the following tables, these phenomena are ordered according to time.

The time values are calculated as follows: If, for instance, the slit lengths for the exposures *a* and *b* are each 7° of the circumference of the wheel, and the distance between the exposure slits is 16°, the entire length (total duration of exposure) is 30°. Thus the proportion to the whole circumference is as follows:

- for each exposure α and β, 51.4 (that is, 360° to 7°);
- for *t*, the interval between exposures, 22.5 (360° to 16°);
- for *c*, the complete time of exposure, 12 (360° to 30°).

If the time measured for 20 revolutions in a specific case is, for example, 20.4 seconds, then the corresponding durations are as follows:

- for one revolution, 1020 σ;
- for *c*, the entire exposure time, 85 σ;
- for the exposure of each stimulus α and β, 20 σ;
- for *t*, the interval between the exposures *a* and *b*, 45 σ.

Example I

The objects were two white strips, 1.5 × 8.7 cm, on a black ground, slanted toward one another at an angle of 45° and touching at the vertex (see figure XVIa, p. 89). The horizontal strip (*a*) was on exposure field *A*, the slanted one (*b*) on exposure field *B*. The optimal motion stage produced a strip seemingly rotating from the horizontal into the slanted position.

Individual exposures of *a b* were presented with pauses of approximately two minutes in between (cf. §7). The conditions of observation in
[p. 179] all cases were fixation and attention (see §11) directed at the common vertex point, as established during preliminary exposure of *a* alone (see p. 39).

The rotation time was varied in steps and measured during the two-minute pauses.

Table I

	σ:	*t*	*α*	*β*	*c*
Observer I	Simultaneity	32	5	5	42
	Dual whole motion (§6)	53	7	7	67
	Identity, rotation, optimal motion	59	7	7	73
	Very slow motion, identity (§7, p. 37)	116	14	14	144
	Succession	178	22	22	222
Observer II	Simultaneity	36	5	5	46
	Identity, rotation, optimal motion	74	9	9	92
Observer III	Simultaneity	31	8	8	47
	Partial simultaneity (footnote 51)	40	10	10	60
	Partial motion (§7)	50	13	13	75
	Dual whole rotation (§6)	58	15	15	87
	Identity, rotation, optimal motion	62	16	16	93
	Identity, rotation, optimal motion	64	16	16	97

Example II

Similar to example I, with longer and different α and β and a small, identical circle at the vertex in both exposure fields for fixation. (See table II.)

Here one sees that the stages depend above all on t. The values of t for optimal rotation are 59, 45; 74, 54, 70; 62, 49, 50 σ.[32] The exposure times α and β could be varied greatly under these conditions without significantly affecting the impressions of motion. It is noteworthy that certain motion phenomena (see §7) occurred even when the times of the two exposures overlapped (see §15).

[p. 180] All the following experiments except §7 (p. 31) and the like covered values of c ($\alpha + \beta + t$) ranging from a maximum[33] of 0.1 seconds (100 σ) to a minimum of 40 σ (simultaneous stage), analogous to the time values given here.

Besides the main experiments with the tachistoscope, I worked with a series of other experimental setups, including the following:

32. These are valid for the experimental conditions used here. Cf. p. 11.

33. For technical reasons (see §4), it was essential to operate under conditions where the total exposure time in the main experiments did not exceed 100 σ, yet the stimuli generated good motion perception, and moreover the rotational speed of the tachistoscope did not become so great that distinguishing the individual exposure of each of the two successive stimuli became uncertain or impossible—all of which was made possible by the conditions above.

Table II

		σ: t	α	β	c
Observer I	Identity, optimal rotation	45	33	33	111
Observer II	Simultaneity	33	17	8	58
	Identity, rotation	54	28	14	96
	Slower rotation	61	31	16	108
	Very slow rotation	131	67	33	231
	Simultaneity (§8)	45	6	8	59
	Identity, rotation	70	9	13	94
	Identity, rotation—slower	90	11	17	118
	Succession	153	19	28	200
Observer III	Simultaneity	32	15	15	62
	Partial motion (§7)	45	20	20	85
	Identity, rotation	49	22	22	93
	Partial motion (§7)	105	57	57	200
	Simultaneity	32	17	9	58
	Identity, rotation	50	25	12	87
	Identity, rotation	53	28	14	95

- the slider experiments described in §2 in their different variations (cf. p. 88f.), with and without projection;
- an arrangement similar to a focal tachistoscope;

[p. 181] • a shadow experiment[34] convenient for demonstration purposes.

Also, for serial exposures,

- an ordinary stroboscope;
- the symmetrical slit arrangement on the Schumann tachistoscope;
- the combination of a tachistoscope with:

—a rotating kymograph drum [*a recording device—Tr.*] (see p. 60),
—a spoked shutter wheel (see p. 61), and
—the well-known spiral (see p. 61);

- a cinematograph.

34. The shadow experiment in its simplest form, though not entirely exact due to a change in brightness, can be performed with two electric lights and a change-over switch. One casts two shadows from one (or two) vertical rods alternately, a certain distance apart, onto a white wall, or from behind onto a plate of milk-glass or a taut sheet of paper. In the optimal stage, one sees a shadow moving back and forth. Various configurations of the shadow arrangements and strengths permit many experimental variations. Even a one-time succession of *a b* can be achieved.

Also, for haploscopic purposes,

- a double telescope arrangement on the tachistoscope (see §15);

and, for easy demonstration,

- a mirror arrangement (cf. p. 52).

In the slider experiments, even just with manual operation, the intervals were approximately measurable. A light kymograph needle attached to the moving portion of the slider (p. 89), in parallel with a Jaquet time recorder, traced the movement of the slider on a rotating kymograph drum. In the resulting curve, the slanted sections corresponded with the periods of motion and revealed the duration of *t*, plus the time intervals —very small when using narrow slits—within which *a* remained visible at the beginning of the slider movement, while *b* already became visible at the end. The catch trials experiment (§2; figure IV) thus yielded, optimally, a somewhat smaller *t* just over 50 σ (α and β = 0.3 second each, duration of slider movement = 0.07 second, slit width = 0.5 mm, and slit separation = 3 mm).

§**4.** One might suspect that eye movements occurred in all this and that they were responsible for these phenomena. [*Consider the following scenario.—Tr.*] Two objects in different locations are presented to the eye in succession. The eyes aim to bring them onto the center of sharpest vision. Thereby they shift from fixating on the first object to fixating on the second, and one might suspect that it is this eye movement that is the
[p. 182] basis for the reported motion phenomena.

But does this eye movement actually occur? [*The following observations suggest otherwise.—Tr.*]

1. The tachistoscopic exposures were arranged so that the entire exposure time (that is, the exposure time α of the first object + the interval *t* + the exposure time β of the second object) was generally less than a tenth of a second, and never longer than that. At such a duration, eye-movement reactions may be ruled out. Investigations of the minimal time for eye-movement reactions[35] show that they become relevant only at approximately 130 σ.

Those investigations do not pertain directly to this kind of motion experiments. Thorough investigations of the relationship between eye

35. Cf. Erdmann-Dodge, Psychologische Untersuchungen über das Lesen, Halle, 1898. Pp. 116ff.; Dodge, Eine experimentelle Studie der visuellen Fixation, *Zeitschrift für Psychologie* **52** 1, p. 335 and elsewhere, 1909.

movements and the seeing of apparent motion remain to be done. However, Dodge[36] has found the minimum reaction time for eye movements in response to a pendulum to be 130 σ.

2. If the task is to maintain steady fixation (in the tachistoscopic experiments, by keeping one's gaze on a certain location during preexposure of a single object), it sometimes seems at first as if the fixation point becomes displaced by the subsequent successive exposure of both objects. One starts out fixating firmly on the desired location, perhaps on the upper end of the vertical bar of the two successively exposed legs of an open angle; after the exposure, when the bar appears to have rotated, the fixation is elsewhere—"The fixation was yanked across [*hinübergerissen*]." At the end, what is fixated is some place on the horizontal bar or a location just above it.

It was soon found, however, that the fixation point could easily be maintained. A particular point[37] is continuously fixated, and motion is perceived just as much as without steady fixation.

[p. 183] Objects, shapes, distances, and angular size were varied in these experiments in several ways. Various locations were selected for fixation, and in the tachistoscopic experiments preexposure of one object established the fixation point: at a point common to both objects (e.g., the vertex of the angle); at a point on one of the two objects; or at a location outside both, in the field of motion or outside it, on the side of the objects or above or below them.

What happens in serial exposure, in the slider as well as the slider projection experiments, is clear and simple. One steadily fixates on a certain place in the projection field, while across it, or next to it, apparent motion occurs.

3. The same was found in testing with an afterimage. Before the observation, a strong afterimage was produced by fixating on the brightly glowing filament of a bulb, or by fixating on a small lit cross in a darkened room. The observer, with the afterimage in his eye, then fixated on a particular location in the exposure field, so that the afterimage appeared at that location.

Here too I worked with various objects and fixation locations. For instance:

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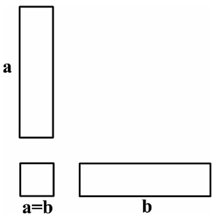
36. Ibid., p. 341.

37. Minimal deviations (a "fixation field") would not provide sufficient grounds for explanation.



When the square at the vertex was presented identically in both exposures, the cross of the afterimage was projected onto this square, appearing as . In preexposure, the common square, or the square along with the vertical or the horizontal strip, was exposed several times.

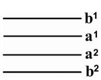
The result was the same. The afterimage remained steadily in its place; the perceived motion was the same.

Analogous results also obtained with presentations in the optimal motion stage, using other kinds of impressions (§7, §11, and §15) and other configurations.

4. The visual impression of a briefly exposed object persists beyond the exposure time.[38]

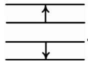
In general, in the successive exposures mentioned here, the first impression did not last beyond the appearance of the second object (cf. here [p. 184] §15). In individual cases, however, an afterimage of the first stimulus was still seen after the total exposure; or it appeared shortly after the motion, together with the afterimage of the second stimulus. In this case, where the motion was seen, one might ask, where did the afterimage of the first stimulus occur? It maintained its correct location, that is, it appeared in the same location as before. For instance, with exposure of two strips at right angles, *a* vertical and *b* horizontal, one perceived "rotation of one strip from the vertical to the horizontal position, optimal motion, immediately followed by a faint afterimage of the whole angle at once in the same place." Or, in the impression of another stage (cf. §9), the slanted strip *a* "moved to the horizontal position, immediately after which an afterimage of the slanted strip also appeared, in its original location, fainter than before, but distinct."

5. Finally, testing the question of eye movements prompted the use of several successive exposures presented simultaneously.



a^1 and a^2 belonged to the first exposure, b^1 and b^2 to the second. This exposure sequence yielded two simultaneous

38. Cf. Schumann, I. Kongress für experimentelle Psychologie. Leipzig, 1904, p. 35.

motions in opposite directions: . Analogous arrangements with stimuli of different shapes and positions did the same. Furthermore, it was possible to create two *opposite* simultaneous motions within the *same* motion field (see figure XXIII, p. 89) with tachistoscopic single or multiple exposures; analogously, cf. the slider in figure XIV (p. 89). It also soon became evident that it is possible to create *several*—three or four—disparate impressions of motion in different directions at the same time, whereby the only limit seemed to be the narrowness of conscious awareness of the field of attention. In this manner, three or even four distinct movements were created simultaneously (figure XXI, p. 90), and similarly in other experiments with different variations. This was the case not only after practice with the objects in question, but also at the first exposure, using a procedure completely unfamiliar to the subject.[39] All subjects saw three simultaneous motions clearly, the first time that
[p. 185] three real, complex objects, such as a small birdcage, a plant, and a bunch of grapes, were unexpectedly exposed in different successive locations.

If one wished to explain these impressions of motion by eye movements, one would have to assume several disparate and, in some cases, opposite eye movements. Even with the assumption of so-called "eye movement innervations" or "remembered eye movements," it would still be necessary to assume several of them, contradicting one another, to be simultaneously effective.

Lastly, consider cinematographic pictures and the seeing of real motion. Just think what complex motions one can see simultaneously in different directions, and what demands this would make on eye movements with respect to "innervations."

Given the spatial separation between the two objects, and the fact that the apparent motion between them occurs even when the eye is steadily fixated, we can rule out the possibility that the appearance of motion in the intervening field arises from simple processes of rise and fall in excitation of the two stimulated retinal locations. Such processes might apply to retinal locations right next to each other, when the images of the successive stimuli overlap one another,[40] but here the apparent motion is seen in the field separating the locations of the two objects.

39. Some observers needed previous practice (not necessarily with the same arrangement) in order to see multiple, disparate, distinct motions with such a short total exposure time.

40. Concerning this, cf. Marbe, Theorie der Kinematographischen Projectionen, Leipzig 1910, p. 64.

§5. The circumstances are these: Two objects are presented successively as stimuli.[41] They are perceived as sensations; *a* is seen at the beginning, *b* at the end.[42] Between them the "motion from *a* to *b* was seen" without actual exposure of any corresponding motion or stimuli in the spatiotemporal continuum between *a* and *b*.

[p. 186]

The psychological circumstances can—without any bias—be designated *a* φ *b* (but cf. §12), where φ represents what is there in addition to the perceptions of *a* and *b*; what occurs in the space between *a* and *b*; what is added to *a* and *b*.

The considerations mentioned on p. 2 would lead to two theses. However one conceives of the perception of motion in any of the theories under consideration (cf. §20), at least one of the two is required by the facts, even though they take different forms and directions.

I. Φ is something which pertains uniformly to *a* and *b*, something that builds on them, engages them, and binds them together.
II. The phenomenal content of φ is given by, or on the basis of, subjectively supplying positions in the intermediate spatiotemporal continuum, that are not present objectively.[43]

One would therefore have to say: φ is an entity that plainly concerns *a* and *b*. It binds them together uniformly. Therefore, *a* and *b* must be considered as the necessary, somehow fundamental, constituting framework for φ. Lastly, φ comes into being by subjective completion of the intermediate positions between *a* and *b*.

Observation of the phenomena, however, pointed in another direction. It became ever more clear that something compelling and specifically *given* must be happening here, and this led step by step to experiments challenging the apparently necessary, absolute linkage *a* φ *b*.

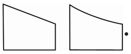
§6. The optimal impression of motion showed a single entity that moves and is identical with itself; an object that moves or rotates; and, in continuous observation of serial exposures (*a b a b a b* . . .), moves or rotates back and forth, or changes its orientation one way or another.

This identity emerges even with some difference between *a* and *b*. In that case a "change" is added: In the optimal motion stage, the one

41. In the tachistoscopic experiments, significant change in the brightness of the presentation field or its border was avoided by using black exposure fields. In the slider and slider projection observations, the presentation field remained the same except for the two "stimuli." Thus one can speak of two individual stimuli.

42. Cf. however §12.

43. *In today's terminology, this is called completion or filling-in.—Tr.*

[p. 187] moving object appears to undergo a change. For instance, if *a* is a longer strip to the left, and *b* a shorter one to the right, what is seen is a single line that shrinks in height as it moves from left to right. Often this immediately resulted in a specific curve of motion: . Or one can use differently colored objects, such as a red strip that moves down and arrives as a blue one; or, in serial exposures, one strip that moves back and forth alternates in color while doing so. Experiments with curved configurations also fit here: tachistoscopic analogs of the sliders in figures VIIIa, VIIIb, IX, and X (p. 88), in which a straight strip [*alternating with a curved one—Tr.*] appears to both move[44] and bend at the same time.

Moreover, this clear and compelling impression of one single object[45] given in experience is entirely distinct from any mere guessing or conviction that might be present in addition to the experience that one is dealing with only one object. The impression is different from: "I see *a*; I see *b*; I confidently assert that they must actually be the same thing." The seen motion is something phenomenal, something absolutely different from a "now here," "now there" with the conviction that the motion must have gone across. Likewise the impression of the identity of *a* and *b* in optimal motion is clearly something different from "there's another one like it; it must be the same thing."

There are cases where such a conviction does arise. Even under unfavorable conditions, careful observation soon recognizes these cases, because the question of identity does not matter for what is actually experienced. One might accept the opposite based on compelling reasons, but that does not contradict what is seen. The eventual conclusion that *a* and *b* are identical does not flow directly from perceptual experience. The observer can easily tell the difference between *seeing* the motion and concluding that *a* and *b* are the same thing, even under circumstances that are favorable to the assumption of identity, for instance, when one knows there really is only one object present.

[p. 188] But on the contrary, in the regular experiments, the observers always knew that it was a matter of the successive exposure of two different objects. Moreover, the successive exposures were presented to the observer with the most varied durations of the interval *t* (see §7 and §9),

44. With a certain depth effect under certain circumstances; cf. also footnote 149.

45. Cf. here Linke, op. cit., p. 476f.

and different dual impressions occurred (see §7f.). It was only within certain specific ranges of *t*—and this very clearly and compellingly—that the unitary impression of identity emerged. Significantly, in such cases the impression was impossible to change, to "assume away." Even when *a* and *b* were clearly different in color or form, a difference which surely should have supported the judgment of nonidentity, optimal motion was seen although accompanied by a change in color or form at the same time.

There were two aspects of the impression, motion and identity (that is, *a* is identical to *b*). Do both of these aspects belong together intrinsically? Are they necessarily coupled?[46]

Theoretically one might expect that the appearance of identity is a necessary prerequisite for the impression of motion; or, conversely, that the experience of motion necessarily brings the impression of identity with it.

This raises the experimental question, is it possible to separate these two aspects? Wherever motion is seen, is identity ($a = b$) always necessarily given also? Do these two aspects always necessarily arise together, disappear together, and inherently belong together, perhaps even in the transition from the optimal motion stage to the simultaneous stage?

If one presents the stimuli with a *t* close to the threshold for optimal motion, for instance, if one shortens *t* somewhat, soon impressions emerge in which the motion is quite clearly there, but the identity of *a* and *b* is *not*. One sees the motion, yet *a* and *b* are two separate entities. If *t* is changed in small steps, starting from the optimal *t*—while the ability to
[p. 189] distinguish between the characteristic impressions of the main stages is sharpened—a sequence is observed where the impression of motion is initially preserved, but identity is lost.[47] When *t* is changed in the opposite direction, from the simultaneous stage toward the optimal motion stage, the reverse sequence is observed, with motion occurring first, and motion with identity of *a* and *b* only later. Right at the border of the identity zone, identity often appears to be "somehow there, uncertain, or with a remnant of duality still." Likewise, in working with individually selected values of *t* of this kind, in single exposure of *a b* as also in continuous

46. Linke asserted that the appearance of identity is essential for explaining stroboscopic appearances, but Marbe disputed this (cf. II. Kongress für experimentelle Psychologie, op. cit., pp. 216, 218; see also p. 67 of this paper).

47. Cf. §7; for limitations, see footnote 51; p. 46.

observation with several exposures, there were frequent instances with no identity of *a* and *b*, but motion nevertheless.

This was observed with various stimulus configurations; likewise when using two objects of different color or shape. In that case this phenomenon [*of nonidentity, but motion—Tr.*] was clearly distinct from the impression of the optimal stage, that is, the impression that "one single object changes." Here motion was seen, but *a* and *b* were two objects, qualitatively different from one another.

At the limit of the identity stage, focusing attention plays a role (cf. pp. 40 and 43).

Far more blatant, specially determined examples of clear duality of *a* and *b*, accompanied by distinctly present motion, are yet to come.

There is one more point to make about the impression of identity. Aside from specific past experiences, one might perhaps want to think [*that the impression of motion is not so much perceived, but inferred, and—Tr.*] that it is only the "inference of identity" that brings about the "assumption of motion." I see, for instance, a white strip of a certain size and shape by itself in the visual field, then another similar one in a somewhat different location again by itself. This strongly suggests the conclusion that it was the same one in two different positions, and consequently that it moved from the first position to the second. The same could be the case for certain differences of shape, color, or size between the two seen objects, implying that, in between the positions, the object must have changed.

[p. 190] Such cases are conceivable, in which nothing more is present than that *a* and *b* were seen, and as a consequence of such "inferences" one could also wrongly assume that one had seen the motion. But against such an account of the phenomena—quite aside from the clear evidence of the experience itself—there exist the diametrically opposed instances that have already been mentioned, where one knew quite well that there were two stimuli and saw them in different modes of appearance (see §7). Nevertheless, with optimal exposure conditions, movement with identity was seen consistently. Also, despite the observer's knowledge, longer observation turned out to be *favorable* for that impression (cf. p. 32).

Far from any assumptions or conclusions, attention was so focused on *what was actually seen* in all these specific observations that in none of the often-repeated and modified experiments was it ever reported that identity was perceived and yet, at the same time, there was uncertainty or doubt about whether one had also seen motion. Even with nonoptimal conditions, while the object might have appeared identical, it was never reported that it was doubtful whether motion had been seen or that it definitely had not been seen. Very often the opposite was the case, motion was seen, but the identity $a = b$ was either doubtful or entirely absent. Moreover, the cases where motion was perceived with or without identity of *a* and *b* did not arise randomly, such that sometimes both "illusions" occurred and at other times only one of them (strangely, here, only motion by itself). Rather, the impression of motion *without* identity occurred above all at a specific stage, with *t* set slightly smaller than the optimal value (see §11).

§7. Are there qualitatively distinct impressions between that of optimal motion from *a* to *b* and either simultaneity or succession?

Especially, what is *given* in the transition zones that lie between the time intervals of these three distinct stages?

If one were simply to deduce the answer from the existing theories, it appears certain that here, in the region between the principal stages, there should be nothing except perhaps a deterioration or vagueness about the [p. 191] impressions. Whether one is dealing with still or moving strips became less certain, less distinct, and less compelling, until clear motion finally arose at the transition to the optimal stage, or the extreme stages produced a convincing, clear impression of two stationary objects, either simultaneous or successive.

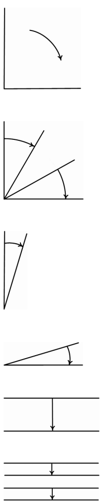
More precise observation of the development during the transition from the optimal stage to either simultaneity or succession, and vice versa, includes impressions of *a b* in *t* intervals that lie between the optimal stage on the one hand and the extreme stages on the other. Such observations with single successive exposure and stepwise decrease or increase in *t* produced impressions of a qualitatively specific kind: most significantly, the phenomenon of *partial motion* [*movement of one or more parts—Tr.*].

These specific phenomena occurred spontaneously for all observers, even inexperienced ones, who participated in experiments of this sort. For some, such judgments as "worse motion," "not so nice motion," "hard to describe," "not as good motion as earlier," predominated initially. This is probably the reason why, despite the diverse stroboscopic investigations in the literature, and despite isolated findings,[48] these phenomena have not received the attention they deserve. From the outset all interest is focused on the phenomena of the three distinct principal stages. Intermediate phenomena have been interpreted as "worse" modes of

48. Cf. Fischer, *Philosophische Studien* 3, p. 132.

appearance, and initially that is what happened here with the curious and initially hard-to-describe qualities of these intermediate phenomena. But even those observers who did not see anything specific at first soon reported in further observations "it's not as continuous[49] a motion, more twitchy," "there's a particular type of motion there, with a twitch," "the motion has a sort of two-stroke to it," "it's not a unitary motion"; and what was seen was soon thoroughly described in more specific terms, of the kind obtained promptly at the first viewing from other observers.

[p. 192] schematically:



The typical form of dual partial motion appeared as follows: For instance, in the angle experiment, with *a* as the vertical line and *b* horizontal, at the optimal stage the vertical rotated to the horizontal position. With a shorter *t*, intermediate between the optimal and the simultaneous stage, dual partial motion occurred, two lines, each of which made its own, smaller partial motion. For example, one sees a vertical line (*a*), which rotates about 30° to the right, and another (*b*), which exhibits a motion from about 30° above the horizontal to a horizontal position.

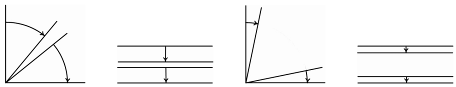
Or, in the parallel arrangement (figure XV, p. 89), with *a* being the upper horizontal line and *b* the lower, where the optimal stage showed motion of one line from the upper position to the lower, now [*using the intermediate t—Tr.*], each of the two lines makes a small motion of its own. The upper line clearly moves down a bit, and the lower one starts a bit higher than its final position and moves down into it.

There is no need to elaborate on this for all the many different stimulus arrangements used. The two objects always displayed the corresponding dual partial motions, each clearly with individual motion, *a* moving some distance in the direction of *b*, and *b* starting from a location a bit in the direction toward *a* [*and towards its end position—Tr.*]. The direction of the partial motions is uniquely determined by the succession *a*, *b*.

Thus, here *φ* turned out to be dual, pertaining separately to each of *a* and *b*.

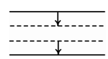
Different magnitudes of partial motion were also observed, from those that covered nearly half the field of separation to small ones that covered hardly any, for example:

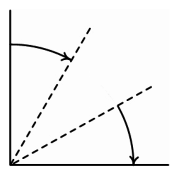
49. Cf. Linke, *Psychologische Studien* 3, p. 522.



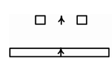
If *t* was shortened in small steps from the optimal to the simultaneous stage (or, conversely, lengthened from the simultaneous to the optimal [p. 193] one), partial motion of progressively smaller and smaller (or larger and larger) magnitude was often[50] observed. If the motion of *a* was at first almost to the middle of the distance *a b*, and the motion of *b* went from just beyond the middle to its final position, gradual reduction of *t* toward the simultaneous stage led to each partial motion taking up less of the movement space, for instance, first a quarter of the distance, then even less. The motions of *a* and *b* got smaller and smaller until nothing more than a "twitch" was left, the "germ of a motion" of *a* or, respectively, an "arrival" of *b*, and ended up as a completely stationary simultaneity of the two objects. Analogously, in increasing *t* from simultaneous to the optimal stage, often the partial motions grew larger and larger, until they fused into a unitary whole motion.

Similar observations were made with yet other stimulus configurations.





Dual partial motion was also observed in cases with objects having different colors or shapes. For instance, in the parallel stimulus arrangement in figure XV (p. 89), with *a,* a red horizontal strip of about 6 cm on top, and *b,* a blue or green strip 4 cm below, the red strip exhibited a short downward motion from its starting position, while the blue strip moved a short distance downward to its end position. Analogously, with the reverse succession (exposure of *b* and then *a*), the blue strip exhibited an upward motion of about 1 cm, while the red one moved upward from about 1 cm below its final position. Similarly with other arrangements, the angle experiment, for instance, with a red vertical *a* and a blue horizontal *b*, the red rotated about 30° into the angular space from the vertical position and the blue from about 30° off the horizontal to the fully horizontal.



Likewise with a difference in shape: For instance, the long straight strip shown here as *a* exhibited a bit of an upward motion, while the two squares (*b*) moved upward into their final position; and similarly when both the color and shape were different.

50. For other results, see pp. 30, 32, and 48.

Dual partial motion also resulted in the same way in cases where the [p. 194] stimulus strips were of different color and too widely spaced for achieving optimal whole motion.[51]

Dual partial motion was reported even during continuous observation in the transition zone between the principal stages or during serial exposure *a b a b a b* with selected intermediate *t* values (note the complicating circumstances below). Here, two lines were seen, each continually making small movements: in the parallel arrangement, for instance, two lines, each of which moved up and down by itself. In another arrangement with an obtuse angle in one exposure field and a longer, more acute angle in the other, their vertices pointing upward and superimposed at the top, the phenomenon described was "two that move up and down, like a person doing jumping jacks." The progression from simultaneity to optimal motion as *t* increased was often[52] characterized as "two at the same time, stationary; then both move, more and more; they latch onto each other—and now there is only one, moving back and forth the whole way."

The factor of *set* [*Einstellung*], primarily in the ranges in between the three main stages, plays a role that is quantifiable to some extent. Here, "set" must be understood in a purely technical sense, referring to the determining effect of earlier φ impressions on later ones [*priming—Tr.*].

For instance, repeated exposure to optimal motion of certain successively presented stimulus objects, with pauses of 1 second to 1 minute or [p. 195] more between single *a b* exposures, facilitated whole motion in subsequent exposures, using a slightly shorter *t* that would otherwise produce only partial motion.

As expected, it does therefore make a difference whether, in observing transitions between stages, one descends from the simultaneous stage by increasing *t* or, conversely, rises from the optimal stage by decreasing it.[53]

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51. To mention still another subjective temporal aspect: Partial motions of *a* and *b* usually appear as nearly successive (first *a* moved, then *b*), but sometimes as nearly simultaneous, resulting in partial simultaneity. Such a temporal aspect was also observable fully within the range of simultaneity: the occurrence of *a* and *b* in the range of simultaneity need not always be perfectly simultaneous. True, *a* and *b* are there together, but *a* is a trifle earlier, *b* a bit later. In certain cases, directing attention to these temporal aspects had the effect that when with partial simultaneity the impression arose that *a* disappeared earlier than *b*, this led to motion emerging more quickly and eventually to whole motion with no transition through partial motions. Cf. however §15:2.

52. On the other hand, cf. p. 46.

53. Cf. Wundt, *Physiologische Psychologie*, Vol. 2, 5th edition, 1902, p. 582.

In the latter case, as a rule, the range of optimal *t* for whole motion is generally extended somewhat in the direction of the changes in *t* along the *t*-parameter, and likewise in the other direction, with stepwise increase in *t* from the optimal motion stage to the successive stage, rather than decreasing from the successive to the optimal stage.

The range of *t*-variation for optimal motion stretches further in both directions when starting from the optimal motion stage and progressing incrementally in either direction [*hysteresis*—*Tr.*]. Especially with a strong set [*Einstellung*] and using very small steps in changing *t*, the range of the optimal motion stage increases considerably: In order to achieve the final stages of pure simultaneity or succession, one must use quite large decrements or increments of *t*, even relative to exposures without such set, while conversely, in starting from the extreme stages, the range of the optimal motion stage appears considerably more restricted.

In the range below the optimal motion stage, lengthening *t* toward the successive stage produces the impression of slower, less energetic motion. For *t*-values going from the successive stage that still yield quiet succession or partial motion, going from the optimal stage in small steps of *t* often produces persistence of optimal identical slowed down motion, reported as "eminently clear, colossally slow," "lazy," "sluggish" motion (cf. table I, p. 17).

A similar effect of set [*Einstellung*] as with temporal factors occurs with the size of the spatial separation between the objects. Thus it was found in the experiment in §14 (p. 50; see figure XXV, p. 91) that, while a smaller separation is usually more favorable[54] for inducing the impres-
[p. 196] sion of motion, by contrast certain effects of set achieve motion at a larger separation.

Finally, general set [*allgemeine Einstellung*] and repeated exposure to illusory motion stimuli facilitated later exposures so that generally motion was seen at greater separations or across larger angles than without prior exposure. Therefore it became useful in the experiments with Observer II to begin with smaller separations in the linear stimulus, and analogously to experiment initially with smaller rotational orientations in the angle experiment, before proceeding with angles of 90° degrees. Thus both set and practice turned out to have an effect. There were also initial individual differences among subjects with respect to separations as well as times. Observer II did not always attain the impression of optimal motion at the beginning of the experiments, or only at smaller

54. Cf., for instance, Fischer, op. cit., p. 147, 149; Linke, op. cit., p. 494.

separations and in a narrower range of *t*. With the other observers, such shorter separations at the beginning of the experiment were not needed.

Findings for continuous observation corresponded with those for set [*Einstellung*]. If one observes individual exposures of *a b* not with longer pauses, but continuously, while varying *t* in small increments, then the range of the optimal stage is somewhat enlarged when moving away from it [*towards the simultaneous and successive stages—Tr.*]. Continuous observation with a constant *t* close to the motion stage generally favors the seeing of motion. The motion gets better, more compelling, and clearer, and the impression of motion more intense. Also, with continuous observation, an initial impression of partial motion can become an impression of optimal motion. Continuous observation in the intermediate range, bordering on either the simultaneous or the successive stage, can exert an influence on simultaneity or succession [*in the direction of more perceived unified motion and less fragmented partial motion—Tr.*]. Correspondingly, in transition experiments with continuous observation, there often resulted no partial motion, or no stable partial motion stage. In this, other complicating factors come into play; for example, continuous
[p. 197] observation can lead to a sudden switching [*Umklappen*] of attention and focus. (Cf. the special influences noted on pp. 40 and 43.)

Since special effects occur with continuous observation, it is also appropriate to include experiments with single exposures of *a b* instead of continuous observation of serial exposures.[55] The results described here were obtained initially with such single exposures, with larger rest intervals of 2 or 3 minutes or more between individual experiments and with appropriate variations in the presentation sequence.

On the other hand, continuous observation in serial exposure of *a b a b a b . . .* with a constant *t* is favorable for demonstration and comfortable observation in stable stages where these special effects do not come into play so much. Under these conditions one can examine the back-and-forth motion at leisure.

§8. In the range just below the extreme stage of simultaneity, still further special phenomena frequently appeared, no longer as events in the

55. Even cleaner than serial exposure, in the sense of the sequence *a t b t a t b . . .* with symmetrical arrangement of the slits in the tachistoscope, the repeated exposure of *a t b T a t b*, where *T*, the interval between *b* and *a*, is relatively large, so that only repeated sequences of *a b* appear, but not also interleaved with *b a* sequences, equally engendering impressions of motion. But effects of set appear here as well; cf. §14.

space between the two objects *a* and *b*, but affecting only the objects themselves: "pulsing," "interior motion," flickering, and brightness events inside the objects.

When motion was perceived, the two objects[56] were generally stable (provided sufficient exposure times $\alpha\ \beta$) and clearly present as simultaneous wholes. In contrast with that, flickering, brightness instability, and brightness fluctuation showed up within the objects. Perhaps one or both strips were no longer seen as a simultaneous whole, when, for instance, the upper end was there somewhat sooner, inducing a shift in brightness toward the bottom; or the middle of the strip was there before the ends, whether within the existing contour or in the emergence of the Gestalt of [p. 198] the strip itself. Occasionally, there was nothing more than an indefinable flickering in the strip, or *internal* motion in a certain direction (for instance, in the vertical line of the angle arrangement as a vertical internal motion or emerging ↓) or, in serial exposure, a "beating" or "bumping" of the line that under continuous observation grew into an intense up-and-down (↓↑↓), a successive back-and-forth, "stomping"; and likewise with the horizontal: →, ←, ↔.

To some extent, the well-known phenomena in recognition experiments[57] obtained with very short tachistoscopic exposure times are relevant here: the partial lack of clarity, the successive emergence of particular parts, and the "explosion" outward from a particular location, when turning off a stimulus.[58] So are the general postexposure observations[59] in which surfaces of different brightness or color were rapidly exposed at short time intervals in the same location,[60] resembling the way in which, here, the white or color of the object follows the black of the background, only to be replaced by it again. All this is consistent with the finding that still further reduction of the times α, β, and *t* often led to a completely simultaneous stage in which there was nothing left of these phenomena; when presented with very brief exposures of $\alpha\ \beta$, the objects appeared stationary and with diminished brightness.

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56. In the optimal stage, a single strip; in the sequence $\varphi\ a\ b$ (cf. p. 56), *the* strip.

57. Cf. the pertinent literature (see Schumann, Sammelreferat, Kongress für experimentelle Psychologie, I, **34**; II, 153f.).

58. Ibid. II, p. 164.

59. Dodge, op. cit. p. 335f.; in a sense, even with successive brightness and color mixing, although these do not come into play in the form issues discussed here except for the "flicker."

60. Cf. also Stigler, Über den chromophotischen Kontrast, *Pflügers Archiv*, 1910.

Dodge's experiments along these lines first began to explore these post-exposure phenomena in our sense of the word. Particularly important here is the question of what brings about exactly this or that percept of defective surface structuring [*Flächengestaltung*], or this or that kind of disappearance and appearance, depending on the direction in which attention is distributed or focused (cf. §11); for that also seems to have a qualitative influence.

[p. 199] What is of interest here in regard to "interior motion" is that it strikes one not only or not directly as a spatiotemporal distribution of brightness, or as successively becoming distinct or emergence of object parts, but rather as interior *motion*, such as something bumping up and down. In this regard it resembles experiments in which two objects with no space between them or partially overlapping (see figure XVIb c d, p. 90) produced motion in the direction of succession or (as in figure XVIc, p. 90) motion with "growth" or "expansion" of the object.

§9. In the range between the principal stages, there emerged yet another special kind of phenomenon, the effective factors of which were experimentally identified through further experimentation. However, its quality is theoretically significant in itself.

From Thesis I (p. 23) it follows that φ is an entity which, by combining *a* and *b* (at a higher level), must [also] affect them phenomenally.

But φ can be an entity that involves only one of the two objects, *a OR b*. The other remains stationary, totally untouched. Its appearance is simply perceived, untouched by φ.

For instance, in the angle arrangement, the vertical line *a* appears, remaining perfectly still, while *b* moves on its own, rotating out from about 45° to the horizontal position, or (cf. §16) from about 45° onward there appears a motion into the horizontal position of *b*. Here is an apparent motion that does not originate phenomenally from *a*, does not involve *a*, and does not affect *a* or the vicinity of *a*.

In multiple variations with respect to the range of motion, motion to the final position is perceived from the region next to *a*, or from about 45°, 30°, or 15°, all the way down to the final position [*eliciting reports such as—Tr.*]: *b* has "a minimal motion," "gives a small twitch as it lies down," "snaps down into its position from above." Meanwhile *a* has remained untouched, stock still.

It is not only *b* that can exhibit this *solitary motion*. There are also opposite cases in which it is *a* that moves, again depending on the range
[p. 200] of motion to the extreme position: *a* exhibits an initial twitch, an onset, a tendency toward motion, while *b* is perceived as perfectly still.

And all this occurs analogously with the exposure sequence reversed (*b a*); when *a* and *b* are arranged in parallel; and with a variety of other stimulus arrangements. Here too, the direction of motion is always unequivocally determined by the succession *a b*.

Both of these phenomena—solitary motion of *a* or *b*—were achieved in a special way in separate experiments (see §11).

Analogously to the dual partial motions above (p. 29), such motion phenomena involving only one of the two objects, without a phenomenal coupling with the other, also emerged especially when using objects of two different colors or shapes, and with increased separation between the objects, when fully optimal motion did not arise.

Similarly to the way dual partial motion borders on dual whole motion when the sum of the partial motions gets large and the two partial motions touch each other, solitary motion also borders on a kind of dual whole motion. "A line moves over from the initial position, rotates, and at the end another line lay there quietly," or "The other line already lay there before the first line reached it." And conversely, "Very close to the first one that remains stationary, the second one moves through the field into its final position" (cf. §11, p. 42, where different colors were used).

Solitary motion also showed up during continuous observation of serial exposures with the tachistoscope (*a t b t a t b t a*). For instance, in the arrangement of two parallel horizontal strips, one a certain distance above the other: "The upper one is dancing, always going a little up and down; the other, lower one is stationary;" or conversely, the lower one "danced," in contrast to dual partial motion in which "both are dancing." In solitary motion of this kind, the motion was bound to the one object; in other cases, the upper strip exhibited a small motion downward, the lower one upward.

There were also solitary motions, especially with shortened exposure [p. 201] time, in which the *other* object, which stayed motionless in place, exhibited a kind of internal motion (see §8). In the angle experiment, for instance, *a* (the vertical line) exhibited rotation in the range of 30°; the horizontal line *b*, internal motion from right to left or the reverse; or from the middle toward the ends. Incidentally, this indirectly confirms what the above phenomena revealed with certainty, namely, that in the case of solitary motion, it is not just a simple matter of not knowing whether the other stimulus object had moved nor how it might have been there.

§10. Motion in the absence of a perceived relation to the corresponding stimulus *a* (or *b*, respectively) occurred also with the introduction of a *third* object (*c*) in one of the two exposure fields, preferably the second.

The introduction of a third object is properly done only after the desired phenomenal stage has been established with exposure of *a b*, without *c*. One controls for possible effects of surprise or of capturing of attention with counterexperiments (p. 38) using naïve observers (cf. p. 46), by varying the temporal sequence, the location of fixation, the focus of attention (cf. §11), and preexposure of one or the other of the exposure fields.

One can choose *c* to produce simply the effects of two simultaneous successive exposures *a* : *b*, *a* : *c* (cf. here for comparison p. 55), for instance, by arranging two lines, *b* and *c*, to the right and left of a central line *a*. These kinds of experiments, in various arrangements, exhibited not only the phenomena discussed in §7, §9, and §13, but also phenomena that corresponded with the results from two successive objects.

One can make *c* a smaller object, different in color or shape, and locate it anywhere in the exposure field: in the field of the motion *a b* (the separation field), or at its periphery, or displaced to the side of the field of motion, or completely outside it, or in front of *a*, or behind *b* (see figures XVIII, XIXa, and XIXb on p. 90).

Especially with the gaze and attention directed at *c*, this resulted in the experience of a stationary *c* while the motion *a b* remained undisturbed. [p. 202] But often there was a small partial motion of *c,* with the *a b* motion remaining undisturbed, an event phenomenally involving not *a c*, but just *c* in itself. *c* is not coupled phenomenally with *a*: The motion of *a b* is there, perhaps even optimal motion with *a* and *b* closely coupled, and in addition there is a small motion of *c* as well.

In these experiments there were occasionally solitary motions of *c* that indicated a dynamic influence from *φ*, rather than from *a;* that is, *c* displayed motion not in the direction from *a c*, but, for instance, a tiny outward twitch away from the field of motion *a b*.

These observations raised the question: Might not a *φ* process have certain effects on a neighboring successive exposure? [*To find out, —Tr.*] two parallel strips with a certain separation, *a* above and *b* below, were presented under conditions between optimal motion and the simultaneous stage, so as to create "bad motion" or "dual motion." Then onto each of the two exposure fields, one leg of an angle, *c* or *d*, opening toward *a b* (see figure XXIV, p. 91), was added, such that *a* and *c* appeared in the first exposure field, *b* and *d* in the second. *c d,* which favored motion through the smaller separation between the two legs and their angular arrangement (cf. p. 43) produced optimal apparent motion under conditions where *a b* produced only bad motion.

In this series of experiments, attention was focused on the middle of the field, between the parallel strips *a* and *b*, not only in the *a b* exposure, but also in the *a c* – *b d* exposure.

When *a b* with exposure of the parallel strips alone exhibited bad motion (such as partial motion or dual motion), the full *a c* – *b d* exposure generally produced optimal motion between *a b* immediately. This occurred even in several cases where exposure of *a b* alone exhibited no or almost no motion.

Note: Thus, in a sense, a "dead" interval was transformed into a "living" one. By analogy with terms recently used in the psychology of music, I here call *a φ b* a "living" interval, and *a b* without *φ* (or without optimal *φ*) a dead one. In these terms, the experiment shows that the adjacency of the "living" interval *c φ d* can [p. 203] transform the dead interval, whose *t* interval was insufficient to achieve *φ* by itself, into a "living" interval, or rather from an incomplete to a complete interval. Without any bias concerning the *difference* in what is presented, one can think of this musical example: *C*(¼), *E*(¼), *D*(½); *F*(¼), *A*(¼), *G*(½) presents the same motif twice. Within the motifs, the intervals are perceived as "living": The motifs consist of the unitary motion of a major third upward and then a major second downward. In listening naïvely to the melody, though, the interval *D F*, the last note of the first motif and the first note of the repeated motif, is presented phenomenally not so much as a transition as it is a "living" interval, a "living" musical major third.

In the case of an accompaniment, specifically *D F* through *F A* in the bass, the interval *D F* easily strikes one as a "living" interval, perhaps even more than was the case with the interval *C E* or *F A* in the motifs. In general, "dead" intervals can under certain circumstances become "living" due to neighboring "living" intervals, even when they are not made prominent so directly as by the bass pauses in the example above and when the interpretation of the musical third does not suggest a simultaneous sixth.

These comments are intended only to illustrate the analogy, in music, to the expressions "living" and "dead" interval and the transformation of one into the other; investigating the psychological nature of musical intervals and the "living" interval event, with its generation and laws, is a task all of its own.

The integration of *a* with *c* and *b* with *d* (that is, the unit *a c* first, then *b d*) could be taken to favor the impression of motion [*by neighboring exposures—Tr.*], despite a spatial separation between *a* and *c* and between *b* and *d*; and despite the same effect when using, for instance, two circles as *a* and *b*, with lines as *c* and *d*. In some cases this does indeed correspond with the observation. By contrast, in other cases there was no integration at all, at least phenomenally; and the phenomenal is what raised this inquiry in the first place. Indeed, often facilitation of *a b* occurred even though the observer was hardly aware of *c d* (see §14), having noticed *c d* only dimly, or not at all. Consciously, it was only that "something else was there" or "something else was happening; exactly what is hard to say."

Further, one might assume that the effect of the *c d* process on *a b* motion can be traced merely to reduced attention to *a b*. Attention is partially absorbed by the presence of *c d*, or of the *c d* process, and that facilitates the emergence of φ for *a b*. But what argues against this view is the observation that a reduction of attention does not inevitably improve [p. 204] the impression of φ motion (cf. §11). Furthermore, in direct counter-experiments when attention was equally or more absorbed due to ancillary objects other than *a b*, that never improved *a b* motion. This included *c d* arrangements that did not give rise to *c* φ *d*, such as wider angles or similarly parallel arrangements slanted with respect to *a b*; or the introduction of more than four objects; or employing *c* φ *d* (or additional objects *e* and *f*) in another arrangement, such as at the same distance from *a b* but with the vertex pointing the other way. Under these circumstances *a b* was indeed somewhat less clearly there but did not produce better motion than when exposed alone.

§11. One can set the task of fixating on a particular point during the exposures and, further, to focus attention on a particular location in the exposure field:[61] The center of attention is now directed to a particular spot, and the phenomena at this location are attended to from the beginning.

This can be arranged by directing fixation and the center of attention to one and the same location or, with some practice, by aiming one's fixation at one location and the center of attention at a different one.[62] In the angle experiment, in the first case fixation might be directed to the location of the vertex, while at the same time attention is concentrated on phenomena occuring in the same region. In the second case fixation could be on the vertex, but with attention aimed elsewhere, such as further to the right [of the vertex] in the angular space, or on the upper end of the slanted line. The instructions can make this task clear from the outset: "Fixate on the vertex, but pay special attention to what is there and what is happening at the location of the upper end of the slanted line (several centimeters above the vertex), so that you can report it exactly." Later: "Concentrate your attention continuously and firmly on this place" (cf. p. 73).

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61. Cf. footnote 25.

62. Gaze fixation in itself requires careful, deliberate vigilance, but here too it was easily possible to direct attention to a different place in the visual field, even at peripheral locations.

[p. 205] In this case, the entire field under consideration was not so large that the remaining relevant locations, wholly peripheral to attention, were no longer clearly within awareness (cf. point 2 on p. 41).

In the tachistoscopic experiments, at first one of the exposure fields with one of the two objects was exposed once, twice, or three times by itself, until the observer established the fixation point and the focus of attention at that particular location in the exposure field. These preexposures occurred at intervals of one rotation of the tachistoscopic wheel each (or rather, precisely, the 360° of the wheel circumference minus the angular extent of the exposures; see p. 16). Thus they occurred at intervals of about a second or somewhat longer. The observers indicated when they succeeded in fixating and attending to the designated locations. Thereupon, immediately after the last preexposure, the command "Now" was used to announce that the entire exposure would follow after one more turn of the wheel.

In continuous observation of serial exposures (*a t b T a t b T a*), the point of fixation and the direction of attention were also varied *during* these observations.

A certain amount of practice is required for these experiments. It started with easier tasks and then incrementally proceeded to more difficult ones. With some exercise, placement of attention was soon easily achieved: first, placement on locations readily distinguishable by parts of objects or other designated marks; and then also, without special help, on a particular region of the exposure field. In the former case, for instance, initially a location common to both objects (the vertex) was used, or a third object *c* that displayed no motion itself (see §10). After some practice, which was first undertaken with serial exposures, observers found it easy to direct attention to particular regions of the exposure field without such assistance. As an intermediate task, one could also use a background that was not completely homogeneous, which facilitated spatial set [*Einstellung*].

The experiments usually progressed such that an arrangement with particular stimulus configurations and particular exposure conditions [p. 206] presented the impression of a stage, such as the stage just beyond optimal motion and thus exhibiting dual, "worse" unitary motion or larger partial motion, first perceived with diffuse attention and no particular instruction for a particular placement of attention, and then with instructions for specific spatial attention.

The same regimen was followed in reverse, and in retesting with changes in the placement of attention, during continuous observation of multiple successive exposures, and with other variations.

Such placements of attention and fixation had effects on certain aspects of the impressions of motion that arose, especially in the transition zones between the three main stages. In truly optimal motion, when the separation between the objects was not too great, it was generally impossible significantly to influence, degrade, change, or eliminate the impression of optimal motion by any spatial variation in the focus of attention; likewise in the extreme stages of the impressions of simultaneity and of succession. However, in the region *between* the stage of fully optimal motion and that of complete simultaneity or succession, focus of attention played a fundamental role: Certain directions of attention can qualitatively improve the impression of motion while others can degrade and even eliminate it.

One might initially assume that the impression of motion, conceived as an illusion, must be compromised by directing such focal attention, which favors detailed observation, specifically at the most critical location of the illusion.

This is not so. It turned out, with the most varied procedures, and with different stimulus arrangements, that focusing the attention on the space separating the objects (for instance, in the angle experiment, into the middle of the angle), and thus right at the central location of the "illusion," did not degrade[63] the impression of motion, but indeed improved it. This occurred, for instance, when presenting a stage beyond the optimal, which produced degraded motion such as dual partial motion in cases with no instructions or with diffuse attention or with other special in-
[p. 207] structions (see p. 41). In this case, focusing the attention on the space between the objects very often produced excellent motion immediately, identical to that observed under optimal conditions; or similarly, whole motion arose instead of small partial motions. In this, focal attention remained concentrated on this location during the entire exposure.[64]

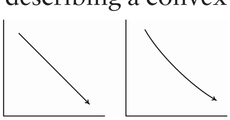
Focusing attention at the location of the end of *a* or *b* (in the angle experiment, at the free ends away from the vertex) showed:

1. The effect was adverse, degrading the emerging impression of motion, not in the sense that the experience was unclear or uncertain, but rather if a certain impression of motion was present with diffuse attention, or with observation in the absence of a specific instruction, or when attention was directed to the space between the objects, then focusing attention on the end of an object generally resulted in the impression of a stage far

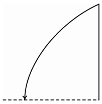
63. Cf. p. 44.

64. Cf. pp. 72–73.

removed from the optimal. The motion was "worse," more dual, or instead of unitary motion there was only partial motion or no motion at all.
2. In a whole series of cases, though, it was found that partial motion of one of the two objects appeared (solitary motion) while the other remained stationary, untouched. However, it was not the less-attended object that performed partial motion, while the attended object remained stationary, but rather it appeared that focal attention directed at the end of *a* produced partial motion of *a*; thus, *a* underwent motion while *b* remained perfectly stationary, or perhaps displayed "interior motion."
3. In such cases, focusing attention in the motion field, in the space between the objects, again produced good motion immediately. This generated the same or even a better impression of motion than observation without specific focus of attention. In the angle experiment, this occurred equally with attention focused on the space between the legs as with attention focused on the vertex.
4. Similar results were obtained in certain cases that used alterations of
[p. 208] the objects (with a naïve observer), rather than instructions to focus attention. For instance, figure XVIIb (p. 90; a new third object inserted at the end of the slanted strip *b*) produced this effect: "the horizontal is stationary, the slanted strip ('colossally long!' or 'with a new piece') has turned upward a bit in its position." And, with an arrangement of two rotational strips oriented at right angles (resulting in whole motion), "the vertical column exhibits a small rotation" (solitary motion) when it was replaced by a column of small squares (with gaps in between).
5. Focusing attention at the middle of one leg in the angle experiment turned out to be better for the impression of motion than focusing it at the outer end of the strip. If focusing attention on the middle of the leg had no detrimental effect on the impression of motion, shifting attention to the end of the leg degraded it. Conversely, the impression of motion that resulted from focus on the end was somewhat improved by moving the focus to the middle. Generally it appeared that, the closer to the vertex, and thus the closer to the other object, the focus of attention was directed, the stronger the beneficial influence on the impression of motion.
6. These placements of attention on the end of one leg occasionally also degraded the motion impression in the sense of flattening the motion curve. What is meant here by the motion curve is not the tracing of a subjectively completed borderline, but the outline of the actual field of motion. The path of the perceived rotation, instead of describing a convex arc, followed a flatter, straighter, even concave route.



Occasionally this was observed also in experiments with naïve subjects, not by directing focal attention, but with variations in the objects. For instance, when the vertical strip in the angle experiment was replaced with the column of little squares, the motion path became flatter or even concave.

[p. 209] Yet a different curve occurred when the horizontal strip too was replaced with a row of small squares (see figure XVIIa, p. 90). The vertical strip *a*, with the horizontal strip *b*, each composed of four squares in a row, produced good full rotation through 90°. When hereafter attention was directed at the upper third of the vertical, rotation continued, but only to the third horizontal square.  With successive reductions of *t*, this changed to ever-narrower rotation that encompassed only the second, and eventually the first of the squares.

7. It was mentioned in §7 how the phenomenon of partial motion emerged when using objects of different colors; this also led to solitary motion (§9). As with the other experimental arrangements, the focus of attention was also varied here.

A red horizontal strip (for instance, 1.5 × 7 cm) was used for *a*, with a similar blue or green or white strip for *b*, presented 5 cm lower in a perceptual stage that produced an impression just beyond optimal motion (see §6 and §7); likewise with the angle arrangement and with both parallel strips slanted. Attention was concentrated on one of the two strips, with or without the help of preexposures of one strip alone, or during continuous observation of serial exposures. Generally the point of fixation and the focus of attention fell together, although different locations for both were also used. This was simplest in the angle arrangement, with fixation on the vertex but attention focused on one or the other of the strips.

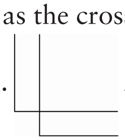
Usually it was only the strip to which attention was directed that exhibited motion; the other was stationary, unaffected by the motion. For instance, when attention in the above experiment was focused on the lower blue strip, "the red one lay there quietly; from a location slightly below it, the blue one clearly and distinctly moved down to its position."

[p. 210] And conversely, with attention focused on the red strip: "The red one moved downward a bit, while the blue one remained calmly in its position below."

Here again (cf. §9) a varying amount of motion appeared. If at first, without instructions, a higher stage had resulted, such as a smaller dual motion, then with these instructions there was occasionally solitary motion of the strip in question to a smaller extent; and similarly with reduction of the interval *t* with attention remaining in place. If a stage was presented that was very close to the optimal, this eventually resulted in corresponding solitary motion over almost the whole field, close to or all the way to the other stationary object. For instance, “The red one moved from its starting position almost down to the blue one, which lay there quietly,” and the converse, “The red one remained stationary, while from immediately below it, the blue one moved down to its final position.” Similar results were obtained with other stimulus arrangements and also through the use of differently shaped objects, such as an arc segment as *a* and two squares as *b*.

In this way either of two different colored objects could be made to appear predictably as the bearer of an impression of motion.

In all such experiments, it is naturally important to pay proper attention to the exposure conditions chosen and to the normal motion impressions with which the effects of focal attention are compared. For instance, if one works with truly optimal exposure conditions, focusing the attention need not result in any effects, and similarly with strong *set* [*Einstellung*] (see p. 30, among others). Therefore, it is necessary to take the sequencing of experiments into account because of the influence of qualitative aftereffects (see p. 50). Moreover, the concentration of the focus of attention is not always equally strong. Due to the effects of set and variable attention during extended observation, it is desirable to test all conditions first with single exposures, including sufficient practice for the observers in experiments that require directing the spatial focus of attention.

It should also be borne in mind that directing attention on some particular location or region is not the same as, for instance, extracting or [p. 211] subjectively emphasizing the *shape* of the gap or the *contour* of the object. In the case of plainly optimal motion, it often seems simply impossible perceptually to emphasize a contour (such as the inner triangle of the angle arrangement, or the shape of the angular surface, or the inner rectangle of the parallel arrangement) or the outer contours of the rotational vertex (such as the cross-over at the vertex, or the outermost right angle in the vertex).  Aside from this, the contour factor (that is, perceptually singling out the figures just mentioned or the contours of an object) seems to work *against* the impression of motion, in the sense that it degrades and eventually eliminates entirely that impression, thereby transforming it from a percept beyond optimal motion to a percept of being stationary. Similarly, directing attention to the surface encompassed by the rotating strip (with the vertex removed), that is, trying to get a grip on and emphasizing the distance between the ends of the two legs, also degrades the motion. This is probably related to the observation that presenting an angle of two lines connected at the vertex generally yields better motion than presenting the same lines without the vertex or vertex region.

Finally, the facilitation of the motion impression by focusing attention on the angular space was found to be different in experiments in which there were two possible ways for motion to emerge. Thus, for instance, in the arrangement of a shorter vertical line *a* on the middle of a longer horizontal line *b* (figure XXV, p. 91), focusing attention on the angular space on the left favored rotation to the left, while attention to the right favored rotation to the right. Thus, motion occurred predominantly in the angular space which was attended, even if only one motion was perceived, or [in the case of two motions] one motion was stronger than the other (cf. §14 and §16). Similar effects were observed with various angular settings of *a*, and in other stimulus arrangements.

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Two possible interpretations should be mentioned here: First, one might seek to explain the facilitating effect of directing attention on the [p. 212] angular space by saying that both vertex lines in such a case were viewed more peripherally and by assuming that distance of the objects from the center of attention simply enhances illusions of motion. But one must realize that the results of focusing attention on one of the objects strictly contradict this. According to this interpretation, one would expect that the object in peripheral attention would exhibit solitary motion; that focusing attention on the angular space would prove more facilitating for the impression of motion than a peripheral location of attention to the side, above, or below the objects; and, finally, that focusing attention within the angular space between *a* and *b* closer to the vertex would be more favorable than farther from it.

Second, if one wishes to account for the facilitating effect by saying that it is a shift of attention in the same direction as the motion that facilitates the appearance of motion, then one should note that an observable shift of attention, in the sense used here of spatially focused concentration, did not necessarily occur. Rather, attention focused on the place to which it was directed appeared to remain there steadily. (Cf. p. 72.)

The experimental results thus seem to lead much more to this conclusion: The emergence of φ is typically facilitated at the location where extra attention is focused.

§**12.** I said in §5: First *a* is seen, and finally *b*; in between, the motion from *a* to *b* was seen. That corresponded in simplified form with the formulation on page 34: The perceptions of *a* and *b* are there, and in between them arises φ. Is this always the case, or are there perhaps cases where the φ character of the passage across, of the motion, also incorporates completely one of the two "foundational" *givens*? Just as the passage across, the motion, is something different (cf. §16) from a sequential occurrence in different positions, so also is the statement "*a* is there in its initial location and then moves" different from "*a* itself was never there as an initial *position*."[65] *a* was perceived not as *being* at a location, but as already [p. 213] *caught up in motion* right from the start; not as "being at a location," but as "beginning the motion"; not as something in some "position," but as something in motion. The contrast in this distinction between seeing something in motion and perceiving an object "in a location" is no exaggeration of subtle differences. Rather, the two are grossly distinct in perceptual experience. This has theoretical relevance in that, in the former case, one "foundational" element is no longer perceived in the normal way, as an object "found in a particular location," but already as something in progress, moving: It is not *a* φ *b* that is experienced, but rather *a* already incorporated in φ: $(a\varphi)$ *b* or, analogously, *a* (φb).

These kinds of impressions were often reported. They can be deliberately produced by reducing the exposure time for one stimulus relative to the other.

There are also cases—and here we see the distinction most simply—in which the φ motion incorporates both objects: (φ_{ab}).

When experimenting with continuous observation in the serial exposure *ababab* . . . ,[66] where the motion occurs from *a* to *b* and returning from *b* to *a*, continuously back and forth, it was found that when exposure times for *a b* were not too long, it is no longer that alternately the *a* location is there at one moment, the *b* location at another, and in between the back-and-forth motion (or rotation). Rather, the object moves back and forth without existing at the starting or ending location, the outermost locations, any more than in the motion itself. One cannot say, "I

65. In the precise psychological sense.

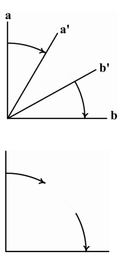
66. In serial exposures of this sort, where it is not a sequence of *a b* exposures with shorter or longer intervals, but *atbtatb* . . . , naturally one must be careful to ensure symmetrical arrangement of the slits in the tachistoscope.

saw it located in this or that place." At the outermost locations it was no less "in motion" than in the middle locations. This experience is distinct from the perception of an object in some specific location; what is seen is not *a*, *b*, and motion, but definitely only something moving.

Conversely, in the transition from the optimal impression of motion to the stage of simultaneity or succession, there sometimes occurred a stage [p. 214] where "positions are perceptually emphasized," as follows: If overall regular back-and-forth was typically seen in the optimal stage, reduction or increase of *t* emphasized the extreme positions, that is, the starting and ending positions stand out as such, often suddenly. Now the motion is from one *location* to another; and soon that motion becomes a higher-stage impression, dual motion, partial motion, or being stationary. This emphasis on the positions (cf. §7 and §11, p. 44) proves to be a factor that works against the impression of motion.[67] For instance, if it emerges under exposure conditions that first produced whole motion or partial motion, that same exposure would now produce smaller partial motion or no motion at all.

This difference between the perceptual emphasis on the end positions and the motion perceived between them involves also the specific phenomena of "snapping into place" and "initial and terminal twitches." "The motion begins with a twitch at *a* and ends with a twitch at the end point; the very first portion of the motion is a strong, abrupt, energetic launch from position *a* and the very last a snapping to a stop at the terminal position."

So, at the extremes, two distinct forms of apparent motion occurred: *a b* with the φ process in between (cf. also §16), and φ_{ab}, so fused that *a* and *b* can no longer be distinguished or perceptually separated from the whole.



Observations of partial motion also occasionally led not directly to appearances of locations, but to something similar. Partial motions in a particular region were distinguished from those that were vague. For instance, in the angle experiment *a* rotated from its vertical position into position a_1 (strictly speaking, somewhere in the vicinity of a_1) and *b* from b_1 into the horizontal position. This contrasts with cases in which rotation from the vertical position (cf. §16) and likewise from the middle region into the horizontal position was vague.

67. This holds for a subjective emphasis on the positions, and likewise for more experimental conditions that produce a particularly sudden emphasis on the positions; so, for instance, very intense, lightning-like stimuli are similarly unfavorable.

[p. 215] **§13.** It is known that in tachistoscopic experiments[68] not everything that is exposed is also seen. In these cases, certain exposed objects, or parts of them, were simply not there for the observer. This fact is noted and discussed in the literature on the psychology of reading, and there too it has been successfully differentiated into distinct stages.[69] Consider the cases of successive exposures here where this phenomenon occurred, particularly the extreme cases where one of the two objects was not at all present, and the observer was convinced that this time—as really happened on several occasions—only one object was exposed.

These occurrences were important for examining qualitative problems. They generally happened in one of these ways:

1. Absolutely nothing of the objects was perceived; cf. §16 (p. 56).
2. One of the two objects was not perceived; cf. §14.
3. Parts or pieces of objects were perceived either not at all or recalled later; cf. §8. For instance, in the angle experiment, at one time the upper portion of the vertical was perceived a bit earlier than the lower; at another, only the upper portion was seen.

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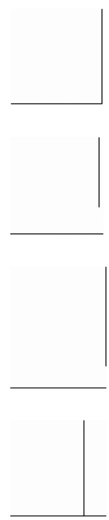
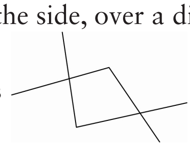
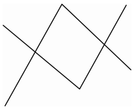
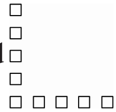
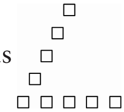


Another phenomenon emerged in definite analogy to individual findings in tachistoscopic recognition experiments:[70] displacement. This emerged only relatively rarely, only for subject I and occasionally for me, and indeed predominantly in continuous observations very close to the simultaneous stage. For instance, with continuous observation of figure XVIa (90°) in the simultaneous stage with very short exposure times, suddenly the portion of the vertical *a* where it touches the horizontal was simply not seen; or the vertical
[p. 216] was perceived in its entirety, but higher, at a distance from the horizontal; or, once, the vertical line was not seen at the end of the horizontal, but to the side, over a different point of the horizontal. Similarly, this  was suddenly seen

68. Cf. Schumann, II. Kongress für experimentelle Psychologie, p. 167, Leipzig, 1907.

69. Ibid.

70. Cf. A. J. Schultz, Untersuchungen über die Wirkung gleicher Reize auf die Auffassung bei momentaner Exposition, *Zeitschrift für Psychologie* I, **52**, p. 245.

as this ;  as ; and  as  (once in a "clipped" position). It also happened with impressions of motion: The objectively vertical was not present, but instead there was rotation from a slightly slanted initial position. (This latter phenomenon is relevant to the observations of solitary motion, p. 46.)

These rare but clearly substantiated events are a problem all of their own.[71] They seem to be related to central [*cortical—Tr.*] conditions of comprehension and will receive special treatment in subsequent studies of spatial comprehension (cf. p. 87 below).

§**14.** Based on the thesis cited on p. 23, one might say: φ builds itself upon *a* and *b*, the pertinent primary *givens* on which the φ impression is founded. But, in whatever way these two are given—separately, or fused together into a whole $a\varphi b$—the question arises whether the impressions *a* and *b*, the perceptions of the two objects, must actually be present for motion to occur.

Consider the cases of §13:2, in which the angle arrangement, with *a*
[p. 217] vertical and *b* horizontal, was presented using temporal conditions for optimal (or dual) whole motion. Here it happened that the observer did not see one of the two objects at all. In the most extreme sense, the observer had no inkling that a vertical had actually been exposed. Now, in the course of the experiments, single exposures consisting of only one object were, in fact, frequently interposed as control exposures and for special purposes (cf. §11). In these cases, the observer repeatedly reported that this time only one object was exposed; the other, unseen, really had not been shown, but had been taken away between exposures—as actually happened on several occasions.

And what of the other, seen object? According to the thesis that φ is founded on the perceived *a* and *b*, it would necessarily follow that here no φ impression can occur; the other object is perceived as stationary.

During the course of the experiments several such instances were encountered, in which one of the two exposed objects was simply not seen, was not even suspected to be there, and the observer judged that only one object was exposed. With respect to the other, perceived object,

71. As I discovered after completing this article, the thesis of a cortically determined metamorphopsia has been proposed from a psychiatric perspective, based on certain pathological cases (Pötzl).

φ motion was clearly perceived from its position (at *a*) or toward its final position (*b*). For instance, in the motion stage, the vertical *a* was psychologically not there, while the horizontal *b* carried out a partial motion, a φ rotation from the region of 45° more or less into the horizontal position, even quite a small motion (cf. p. 29).

Occasionally the same result was also obtained by reducing the exposure time of one object without the observer's knowledge and furthermore by reducing the brightness of one object.

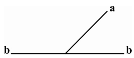
The essential point is that in the emergence of this (partial) φ, the other object was not seen, not given for observation, not even in imagination. And φ did not arise from the position of the unseen *a*, but rather only, for instance, from a region of about 45° (and analogously with *b*).

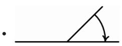
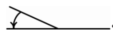
Such a case occurred in the angle experiment of figure XVIa (90°). The observer said, "There was a small but clear motion there toward the [p. 218] vertical standing line, from the right, a rotation of about 40°. There was nothing else there. The horizontal line? You must have removed it." Without letting the observer know, I immediately changed the arrangement by *actually* taking away the horizontal line, so that only the vertical line was left. The exposure once again exhibited the same result: Only the vertical line was seen, with motion.

Through the effects of set [*Einstellung*], one can predictably achieve such φ phenomena, in which even objectively only one object is presented. For instance, the angle arrangement, *a* vertical and *b* horizontal, was presented with good motion several times in succession, between brief pauses of 1–5 seconds. Then, unknown to the observer, during one of the pauses the vertical was removed, or exposure field *A* was covered. Over the next two or three exposures, all with only a single object present, there was a weaker motion, a rotation into the horizontal, from the region of 45° for the first such exposure and through a smaller angle for the second, arriving at complete stillness only by the third or fourth exposure.

This phenomenon definitely cannot represent a mere error of judgment (cf. §20); it occurred predictably and was clearly observable in both naïve and informed observers.

This definite, lawful, and quantifiable effect of set [*Einstellung*] was found across a number of experimental variations. If *a* and *b* were presented in either naïve or informed procedures, in a stage of motion several times in rapid succession with short pauses, followed by exposure of *a* or *b* alone, motion of that particular object was still seen, although to a smaller extent. It got successively smaller with further single exposures, until complete stillness appeared in the third, fourth, or sometimes only the fifth exposure.

The effect of set [*Einstellung*] on the φ phenomena in a particular field could easily be seen in the following experiments: One object is a longer horizontal line (*b*); the other, a shorter line (*a*) standing on its middle, for
[p. 219] instance, 

. If the middle line is tilted to the right by about 20° to 80° with *t* approximately 70σ, without prior set-inducing exposures, there is a rotation to the right, toward the smaller angle.  If the line is slanted to the left at about 100° to 170°, then correspondingly there is a rotation to the left . (Regarding the emergence of 2φ, see §16.)

Now, if a series of successive exposures is presented such that *a* is exposed slanted to the right first at, for instance, 30°, then 40°, then 50°, and so on, then the line can be slanted far beyond 90° without a reversal in the direction of motion occurring. An angle of 120° still produced rotation to the right through the longer stretch, that is, across the larger angle. 

If one is set [*eingestellt*] to a particular direction of motion or a rotation to a particular side, one often strains vainly to rid oneself of it, even with unfavorable positions [*that strongly favor the other direction—Tr.*]. To no avail: Often only in the very unfavorable position of, for instance, 160° does the direction reverse. The strength of this effect of set [*Einstellung*] was found to vary somewhat across individuals, and it depended on the number of previous set-inducing exposures. It turned out to be regular and easily measurable: I presented *a* at various rotational angles, progressing stepwise from left to right and from right to left. The reversal [*apparent rotation through the larger angle—Tr.*] occurred in several experimental series with Observer I at about 160°, and with Observer II at about 130°, but even stronger effects of set could occasionally still be achieved, up to 175°!

In other words, frequent occurrences of φ in a particular field of motion generally predispose the observer to perceive φ in subsequent exposures in that same region, so that even under unfavorable conditions, a φ is observed that would not have otherwise been seen without a preceding set [*Einstellung*].

Aside from the motions of a single exposed object (p. 49), there were occasional phenomena where, *without* preceding set [*Einstellung*], noth-
[p. 220] ing at all was seen of the objects. The observer reported, "Nothing was

there except a strong rotation (indicating the correct direction); *what* was there, I don't know; I didn't see any objects whatsoever" (see also p. 56).[72]

§15. The following findings are significant with respect to certain theoretical possibilities:

1. Even with long exposure times α and β, for example, 2 seconds, impressions of motion can occur with set [*Einstellung*] (see p. 30), as well as under favorable conditions of attention (see §11).
2. With the exposure slits of the tachistoscope formed as in figure XXVI, 2 and 3, and even 4 (p. 90), where the two exposures of *a* and *b* overlapped in time, and also where *a* and *b* were exposed simultaneously, clear impressions of motion in the sense of §7 occurred.
3. Impressions of motion, including optimal whole motion, often occurred during continuous observation even when the two fixed slit lines in the slider were themselves visible,[73] that is, when the fixed card of the slider facing the observer was not so much in darkness that the two slit lines could not be seen when there was no exposure. Here a bright strip was still seen to move from one slit to the other.

Likewise with exposures where *a* and *b* were presented at the same time in different colors (see figure XII): In location *a*, one saw the line, first red and then blue, while between locations *a* and *b* the red line moved back and forth. Results were similar, though more complex, when the colors alternated in both locations together.

4. It is significant that motion was observed even when one object was presented to one eye and the other to the other eye,[74] with a common fixation point.

[p. 221] These results were confirmed through a variety of stimulus arrangements:

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72. Similar results were obtained in experiments with a special arrangement which, without preceding set [*Einstellung*], used only one object (*b*) and, instead of the other, a subliminal change at peripheral locations in the other visual field; likewise in experiments with reduction of the two stimuli to subliminal levels. Both kinds of experiments touch on wider, more complex issues, which should themselves be investigated thoroughly and experimentally in conjunction with these findings.

73. The slits remained stationary; so did a whole ornamented background.

74. This fact of the haploscopic impression of motion has already been established in an experiment by Exner (Binokularstroboskop, *Biologisches Zentralblatt* **8**).

1. View the tachistoscopic exposures through two tubes, arranged so that one eye saw only one object, and the other saw only the other.
2. Place a screen between the slider slits, so that the left eye saw only the left slit, and the right eye only the right one.
3. One can demonstrate this fact [*the interocular impression of motion—Tr.*] in a less exact but very simple manner at any time:
• Looking down, lean the head on the edge of a raised book cover, so as to separate the visual fields of the two eyes. Put down a small bar to the left and right of the cover, not quite symmetrically. Fixate a common point with both eyes, and rhythmically alternate occluding each eye. Motion of the little bars soon occurs.
• In close-up viewing of three-dimensional objects, the visual fields of the two eyes are already quite different, so by alternating monocular vision, one can achieve motion, wobbling, and the like in the same way with all sorts of objects. One can achieve the same effect looking at two fingers, such that both images produce motion.[75]
• It is even more convenient to stand in front of a mirror in a position that produces a difference between the two visual fields.
• Finally, this phenomenon also occurs with a simple haploscopic mirror setup. Arrange two mirrors at an angle to one another, with the vertex line between them aligned along the bridge of the nose such that one eye looks into only one mirror and the other eye into only the other. Facing the mirrors are screens to which one can now attach one object each.

§**16.** What is it that is observed, phenomenally, in the field of motion? According to the thesis on p. 23, the intermediate positions between the stimulus objects are perceptually completed. One could also say a priori that motion would be inconceivable without a thing, an object, a visual item that moves.

If it were true that fully optimal motion could occur only in the sense that an object moves or rotates clearly and distinctly from the initial position through the field into the final position, then this assertion would be easy to demonstrate.

[p. 222] But it became apparent that the essence of the perceived passage or rotation has nothing to do with subjective intermediate positions. There are cases where φ, the motion across or the rotation, is clearly and distinctly *given* without a moving line being seen anywhere in the motion field. The initial and final locations [of the stimulus object] were there, and motion between them, but there was no visual completion in the field

75. See Ebbinghaus, Grundzüge der Psychologie, p. 469, among others.

of motion, neither seeing nor imagining of the intermediate positions of the moving strip.[76] All subjects reported this phenomenon spontaneously. This "pure" φ without completion of any intermediate positions was easily demonstrated using the experimental setup on p. 55.

With impressions of unitary whole motion [*einheitliche Ganzbewegung*], close observation of what is given in the field of motion often showed that, although unitary motion from *a* to *b* was there—for instance, with *a* and *b* as white strips on a black field in the angle or parallel line experiment—no passage of the strip through the intermediate positions was seen whatsoever, nor even the color of the strip except right in the positions *a b* and perhaps at the edges of the field of motion.

In the angle arrangement of red strips on a black ground, with *a* horizontal and *b* vertical: "Very clear unitary rotation, easy to grasp. The horizontal strip rotates visibly upward a bit; the vertical, a bit into its final position. But the whole motion is uniform, not disjointed; rather, a whole rotation is clearly seen from *a* to *b*. Regarding the middle of what is otherwise there visually: there was no sign of strips, no sign of red."

Likewise, with white strips: "It is remarkable that I do not see the white bar anywhere during the motion; yet in the last part of the motion, at about 15°, that is, when the white is already there, it nevertheless makes a final motion, although a moment earlier the same motion was not there. It is never the case, for example, that I see the white bar here in the region of about 45°."

Further, with *a* vertical: "There is a kind of clear, compelling motion, a rotation through 90°, which is impossible to conceive of as a succession.
[p. 223] It is not that the white vertical itself moves, rather there is some kind of event, a passage across. One sees the horizontal bar 'laying itself down' although earlier locations of the strip or of something white in the region of about 45° were certainly not there, nothing of that kind. And yet although nothing white is observed to rotate, and the object itself does not rotate, there is nevertheless clear motion; and, separately, even the final part of the motion is given, in the 'lying down' of the horizontal."

And in many cases, always spontaneously: "Saw the strip *a* and *b*, clear motion between *a* and *b*, nothing of intermediate positions. The strip—neither its color nor the object—did not pass through the field. The background was absolutely bare and stationary. But the motion passes across."

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76. See Schumann, op. cit., p. 218: ". . . the image of the vertical bar maintains its vertical orientation, and yet the impression of rotation is there . . ."

Finally, there were also cases in which the two strips, *a* and *b*, were there, perfectly stationary, with nothing but [pure] motion between them.

In all these cases, this phenomenon was especially easy to produce with a larger distance between *a* and *b*. Observation showed unitary, clearly given motion through the motion field, while nothing of *a b* was visually there at all.

In these cases there was not even a thought that an object had moved across the field. Whatever of the objects was there was seen in the two extreme positions only. Neither one nor the other nor anything else had anything to do with the motion. Rather, motion was given between them—but not motion of an object. It was not even that the object moves across, only I don't see it. Rather, only motion was there, unrelated to any object.

What is it that was phenomenologically given there in the motion field where none of the usual visual features[77] were to be seen, except for the bare ground? Where there was nothing to suggest completion of a strip passing across these locations, and where there was no thought that the strip itself might have crossed over there?

When attention was directed there, the impression [*of pure motion—Tr.*] continued to be seen, just more strongly (cf. §11). None of the usual visual features were there, certainly no strip passing across the intermediate locations, but instead "strong unitary motion in the field; a specific, forceful 'motion across' or 'rotation.' "

I presented the angle arrangement at 90° for optimal identical rotation
[p. 224] and added, in exposure field *B* in the region of 45°, a shorter strip *c* of the same color, some distance from the vertex of rotation (figure XXa, p. 90). This put *c* in a place which the strip would have to cross over in completing the intermediate stages. If, for instance, *a b* were white strips ½ or 1 cm by 6 or 8 cm, *c* was just as wide but shorter, 1 or 2 cm, like a piece of a strip lying in the middle. Attention was placed on the inner end of *c*, or on the space between *c* and the vertex. The motion *a b*, whole rotation through 90°, remained optimal (cf. §10 and §11).

Does the white strip *c* get completed in any way? Does *c* appear somehow lengthened for an instant by the passage of a completed moving strip? Or does a shimmer glide across the place between *c* and the vertex?

Numerous observations always yielded this characteristic result:

- there is clear, compelling motion through 90°, and
- the specific "passage across" can be observed clearly, and

77. *Features typically visible in cases discussed previously, such as an object in the field of motion.—Tr.*

- in the place between *c* and the vertex, nothing white glides across, and
- the background in that place remains quietly black, and
- there is no hint of a completion even for a moment, and
- there is a "passage across" right there: not the passage of the strip, just a "passage across," a "rotation."

I also performed the same experiment with the slider (cf. figure XIIIa and figure XIIIb, among others). Analogous results were obtained in tachistoscopic experiments as well, with *c* mounted identically in both exposure fields of the tachistoscope. It was also the same with figure XIV, in which *c* remains continuously illuminated.

But even simpler was the following demonstration: Sitting in front of the slider with two object slits, such as figure I (§2), place a small bar or similar object between the two slits, and fixate on it. Or similarly, on a larger scale, project the slider strips in optimal motion onto a white wall in a room not fully darkened. Between the two projected images, separated by, for instance, 60 or 30 cm, put a light brown wooden support about 10 cm wide.

Several times observers exclaimed initially, "Wow, I *see* the motion going across! Even there where the wooden support is—but the brown support is clearly there, completely motionless; no strip passes over it. It looks at first as if I saw the motion go through a tunnel?!"[78] Then further:
[p. 225] "The exact situation is like this: The passage across, the compelling motion from *a* to *b*, is clear and unambiguous, vividly there and totally continuous. But nothing white is going across, and the strip doesn't go across."

And similarly:

"Even to the left and right of the support, the background stays totally clear; nothing sweeps over it."

"In the back-and-forth motion, I see white only at the initial and final positions. In between, there is given only this curious passage across the space between *a* and *b*."

"But there is absolutely no passage across *by the strip* itself! Only the passage across, a strong motion by itself!"

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78. A "tunnel observation" was occasionally reported by von Kries while conducting "ghost experiments" (*Zeitschrift für Psychologie* **29**, p. 81). Cf. Linke, II. Kongress für experimentelle Psychologie, p. 217: "The observers now [with stroboscopic wheel rotation] believed that the wheel was suddenly occluded by a screen or shadow during its rotation and then uncovered again immediately thereafter. But the rotation was not inferred; rather, and this is the most important, it was seen directly." Cf. also Wundt, *Physiologische Psychologie* II, p. 582.

In this disconnection of the phenomenon from the visual objects *a* and *b*, there also occurred cases where *two* pure *φ* motions or rotations emerged from *one single a*, in such a way that in no sense did it appear to split toward the two sides [*moving in opposite directions—Tr.*]. With the shorter vertical *a* in the middle of the longer horizontal *b* (figure XXV), so long as one direction was not favored (see p. 50), often the phenomenon of rotation through 90° to the left *and* to the right was clearly there in both directions at the same time. It was not at all as if the vertical itself rotated, nor even as if two lines went toward opposite sides. Rather, the vertical and horizontal lines were seen, and so were both of the *φ* rotations. Sometimes the horizontal line participated in the very last part of the rotation, but still with the lines clearly stationary and only the *φ* phenomenon between them.

Occasionally, with different strengths so that the right was favored (see p. 44), there were "two rotations, a strong one occurring to the right at the same time as a somewhat weaker, less pronounced one to the left." This happened not only with an arrangement at right angles, but also when the *a* line was slanted so that there was, for instance, an angular field of 135° on the right and 45° on the left.

This *φ* phenomenon, the "passage across" or "rotation," was sometimes so compellingly there in tachistoscopic experiments, especially with [p. 226] novel arrangements or with reversal from *a b* to *b a*, that the observer was unable to report anything about the objects themselves (in the case of §13:1): "I can't say anything about what objects were there. I saw a strong motion (indicating the proper direction), but I know nothing about objects, nothing about having seen objects." Similarly, when exposing a strip *a* oriented at 45° in the vertex of a right angle *b* (§13:2; see figure XXb) in an uninformed procedure, "A motion was there; at the end, there was a right angle. In the lower portion of the right angle, there was a turning motion around the vertex, down toward the horizontal; what it was that rotated, I don't know. The horizontal, like the vertical, held still. It was not as if the horizontal had rotated into its position."

Experiments concerning peripheral motions would also fit in here; see further footnote 72.

The above experiments provide not only a theoretical argument that *φ* is indeed given without any filling-in of the intermediate positions of the object, and that what is characteristic of the *φ* phenomenon appears entirely unaffected by the absence of completion of those positions, but also a meaningful [*prägnant*] demonstration in which *φ*-motion occurs in its purest form.

Apart from the color of the background, none of the usual visual qualities[79] is given in the field of motion. Nothing in the way of color or contour is there; in the ordinary visual sense, nothing has changed in the intermediate field, the background. The observer does not say that the strip moves across from *a* to *b* and, indeed, does not believe that it moves across or appears to move across. Rather,

> "I see *a*; I see *b*; I see motion between the two. I see the going across, the rotation—not of the strip or strips; they are in their locations *a* and *b*—but a strong or weak 'going across' by itself."

> "I see motion (indicating the direction), not a going across of anything."

And all this with the fullest attention directed at the field of motion and with the most critical observation. The stronger and more focused the attention concentrated on the field, the better.

[p. 227] One might think: Now, when there certainly appeared no completion, no imagined motion of an object moving across, no intermediate positions of the object, now the "illusion" of motion should vanish. But on the contrary, the motion is there, compelling and characteristic in its own specific unique way, given clearly and distinctly, and always observable again.

These motion phenomena can be weaker or stronger. At the extreme, two simultaneous φ motions as in figure XXV (p. 91) can, with the effect of set [*Einstellung*], occur even for the *larger* angle to the right: a colossally strong φ phenomenon to the right simultaneous with a weak one to the left.

And they have their characteristic nature, depending on the conditions of the experiment: a "rapid" passage across, "sluggish," "slow rotation," "calm rotation," "rotation with twitchy beginning and end portions."

They further exhibit specific motion curves (see pp. 24 and 41) and have a specific spatial localization.[80]

These psychological phenomena are specific, observable *givens*. They appear to be inherent: not subjective, but just as objective as sensations of form and color. However, by contrast with other psychological *givens*,

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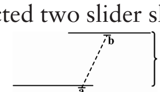
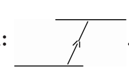
79. *See footnote 77—Tr.*

80. In the experiments discussed: a spatial section of the field of presentation. To determine whether a φ phenomenon occurs at a particular surface under more complicated circumstances, I projected two slider slits, each on a different wall at a different depth (bird's-eye view: 

1½ m. apart). The observer stood to the side. The result was this distinct motion phenomenon:  .

their nature is not static, but dynamic. Their psychological reality, their flesh and blood, as it were, lies in the "passage across" specifically described above, which cannot be built up out of the ordinary optical properties.

§17. If one returns from such experiments to seeing actual motion in [p. 228] real life, then one sees that the apparently so contrived experimental arrangements are by no means so artificial, strange, and exceptional after all, but can be recognized everywhere when viewing [real] movement. The eye is tuned to seeing the characteristic φ phenomena in motions next to and even contrary to the perception of stationary positions and sequences of such positions.

1. Actual motion

Even in perceiving actual motion, very often it is not spatiotemporal continuity of the visual intermediate positions that is given, but a pure φ phenomenon. For instance, one sees how construction workers toss bricks to one another. While fixating on a particular point, one sees the characteristic arm motion against the background of a white wall. One sees again and again the upward swing from a particular arm position when grasping for the brick to the final position above. One sees the two extreme positions, and sees the motion, but one cannot actually see the spatiotemporally continuous positions between the initial and final positions, except perhaps the very first twitch and the very end of the motion—and yet thereby one sees the whole compelling motion. Even here one might still think first of an illusion; but if one has made such observations often and trained one's eye to perceive in small time periods, as in the experiments above, it becomes clear that this is no inference, no illusion of judgment, but the real-life seeing of motion.

It happens similarly with the shadow of a striding person on the asphalt and watching a metronome tick at a particular rate of speed. One can make similar observations in a simple experiment: At a comfortable distance, hold a pencil[81] vertically to one or more letters printed on a sheet of paper, and move the pencil 10 cm horizontally across a centrally located letter, once, several times, or back and forth, while fixating on the letter in the middle.

If the pencil goes across (or back and forth) quickly, one sees nothing of intermediate positions. The pencil is not seen above the fixated letter; it does not go over it as such. Indeed, between the initial and final posi-

81. Or any very thin object.

tions, the pencil and its color are not there, that is, are not seen in the
[p. 229] slightest. Nevertheless, it is not only the succession of the seen initial and final positions that is there, but also the motion. The physical "being in this location" (roughly over the fixated letter) is not seen here.

If one uses a small distance between the initial and final positions, then even at roughly the same speed, totally optimal motion is perceived (§2). One sees the pencil, the color of the pencil, go back and forth through the field of motion.

If one stays with a larger distance and moves the pencil across more slowly, then one might see how it passes across [*the intervening region—Tr.*] continuously. This is the case of continuous passage (p. 61).

But if the motion is slow enough that one believes that one has seen the pencil in all the intermediate positions in continuous succession, then the characteristic impression of the *motion itself* is often gone. So long as the spatiotemporally successive intermediate positions are psychologically really there, then, paradoxically, motion itself is often no more than a mere inference, a mere awareness. Close introspection shows I have seen the taking up of positions, there, there, there, without interruption. But the specific event of *truly perceived motion* is not there.

2. Successive exposures connecting up with each other

Prolonged viewing of successive exposures that continuously connect up with each other can be obtained in an arrangement like the following: A simple slit or several symmetrically spaced slits were made in the wheel of the tachistoscope, now without the prism equipment described on p. 16. In the exposure field was a Zimmerman kymograph drum on which were drawn a number of lines, each above the next, parallel to the axis of rotation.[82] The tachistoscope wheel and the kymograph drum were rotated, the tachistoscope wheel at a speed that, with a single exposure, showed the parallel lines as completely stationary. Depending on the phase relationship between the sequence of the exposures, on the one hand, and the rotation speed of the kymograph, on the other, three types of phenomena could be seen by continuous observation under optimal conditions:

[p. 230] A. Continuous motion of the parallel lines in the direction of the actual rotation of the kymograph drum.
B. Stationary state, with the lines standing still in the field of vision, or a condition of instability (see below).

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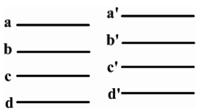
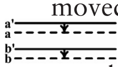
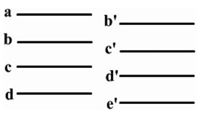
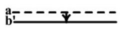
82. Analogous with only one line on the visible side of the drum.

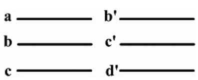
C. Continuous motion in the direction *opposite* the actual rotation of the kymograph drum.



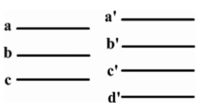
If the exposures follow each other in such a way that in the first exposure the positions *a b c d* are exposed, and positions a^1 b^1 c^1 d^1 in the second, such that meanwhile the lines on the kymograph have moved up by one fourth (¼) of the distance between the lines, then  motion is seen in the actual direction of the motion of the kymograph lines.



If, however, in the time between the exposures, the lines move up by *three* fourths (¾) of the distance, then one sees motion in the *opposite* direction. As predicted by the principle of the smaller distance (see p. 19), this gives motion $a \rightarrow b^1$:  [*consistent with the Gestalt factor of proximity—Tr.*] and thus downward motion is seen.



If, between the exposures, the kymograph lines move up by the whole distance between lines, then one sees stationary lines, because b^1 emerges in *a*'s place, and so forth. Or, due to insufficient precision of rotation conditions, there could be a small motion upward or downward (depending on whether b^1 has reached a position slightly above or below *a*'s position).



If, during the time interval, the lines move up by *half* the distance, then a deviation resulting from a slight imprecision in the rotation conditions can be decisive [*determine the direction of the apparent motion—Tr.*]. But if there is no such deviation, then both directions of motion are objectively equally favored, and conditions of *set* [*Einstellung*] (§14) and *focus of attention* (§11) decide whether upward or downward motion occurs, or one tips over into the other.[83]

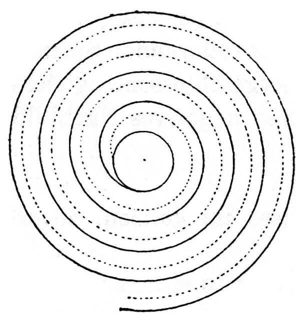
[p. 231] In all these experiments, successive exposures in various positions were connected as ordered sets. With a phase relationship between the two rotations producing a progression of ¼ or ¾ of the distance between successive objects, continuous observation showed continuous uniform motion in one direction. The field is continuously filled with unidirectional, connected φ phenomena, which flow seamlessly into one another. Thus "sinking" or "rising" of the lines or "rotation" is seen continuously in the field.

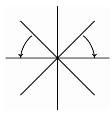
83. In extended viewing this often leads to an odd state of instability, a vacillation or uncertainty, similar in some respects to the appearances discussed on p. 79.

In the optimal impression here, the individual positions in the sense of §12 (pp. 45–46) were no longer imposing as such. There was continuous uniform motion, without any definite "positions" standing out as such (cf. below, §21, p. 77). Under these conditions, a transition to seeing slower, continuous real motion appears to be given.

Similar results were obtained using a spinning spoked disk instead of the kymograph drum. In purely tachistoscopic successive exposure of two intersecting lines, the smaller distance was decisive at first: In a single successive exposure, motion over the smaller angular space was seen, and with serial exposure, back-and-forth motion was seen in that space. If the lines stood at right angles to each other, the distances were equally favored, and it turned out that set [*Einstellung*] and focus of attention on, for instance, the top or side of the angle decided whether rotation was seen to the right or left. If a spoked spinner with two or more spokes was used in this arrangement, the results were analogous to those with the kymograph lines. Thus, for instance, a phase relationship between the two rotations that corresponded with three quarters of the angle between two spokes in the direction of the rotation produced continuous rotational motion in the direction opposite to the real rotation.[84]

[p. 232] The well-known spiral disk was also used in place of the spoked spinner. The slowly rotating spiral gives the compelling impression of continuous expansion outward from or contracting into the center. This is simply explained by the laws of φ motion as treated here:



84. With close observation of real motion in a spoked wheel rotating at an appropriate speed and various foci of attention, one can often notice φ phenomena in the opposite direction. For instance, when on the right rotation is seen in the direction of the real motion,  on the left, it seemingly reverses in the opposite direction. This may constitute a simple explanation of the well-known, puzzling "wheel spoke phenomenon," in which a rotating wheel suddenly appears to rotate in the reverse direction, in broad daylight. As the speed of rotation of a spoked wheel changes, first there occur certain points of a stationary state (not further discussed here), for instance, a stationary cross, and then, at a slightly different speed, φ motion in the opposite direction.

• There is little or no occasion for the development of φ in the direction of the spiral line itself, nor in a circular direction.
• However, there is indeed occasion for development of radial φ motion from one line to the next and onward.[85]

This generally results in connected φ phenomena in a radial, centrifugal (or centripetal) direction and, thus, in the impression of expansion (or contraction). This is illustrated by the figure on page 61: If the rotating spiral appeared first in the position of the solid line, then after 90° of rotation it will be at the location indicated by the dotted spiral.[86]

3. Afterimage

In the continuous observations mentioned above, the field is continuously filled with the uniform appearance of unidirectional, connected φ motion, even with relatively large distances between successively exposed positions.

If one observes such φ motion continuing in one direction for a while and then looks at appropriate stationary objects or a stationary field, an impression of motion in the opposite direction appears spontaneously. This shows the theoretically significant fact that φ phenomena, with sufficient duration and uniform direction, generate a *negative motion after-*
[p. 233] *image*, similar to the known afterimages from viewing real motion.

Exner[87] has already demonstrated afterimages from "apparent motion," with results similar to those here, even when the motion seen initially was in the opposite direction from the actual motion (p. 60); much more strongly with the spiral experiment (p. 61), exactly like the afterimages from real motion; and, lastly, with cinematographic presentation of the rotating spiral.

Φ motion occurring continuously in one direction in the same field produces a strong negative afterimage of motion in the opposite direction.

§18. If we review the situation as a whole, we find the following:

1. With appropriate successive exposure of two stationary stimuli, presented at a distance from each other, *motion* was seen,[88] which cannot be

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85. Cf. recently Pleikart Stumpf, Über die Abhängigkeit der visuellen Bewegungsempfindung, *Zeitschrift für Psychologie* **59**, p. 324. [Translation by Todorovic, D.: *Perception* **25**, 1235–1242 (1996)]

86. The dotted line in the figure being a different type of spiral is not intentional!

87. *Zeitschrift für Psychologie* **21**, p. 388, 1899. See Exner, "Nachbild einer *vorgetäuschten Bewegung*."

88. Cf. Pleikart Stumpf, op. cit. p. 231, Law I.

attributed to eye movements, or to conditions of the onset and offset of excitation in the two stimulated places on the retina.

With the eye fixated, two spatially separated places on the retina were stimulated successively. Under the given conditions,[89] with succession at a time interval of about 30σ, both stimulus objects were seen as simultaneous and stationary; with an interval of about 200σ, successively stationary. With an interval of about 60σ, motion was generally perceived from one position to the other. Aside from these temporal conditions, this effect appears to depend primarily on the distance between the two objects. For instance, a smaller distance expanded the range of time intervals that enabled optimal motion. Both continuous observation and set [*Einstellung*] had specific and lawful effects.

2. The impression of motion is not intrinsically, necessarily bound to the impression of perceived identity of *a* and *b*. In the progression of stages
[p. 234] from simultaneity downward, motion generally emerged first, and then identity afterward. From optimal motion upward, the identity *a* = *b* generally disappeared before motion.

3. In between the effect of whole motion (continuously from position *a* to position *b*) and the extreme stages of simultaneity or succession, there occurred *dual* motion, that is, partial motion of both objects, each by itself.

Between the effect of identical whole motion and the extreme stationary stages, there were other, *qualitatively distinct, characteristic* impressions. The identity of the two stimulus objects was present only in the stage of optimal motion. Beyond that (for instance, in the process of shortening the time interval), there emerged motion *without identity of the objects*, and also the specific phenomenon of *partial motion*: two smaller motions of the objects, each by itself. These dual partial motions were of greater or lesser extent; for instance, with further reduction of the time interval toward the stage of simultaneity, both ranges of this kind of motion got smaller. Just short of the simultaneous stage, unrelated to processes within the separation field, there also often emerged the phenomenon of *internal* motion within the objects and, in some cases, displacement.

4. There were impressions of *solitary motion*, in which one of the two objects remains stationary, untouched, while the other exhibits motion or partial motion.

5. *Focus of attention* and *set* [*Einstellung*] have regular effects on the generation and type of these effects.

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89. Cf. p. 17.

Special factors proved influential in the observations. Duration, set [*Einstellung*], and placement of attention were especially effective. For instance, focusing attention on the separation field facilitated the impression of motion. Experimentally generated set showed a quantitatively measurable influence on the location and type of motion.

6. There were impressions of motion in which one of the two objects was not phenomenologically perceived at all, or indeed was no longer objectively present as a stimulus (which produced partial motion).

[p. 235] 7. The impression of motion does not depend on the subjective completion of intermediate object positions. In certain experiments, although plainly nothing of the objects or any visual quality associated with them was seen or imagined in the separation field, a compelling motion across the field was perceived nevertheless, even with pure duality and stillness of both objects. This φ phenomenon was utterly detached from the appearances of the two stimulus objects.

8. In the optimal stage, a third, smaller object placed midway in the field of motion between the two stimulus objects appeared stationary under certain circumstances, without disturbing the motion between the other two objects; or, under other circumstances, exhibited a small solitary motion. Two successive exposures placed next to each other showed a certain influence on one another.

9. The exposure duration of the individual stimuli themselves could be varied considerably.

The question of whether a time interval between the *end* of the first stimulus and the beginning of the second is absolutely necessary for the emergence of motion was resolved: Motion or partial motion could be seen, albeit with some difficulty, even when the two stimuli partially overlapped in time, and also when one of the stimulus locations was differentially stimulated *during* the presentation of the other one.

In additional experiments, it was confirmed that the motion could be seen even when one stimulus was presented *to one eye, and the other stimulus to the other*.

10. As for the perceived *motion*, the optimal motion resulting from successive stimulation turned out to be equivalent to seeing real motion during exposure of an actually moving object: The apparent motion was seen just as strongly and occasionally even more compellingly than the real motion.

11. In certain experimental arrangements a transition to the percept of continuous motion occurred when a series of successive exposures of stationary stimuli was presented, spatially separated from one another. Here

it was confirmed that the percept of motion resulting from such successive exposures was followed by a *negative motion afterimage*, analogous to the afterimage experienced with prolonged viewing of real motion.

[p. 236] §**19.** The recent extended discussion about seeing stroboscopic motion, with Marbe[90] and Dürr[91] opposing Linke and Wundt, and Linke[92] and Wirth[93] opposing Marbe, characterizes the extreme contradictions that have frequently arisen in recent times on fundamental questions about what constitutes seeing motion.

The essence of the specific, compelling character of motion as seen in real life cannot be adequately grasped as simply the perception of continuous positions nor as the immediate impression of the identity of the object, the identity of what is differentially perceived in space. It is not from these that the vivid impression of up-and-down motion or of rotation, or indeed the impression of any characteristic natural motion, derives its essence and its specificity.

The relevant conceptions rely primarily on the findings in stroboscopic experiments, and further on the fact of the unnoticed missing phases in real motion.[94] The situation with these facts is complex. We must consider a series of stimuli[95] and also the effects of onset and offset of excitation in the same and neighboring retinal locations. To be sure, a great many observations with the stroboscope exist; but due to the complexity of the factors, not to mention the complication of multiple problems, the discussion frequently results in striking inconsistencies concerning the fundamental question of what constitutes the seeing of motion.

In the course of this discussion, Linke[96] on the one hand and Dürr[97] on the other have clarified the problems by identifying key issues and raising key questions, but without resolving the contradictions among the rival theses.

90. II. Kongress für experimentelle Psychologie, p. 214f.; *Zeitschrift für Psychologie* **46**, p. 345; **47**, p. 291.

91. *Zeitschrift für Psychologie* **47**, p. 297.

92. II. Kongress für experimentelle Psychologie, p. 214f.; *Psychologische Studien* **3**, p. 393; *Zeitschrift für Psychologie* **47**, p. 203.

93. *Zeitschrift für Psychologie* **46**, p. 429.

94. Dürr, *Philosophische Studien* **15**. —Marbe, *Zeitschrift für Psychologie* **46**, p. 345f.

95. Marbe emphasizes this.

96. *Psychologische Studien* **3**, p. 393.

97. *Zeitschrift für Psychologie* **47**, p. 297f.

[p. 237] The present investigation appears to have eliminated a number of previously complicating factors. If one examines the foregoing discussion in light of the results of this investigation, this much at least is clear: Marbe[98] deals with the applicability of Talbot's law and the fact of unnoticed missing phases,[99] the perception of the moving *object*.[100] Linke[101] deals with illusions of identity. The question of the impression of motion itself, the question of what is added to the successive appearances [*of the stationary stimulus objects—Tr.*] as *motion*, enters into the theory through the *unnoticed* missing phases [*the observer's failure to notice the lack of intermediate positions—Tr.*], according to Marbe; according to Linke,[102] through the impression of *identity*.

Marbe recurs[103] to the unnoticed missing phases,[104] saying that since attentive observation suffices to eliminate the kinematoscopic phenomenon, it must be lack of attention that produces the phenomenon.[105]

Now, the attention experiments of §11 showed that concentrating attention in the field between the two objects did not eliminate the impression of *motion* but on the contrary *strengthened* it. And the same was true in the experiments of §16: The impression of motion was not eliminated but rather facilitated when attention was directed at the region where there were clearly *no intermediate positions*. Thus explaining the perception of *motion* through lack of attention is not viable. However, if correctly understood, for Marbe it is a matter of *seeing the moving object* in the field of motion. Any illusion of this kind can indeed be eliminated under certain conditions by concentrating attention on the region of the
[p. 238] illusion. Indeed, the experiments of §16 demonstrated that there was *no* seeing of the object, but only of the motion itself, the φ phenomenon.

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98. Cf., for instance, Marbe's formulation in *Zeitschrift für Psychologie* **46**, p. 347.

99. Cf. Dürr, *Philosophische Studien* **15**, p. 501ff.

100. Marbe, *Philosophische Studien* **14**, pp. 399, 400.

101. Linke, *Psychologische Studien* **3**, p. 545; cf. third paragraph following below.

102. Ibid., p. 545: Linke defines it as illusions of identity.

103. *Philosophische Studien* **14**, p. 399f.

104. Besides the various types of successively resulting stimulation of the same retinal locus with the stroboscope, etc. (cf. Marbe's general formulation of Talbot's law); as opposed to Linke, op. cit., p. 479ff.

105. As opposed to Linke, *Psychologische Studien* **3**, p. 474; *Zeitschrift für Psychologie* **47**, p. 204.

Linke approaches the problem from a completely different perspective. For the most part, he arrives at conclusions similar to those presented here in his treatment of the individual aspects of motion perception.[106] But he begins point blank—and decisively in principle—with the hypothesis that the impression of identity, $a = b$, is fundamentally necessary for the impression of motion: "The fact of identification [of $a = b$] is a prerequisite. . . . Associations [with motion] come into it only secondarily."[107] It is only through the existing identification that the impression of motion emerges; it is the "basic condition,"[108] and, "as we know, motion always presupposes prior identification."[109] This is the primary condition, to which association, or assimilation[110] in Wundt's sense,[111] is added; and for the latter, Linke brings up the extreme "variability of the phenomenon."[112]

This thesis of identity,[113] primary for Linke, might not seem implausible. But as it turns out (see above, §6 and §7),

- Impressions of motion are experienced along with pure duality of the two objects.
- In changing from one stage to another, the impression of identity disappears earlier than the impression of motion.[114]
- There is a series of specific motion phenomena (see §16) where no identity of the two objects is perceived at all, but motion definitely is.

So clearly it is not viable to take the impression of identity as an absolutely fundamental principle, the primary sine qua non, of the perception of motion.

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106. Cf. Linke, ibid.—for instance, pp. 476; 481, 542; 481; etc.

107. Ibid., p. 529, among others.

108. Ibid., p. 530.

109. Ibid., p. 494.

110. Ibid., p. 523.

111. Wundt, *Physiologische Psychologie*, 5th edition, Vol. III, p. 528ff.

112. Linke, op. cit., p. 535.

113. Cf. Dürr in Ebbinghaus, Grundzüge der Psychologie, 3rd edition, p. 531.

114. Linke says, op. cit., p. 534: "In all cases the impression of motion appeared and disappeared together with the impression of identity." One can no doubt explain that assertion like this: If one operates under continuous observation, with neither specified selection of t nor regard to the other factors (cf. p. 32 and §11 herein), with a stroboscope it can easily happen that, due to the effects of set [*Einstellung*], one sees no intermediate-stage impressions.

As a factor secondary to identity, Linke brings up the extreme variabil-
[p. 239] ity of the phenomenon,[115] saying that irregularly differing impressions of motion are perceived despite the same objective conditions.[116] The question here is not whether this is a case of assimilation in Wundt's sense of the term (see below, pp. 70–71), which Linke declares to be a secondary factor that supplements the impression of identity. It is quite true that earlier experience can influence stroboscopic perception, but here it is a matter of the irregular variability. The present investigation (see §7 and §11), however, has shown quite definitely that this or that impression was not observed irregularly "despite objectively identical factors." Rather, the nature of the impressions was shown to depend on specific complicating factors such as continuous observation and, subjectively, set [*Einstellung*] and focus of attention. Linke was often working with arrangements of objects in which two different percepts could be seen;[117] but compare the simple lawfulness on p. 44 herein.

Linke himself already has difficulties concerning both of his factors, "identity" and "association."

With respect to the latter, he adopts the formulation that it "is not an influence of certain earlier experiences" (p. 537), because there are motion phenomena "for which no analogies can be found in ordinary experience" (p. 531), phenomena which are indeed "empirically completely impossible, never actualized in motion experience" (p. 537). He falls back on the general statement that "identity of what is spatially distinct is inconceivable without the thought of motion or the existence of intermediate phases" (p. 545). If this consciousness of identity "is not fully achieved . . . then this linkage is the firmest and most effective" (p. 533).

Concerning the first factor, identity, compare his formulation of "relative continuity" (p. 522) and the traces of a dual motion, which he mentions on pp. 531, 535.

§20. If one considers various theories (cf. p. 4) in the light of the results of these investigations, one can conclude the following:

I. The theory of *afterimages*, or rather *afterimage streaking*, which
[p. 240] derives motion phenomena from the offset of excitation in the stimulated retinal locations, is basically not supported here as in these investigations there is no successive stimulation of several neighbor-

115. Ibid., p. 524.

116. Ibid., pp. 495, 524ff.

117. Ibid., pp. 524, 526.

ing places. Rather one is dealing with phenomena observed at a *considerable distance* from the two stimulated places, with both eyes fixating (§4) and motion occurring in the empty space *between the stimulated locations*. Here there is no adjacency, and thus there can be nothing in the way of slowly declining phases [*stimulus offsets—Tr.*] progressing through neighboring retinal locations.[118]

II. With respect to the theory of apparent motion due to *eye movements*, refer to §4.[119] Even if one wishes to recur to "innervations" or the like, the curious consequence of simultaneously perceived motions in opposite directions (§4, p. 22) must be considered.

III. As for the question whether this has to do with *errors of judgment*, the following fundamental points should be raised. This topic must be treated not as a matter of illusion about what is physically real, but as a question of illusion about what is phenomenologically *given*. The issue is not whether I am deceived about what physically exists, but rather whether I am deceived in judging what is seen. Only the stationary *a* and *b* were ever really seen; the illusion is that one supposed that one saw motion as well. Yet it should be noted that the presumed chief reason for such an illusion, identity, is lacking as there are indeed motion phenomena *without* apparent identity (see §6, §7, and §16).

Furthermore, consider the distinct, detailed, and vividly given impression of seen motion between *a* and *b*, apparent from our own observations, time and again. The observer knows that it is a matter of two stationary stimuli, spatially separated and in succession. Errors of judgment would be expected to disappear with repeated, careful, and prolonged observation, with focused attention on what
[p. 241] is given, with extensive practice in observing tachistoscopic phenomena, with thorough experience (one has, after all, become familiar with the different phenomena, including stationary succession, in the most diverse variations)—with all this, errors of judgment should weaken and vanish. But this is not the case; quite the contrary (see §2, §7, and §11).

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118. As far as [*such processes—Tr.*] concern, for instance, a stroboscope (cf. §8), it is necessary to take them into account for an exhaustive description of the circumstances, in the course of which the Marbe theory of elementary stimuli can find useful application.

119. Not only that, but a number of other motion illusions argue against an explanation by eye movements; cf., for instance, the Plateau–Dvorak experiment with several spirals.

Besides these general factors, there is also this specific one: Attention is focused on the most critical location of the illusion, the separation field in the angular space, where the purest "manifestation of the error of judgment" would be expected; yet the illusion is not diminished, but rather improved and strengthened. Also, when attention is sharply focused on one of the two objects in a single exposure, that object does not thereby remain free of the illusion. Rather, partial motion ensued all the more for this very reason.

In the pure φ experiment (§16), where it really is clear now that there is *nothing* to be seen of any intermediate position, any color, any object in motion in the separation field, and one does not even have the slightest thought that the object moves—surely the illusion must now disappear at last?! But it does not (see §16). And what is also remarkable here is the 2φ phenomenon (§16, p. 56): two motions seen simultaneously. In the angular space, for instance, rotation to the right was seen on the right, and rotation to the left on the left. Yet line *a* did not appear to split in the least, nor did it appear to move in either (or both?!) of the two directions.

Furthermore: Naturally the theory must also explain the sequence of qualitatively different phenomena, for instance, the way variations of *t* lead from whole motion through the intermediate stages to simultaneity. Perhaps in any individual case—since one can freely postulate anything in construing an error in judgment—there might conceivably be a special, plausible explanation; but what of the correlation with the variations in *t*? For instance, one would have to come up with fairly extensive postulates to account for the phenomenon of partial motion or of solitary motion;[120] but then what about the gradual transition from optimal motion through the intermediate stages to the extreme stage of simultaneity?

[p. 242] In the end there would still remain the predictable *negative motion afterimage* following continuous exposure of a series of φ phenomena.

IV. With regard to interpreting these motion phenomena as a *fusion* of the stimulus objects, it turns out

1. *a* and *b* do not necessarily fuse into one identity. There are phenomena in which motion is definitely present, but not identity of the two objects. See the dual whole motion of §6 and §7, and partial motion.

120. Relatively complicating constructions would also have to be found to account for the special "motion curves" (see pp. 24 and 41).

2. φ does not necessarily encompass the contents of both objects, *a* and *b*. Rather, in the phenomenon of partial motion, φ pertains to each of the two by itself [*consists of a separate motion for each—Tr.*], without the two objects being at all perceived as fused. Consider also partial motion arising with different colors or shapes of the two objects without a perceived change, for example, something red moves above, something blue below (see §7).
3. With solitary motion, φ pertains only to the one object by itself. The other remains perfectly motionless (see §9).
4. In the cases in §14, there is no stimulus material [*Reizmaterial*] available for fusion. In the cases in §16, both objects are undisturbed by the φ motion; they are dual and stationary.
5. Thus the effort to interpret these motion phenomena as a fusion of stimulus objects ends up assuming certain peculiar fusion phenomena, reproducible in themselves and relatively autonomous, sometimes even arising piecemeal in a curious fashion (see partial motion). In that case, the theory might explain how those phenomena emerge in the first place, but it offers no specifics about how the fusion accounts for the perceived phenomena. One is then dealing with specific phenomena, which can be asserted to have come about through fusion at some earlier point in time but, as they are happening now, do not in themselves represent fusion of stimuli in any way.

V. When interpreting these impressions in the light of the most customary definitions of a *Gestalt quality* or rather *complex quality (or relations)*, certain analogies apply. They necessitate the facts of the aforementioned Thesis I (p. 23):

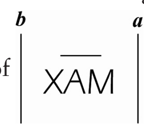
1. φ would have to involve and encompass *a* and *b* in a phenomenally unitary manner. But on the contrary, in §7 φ occurred as partial motion, something which phenomenally involves each of
[p. 243] the two "underlying events" purely individually.
2. φ would have to involve both *a* AND *b*. But on the contrary, consider solitary motion (§9).
3. *a* and *b* would have to be present as constituent percepts—"at least two." They would somehow have to be contained in the experience. But on the contrary, see §14.
4. On the basis of §16 and earlier paragraphs, analogous to IV:5 above, the theory would have to assert *merely earlier generation*, *reproduction* in itself—and the curious *partitioning* in the case of smaller partial motions and solitary motions.

Apart from all this, the theory would have to suffice in itself to explain the other regular phenomena, which occurred as well, such as dual partial motion as a *transitional* stage along the way between whole motion and the simultaneous stage.

VI. Is φ grounded in an event (a displacement, a passage) of attention? First *a* offers itself to the attention, then *b*. The focus of attention, which first seizes on *a*, is torn away from *a* and drawn over to *b*. One might think this displacement of attention underlies the phenomenon of apparent motion.

Attention can be understood in several different ways. If one understands attention in the special meaning as the experimentally established fact (§11) that the observer focuses on a certain location so that the phenomena and events in this location are attended most closely and, as a consequence, these now appear particularly clear and distinct in the "center of consciousness," then—despite the fact that to the observer the φ process, even in the pure φ experiment (§16), appears different from the well-known, familiar phenomenon of a mere passing of the center of attention from one location to another—the following issues arise:

1. The situation here resembled that of §4 with fixation of the eye. The question is: Can one succeed in strictly maintaining the focus of attention (see §11) in the course of the experiments? If so, what then is the effect? The experimental testing required a thorough training of the observers; but with practice in focusing attention, it soon became clear that the observers could reliably report whether or not their focus of attention had [p. 244] shifted. At first, as with the test of fixation, after seeing the motion, the location of focused attention was often elsewhere than at the beginning of the experiment; the attention had gotten "yanked across" and ended up at *b* or beyond *b*. However, it was soon found that the focus of attention could be kept firmly and steadily on one location (again, using a variety of locations), and yet motion phenomena were perceived in just the same way as those in §11 (across the location, away from it, toward it, peripheral to it, and so on).[121]

121. This also suggested additional recognition experiments. Thus, for instance, in a momentary exposure of 

, one tended to read not **MAX**, but **XAM**; and the like.

2. Furthermore, if one were to explain apparent motion purely as a shift of attention, then one would expect that the change of attentional focus (for instance, placement at *b* or more peripherally) must lead to phenomena other than those yielded by the experiments in §11.
3. Finally, in order to do justice to the phenomenal appearances of *φ*, one would have to attribute far-reaching, numerous, and extraordinary achievements to the phenomenal displacements of attention. For instance (see §4, pp. 21–22), when two *opposite* motions were observed simultaneously in the same field of motion, without any figural phenomenal unification *A a : b B*; similarly, when *several* motions in opposite directions appeared (cf. footnote 149); or finally, when *three or four disparate* motions, not unified, were perceived in the same field. In all such cases, one would have to reckon with multiple, simultaneous, independent shifts of attention.

One soon understands that the *φ* phenomena themselves have nothing to do *directly* with "clarity and distinctness" in a particular location. They themselves can be more or less clear and distinct, and they can [p. 245] appear in either peripheral or more central locations of attention. A shift of attention in the sense used here appears as downright *something more*, which can be present in addition to the seen motion and indeed appears even under simple conditions but is not intrinsically necessary.

If "attention" is not understood in the sense defined above, but rather as some kind of central factor that might underlie the origin of the *φ* phenomena and that might work in such a way as to do everything described under items 2 and 3 just above, then I refer to p. 74: Central processes[122] themselves must certainly be assumed to be fundamental.[123]

One might choose to ignore attention in the usual sense, with respect to clarity and distinctness, and to believe on purely logical grounds that an "event" must be considered an "event of something." Against that position speaks that it is *not* supported by the psychological findings, and why shouldn't there be purely dynamic phenomena? There is no fundamental reason a priori to assume that the psychologically "dynamic" arises from the "static."

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122. Exner, *Archiv für Physiologie* **11**, p. 589 etc. 1875. See p. 52 herein.

123. Concerning recourse to the constituent effects of a "central afterimage," refer to §15 (p. 52) on the impressions of motion with stimulus *a* lasting *beyond* the appearance of *b*, and also the experiment with *a* presented during the exposure of *b* in a different color.

Note: Something similar to items 1 and 3 just above could be said about the interpretation that the φ process is grounded in a "successive grasping of the locations between *a* and *b*." Here again item 3 is decisive: What capacities would have to be required of this grasping when multiple motions are seen at the same time! This demand too appears as something still more (which is not achieved either, even in these experiments), if one considers that the relevant locations between the multiple different *a* and *b* objects would have to be grasped [*erfasst*] in succession. A phenomenal transition, perhaps a passage across or through the separation *a b*, is indeed there. But each additional requirement represents something yet more, which leads to excessive demands on what can be achieved psychologically. Consider also the experiment [p. 246] mentioned under item 3, with two simultaneous opposite motions in the same field, and the one mentioned in footnote 121, in which "successive grasping" in the direction toward the left should lead to the suggestion of "MAX."

§**21.** The present experiments deal essentially with the situation where two retinal locations that were spatially separated from each other were stimulated in succession. Eye movements and conditions of onset and offset of excitation in those stimulated retinal locations cannot in themselves be regarded as constituent factors.

It has already been demonstrated that central factors must be invoked as fundamental by Exner[124] in connection with the results from using his "double stroboscope," among others; from another perspective by Marbe[125] on the grounds of Dürr's experiment on missing phases;[126] by Wundt;[127] then by Linke in connection with the phenomena discussed on p. 67; and by Schumann[128] on the grounds of "motion without a change of location of the stimulus objects."

124. Exner, Experimentelle Untersuchungen der einfachsten psychischen Prozesse, *Archiv für Physiologie* **11**, p. 589. 1875: "This sensation of motion occurs either always, or at least in certain cases, in that zone which is common to both eyes."

125. Cf. *Philosophische Studien*, Vol. 14, 1898, p. 400: "the most significant part of these events, stroboscopic motion phenomena, depends moreover on the fact that because of purely central processes, we do not notice missing motion phases."

126. Dürr, *Philosophische Studien*, Vol. 15.

127. Wundt, *Physiologische Psychologie* Vol. 2, 5th edition.

128. Schumann, II. Kongress. p. 218.

The experiment on p. 52, in which the motion phenomena resulted from haploscopic observation in the tachistoscope, like Exner's experiments *without* eye movement, shows clearly that it cannot be sufficient to invoke purely peripheral [*retinal—T.*] processes in monocular viewing. It is necessary to invoke mechanisms that "lie behind the retina."[129,130]

[p. 247] A physiological theory has, in my opinion, a dual function in connection with experimental research. On the one hand, it should unite the various individual results and lawful relationships and make it possible to deduce them. On the other hand, and this is the more essential function, the unification should serve scientific progress by directing future research through addressing specific experimental questions that first test the theory itself, and then penetrate further into the fundamental lawfulness of the phenomena.

In this sense, let me here sketch out briefly, as a supplement, a basic physiological scheme that permits a unifying account of the experimental results and serves to address special issues during the investigation. So far it has already been heuristically helpful in further work. If this hypothesis treads on difficult and still unknown territory, it is because of our current state of knowledge. This would seem necessary and permissible in that the hypothesis itself poses specific problems for experimentation. I restrict myself to sketching out the most important principal features; a fuller elaboration should take place only in conjunction with experimental investigation of other related issues. It concerns particular central processes, physiological "transverse functions" of a particular kind that serve as the physiological correlate of φ phenomena.

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129. The regularities of §11 and §14 with respect to the particular effects of attention and set [*Einstellung*] point to a central basis in another way.

130. A recent pathological case, with an affliction of both occipital lobes, appears to speak to the central basis of the seeing of motion. In *Wiener klinische Wochenschrift* **24**, p. 518, No. 14, 1911, Dr. Pötzl reports of the afflicted patient: "if one presents a strong light in slower or faster motion to her, then she seems not to perceive the motion of the object; she characterizes what she sees as multiple lights. . . ." On the strength of this, I contacted Dr. Pötzl in May 1911, and in the course of the summer of 1911, I had the opportunity to test the patient repeatedly, with various real motions as well as with slider experiments. Stringent observation suffered somewhat from the impaired intelligence of the subject, but her deficiency in the seeing of motion was definitely confirmed time and again, even though she could recognize colors. When helped by acoustic impressions (rustling, etc.), she did speak of "fluttering back and forth." Meantime she recognized the color of what objectively moved past.

[p. 248] According to recent neurophysiological research, one must assume that the stimulation of a central location *a* produces a physiological effect within a certain radial distance around that location. If two locations, *a* and *b*, are stimulated, there should result a similar spreading [*Umkreiswirkung*] for both; each such area is then predisposed for further excitation processes.

If place *a* is stimulated and a certain short time thereafter the nearby place *b*, then a kind of physiological *short circuit* [*Kurzschluss*] would occur from *a* to *b*. In the space between the two places, there would occur a specific cross-over of excitation. For instance, if the amount of spreading from *a* reaches the peak of its temporal course and now the spreading of *b* arrives, then the excitation would flow across, a physiologically specific process whose direction is given by the fact that *a* and the spreading around it are there first.

The closer[131] the two places *a b* are to each other, the more favorable the conditions for the emergence of the *φ* event (cf. the various facts concerning the law of smaller distance [*Gestalt factor of proximity*] in §14 and §17).

If *t*, the intervening time between the emergence of the excitation in the two successively stimulated places *a* and *b,* is too great, then the spreading around *a* has already dissipated when the spreading from *b* emerges (succession stage). If the intervening time is shorter, such that the spreading from *a* is present when that of *b* arrives, perhaps at the peak of its temporal course, then the cross-over of excitation [*i.e., apparent motion—Tr.*] takes place. If *t* is very short, then the spreading of *a* and *b* occur too close to each other in time (or, rather, at the critical moment the one around *a* has not yet reached its sufficient height) to enable the *directional* short circuit (stage of simultaneity). Cf. further p. 79.

However one might think of the central (physiological) basis of attention, it must always be remembered that a place toward which the attention is attracted (by increased excitability, faster conductivity, and a [p. 249] higher state of excitation) thereby acquires an increased disposition for excitation. This corresponds with the results in §11 as a straightforward

131. It is immaterial here whether this "closer" is conceived as purely geometrical (perhaps in the sense of theories about "retinal projection") or as a solely functional relationship. Even if one does not subscribe to an image of the retina [in the brain], the excited places in the brain corresponding to the neighboring locations on the retina must be thought of as standing in a special, especially strong and "close" functional relationship with each other.

consequence: Directing attention into the space separating *a* and *b* facilitated the φ phenomenon, whereas directing it to one of the two objects favored (partial) motion in the very same place; and so on.

On the other hand, letting a figural contour stand out subjectively (pp. 43–44) is a different factor, which operates in a different way. So it is not just a matter of an increase of dispositional relationships, but rather a strengthening of certain relationships. Cf. moreover p. 79.

The spreading effects are naturally strongest in the neighborhood of the stimulated places. If optimal conditions are not present, with, for instance, a *t* between that of the optimal and that of the simultaneous stage, then motion occurs most strongly at the edges of the two objects, while remaining subliminal in the middle (dual partial motion). Furthermore, for fully optimal motion and for partial motion in the sense of the motion of the object, there might be a qualitative influence from *a* or *b*. However, such an influence need not necessarily occur: A mere crossover of excitation without qualitative influence from *a* or *b* would correspond with the pure φ phenomenon (§16). The experiment of p. 42 suggests a "dominance" like that in binocular rivalry.

The more special phenomena in §15 always involve either a later onset of *b* or an earlier disappearance of *a*. With repeated stimulation using appropriate dispositional factors, the spreading effect (partial motion) can also be effective with longer exposure time and temporal overlap. This view is also consistent with the effect occurring with a different kind of stimulation of *a* while *b* is present.

Furthermore, the results of §10, the effects of a φ process on an object in the field of motion and on neighboring successive stimulation, are consistent with the character of this physiological event.

It is to be expected that repeated presentation of stimuli that are too weak by themselves will summate and thereby become stronger, and likewise that multiple repeated activations of the corresponding physiological
[p. 250] process will facilitate its occurrence. (Cf. the effects of set [*Einstellung*] in §7 and §14.)

Also, if a continuous strong passage in a particular direction is present, then it is to be expected that later, when the stimulus ends, there occurs a back-flow, a compensation in the opposite direction. This produces the *negative afterimage* (§17).

With a series of successive exposures (cf. p. 61) under optimal conditions, the resulting φ processes flow together and produce a unified continuous impression [*Gesamtvorgang*] of motion. The characteristic of "being in a particular location" (§12) disappears. Here then there is the transition to seeing actual continuous motion: A progressive reduction of the "separations" merges directly with the physical conditions of actual motion. With this, *aside from the perception of the stimulus* itself and the processes elicited directly by it, there occurs *the uniform passage of a φ process*. The finding that in actual motion there is a far greater range of optimal times (and therewith of speeds of motion) is explained by the fact that the smaller the spatial separation is, the greater the range of optimal *t* times becomes. If the separation is small, or if one works with continuous stimulus sequences (assuming that, in sequential exposure, there is not too great a duration of the α, β to facilitate the characteristic of "being in a particular location"[132]), then in order to arrive at one of the extreme stages, succession or simultaneity, from optimal motion would require quite excessive decelerations or accelerations of the serial exposures (increases and decreases of *t*).

[p. 251] Digression:

The principle that lies behind the assumption outlined above is that, in terms of brain physiology, except for activations of individual stimulated loci and aside from "conduction-associative" [*leitungsassoziativen*"] factors, specific "transverse functions" [*Querfunktionen*] must come into consideration: specifically, central processes that take place between stimulated loci, or rather arise in a characteristic manner on the basis of the individual activations. This principle suggests an outlook in yet another direction.

The basic supposition here is that the excitatory processes in the stimulated cells themselves (received from the periphery or through "associative connections"), or the sum of these individual excitations, is *not* all that is essential: Rather, characteristic transverse and *holistic* processes [*Quer- und Gesamtvorgänge*], resulting from the stimulation of *individual* loci—perhaps as a point of incidence, as a specific whole of greater scope—must play an important role, directly relevant for some factors that still need to be clarified psychologically.

A relatively simple effect of this kind would be likely: a transverse function between stimulated loci (a central process between two temporally determined excitations), a kind of physiological short circuit which corresponds phenomeno-

132. This is potentially also relevant for [specifying the best conditions of] cinematographic presentation: increasing the number of frames is not a favorable factor for the perception of motion in itself. On the one hand, it works favorably only if the exposure durations of the individual frames are short enough so as not to emphasize discrete "frame positions." On the other hand, it is not needed to enhance the vividness of the motion itself (cf. §16). The favorable effect lies primarily in the circumstance that smaller spatial separations are used, which allow for a wider range of perceived velocities [in the movie]).

logically with the φ phenomenon. Some of what happened in the experiments, however, points to yet something else.

On pp. 4–5 it was stated that the simultaneous stage is reached with shortening of the *t* interval. Thereby the two objects now tend to appear in a special way as two in one, a compelling, unified Gestalt: not two lines leading out from one point, but rather an angle; not one horizontal above and another below, but rather the Gestalt. Other results as well[133] point to something remarkable about compelling[134] Gestalt impressions.

[p. 252] One could see in this a simple consequence of what was said on p. 76: With a favorable temporal sequence of the onset of the two spreading activations of *a* and *b*, cross-over of an excitation occurs, but if *t* is very short, then the spreading begins to make its appearance too close to simultaneity to enable the directional short circuit. But in this case, what would occurs initially for certain effects is a kind of physiological connectedness and indeed a *uniform* overall process [*Gesamt-*

133. Arrangement of successive stimulus objects so as to suggest a simple Gestalt interpretation is not without influence on the type of motion phenomena. The influence of the Gestalt factor, as well as various other factors, is accessible to quantitative measurement. On the other hand, it was already mentioned that the *Gestalt* factor can work against the emergence of φ phenomena (p. 43). And yet another complex fact is partially relevant here: if one attaches two or more objects on the band of the stroboscope, and pays attention to the Gestalten that arise with variation in speed, one observes that the various geometric transformations do not develop, say, in continuous succession. Rather, particularly simple configurations suddenly change from one to another, often fairly abruptly. With more complicated object diagrams on the stroboscope band, it takes a bit of experimental experience to predict the type (or types) of Gestalt as a whole. Thus it appears that, insofar as several different types occur in the course of the stages, they do not transform continuously from one to another in geometric approximation, but first one dominates and then suddenly the other, often without geometrical transition between them, similar to the dominance of a figure "winning" over another in haploscopic presentation. These complex phenomena constitute specific tasks for a more detailed experimental investigation of the "Gestalt factor."

134. The "arbitrary" nature of *Gestalt* perception has often been noted. There are stimuli that simply command a certain *Gestalt* interpretation, and there are objects that allow two or more different perceptual interpretations. Examples of this complex type include the observation that one cannot easily rid oneself of a figure in a trick [Vexier] picture once it is found, and the suggestions of a complete Gestalt in "incomplete drawings" and "sketches." Experimental research will have to investigate the conditions that make for a compelling Gestalt, including successive and even simultaneous set [*Einstellung*]. Moreover, even with rather arbitrary interpretations of ambiguous patterns, what is in question is not simply arbitrary intuition [*beliebiges Wollen*], but rather specific psychological modes of conduct.

prozess], resulting *as a whole* from the individual physiological excitations:[135] a *simultaneous* φ function.[136]

* * *

Here again a brief retrospective:

In §16, the word "phenomena" was used in the sense of the psychologically specific, observable *given* that now here, in §21, is ascribed to a central mechanism. Unbiased observation resulted in a characteristically dynamic nature concerning the apparent motion, in contrast with the
[p. 253] "static contents" of the usual optical *givens*—precise specification regarding spatial extent and direction, intensity, salience, and objective (that is, not "subjective") directedness. Various subjective factors are of lawful relevance to the emergence of this motion in certain domains.

While these are specifically visual φ phenomena, analogous topics are studied in other sense modalities. For instance, in the acoustic domain, the previously mentioned phenomenon of the "living interval,"[137] of "tonal movement," though different in principle, resembles a nonstatic type of directed experience.

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§22. Appendix. We normally find ourselves in a particular spatial orientation. The visual space is oriented in a particular way with regard to vertical direction, horizontal extension, and what is level (see below), and it generally remains so. Despite motions of the seen objects, eye motions, and head and body motions, nevertheless the seen objects are generally experienced within a spatial orientation that holds still.

The course of the experiments in §17 affected this condition of a steady, stable spatial orientation in a purely visual manner, and there emerged an essential factor for the condition of "finding oneself in a firm spatial ori-

135. If, then, this were a matter of such a physiological *holistic* process [*Gesamtprozess*], whose characteristic nature *as a whole* were determinative also for other effects, not just the sum of the individual excitations, this would open up a possibility for addressing certain questions to be dealt with experimentally and have a multitude of implications. For instance, in perceptual reproduction and recognition, what were essential would be the emergence of the previously existing, physiological whole-form [*Gesamtform*] of the unitary process, not just the reproduction of particular individual sensory excitations.

136. These comments on simultaneous φ are intended only to point the way toward a resulting possibility, urging specific tasks in experimental research to probe the conditions and workings of the Gestalt factor.

137. *E* (1/16) *B* (1/2); *E* (1/16) *B* (1/2); *E* (1/16) *B* (1/2) *E* (1/2).

entation": the factor of psychological anchoring [*Verankerung*]. Certain cues enable anchoring and set [*Einstellung*] with regard to a certain spatial orientation. This condition of perceptual anchoring becomes weaker when such orienting cues undergo major changes or are absent for a prolonged period of time.

The fact of perceptual anchoring is biologically important. Once it is established, it requires relatively strong distracting stimuli to loosen it, to make the spatial position unstable, to forcibly orient it otherwise, or to make it move.

It is well-known that such effects can be achieved through affecting the [p. 254] canals (in the labyrinth) of the inner ear. The following facts, however, concern influences of a purely visual nature.[138]

I. In the experiments on p. 60f., with an ongoing series of successive stimulus exposures, a percept of continuous "sinking" (or "rising" or "rotation") was observed in the field.

If one projects a strong afterimage of such motion onto a surface, one of two things can be seen: Either there are peripheral anchoring cues, for instance, the frame of the blackboard on which the afterimage is projected, or, better still, objects such as a chair below the blackboard, and one sees at the location of the blackboard a "rising" within an otherwise calm, stationary field with a stable spatial orientation; ***or*** such anchoring cues are missing (or the afterimage is present throughout the whole visual field) and one sees a "rising" per se, now not within a calm, stationary frame but rather encompassing the visual field itself. Similarly with continuous real motion—for instance, from right to left: If sufficient anchoring cues are continuously available, then one sees motion within the stable spatial frame provided by the blackboard. However, without sufficient anchoring cues, the experience is "motion to the left," analogous to the well-known motion inside a rotating cylinder, which results in a percept of "Now the whole room is rotating around me."

Usually what happens is that first the motion is still seen within the stationary frame; then this becomes "unstable,"—often with a feeling of uncertainty about one's spatial orientation, with the familiar "discomfort"—and the whole frame gets into motion.

Regarding the two forms, "there is rotation around me" and alternatively "I am being rotated," compare the note on p. 82. Even this is not arbitrary, but rather, aside from fixation and attentional factors, dependent on perceptual anchoring.

138. Testing with stationary fixation and fixed head position.

These experiments can be performed so that nothing except purely visual sensation is affected; body, head, and eyes remain steadily fixed in one position while a single point is steadily fixated. The most striking impression derives from adapting to the well-known rotating spiral[139]
[p. 255] (see p. 61). If one projects a strong afterimage, say in the middle of a large blackboard on a wall, while fixating one point on it—for instance, one of several letters drawn on the board—then the paradoxical impression easily arises that there is strong radial "expansion" from the middle outward while the board, with its frame located more peripherally in the visual field or, better yet, a chair or a doorpost nearby, "really remain completely stationary"; "the board isn't expanding." The motion appears only within the stationary field. But if anchoring plays no role, be it because there are no objects available for anchoring or because they are too far off in the periphery to attract attention, then there is no expansion in the stationary frame. Rather, expansion per se is simply there, continuously from the middle of the visual field outward. This generates a curious experience with constantly visible letters.

Note: A fundamental point should be raised here. In the actual psychological experience, it appears that the common dogmatic thesis that, psychologically, "motion" is merely relative is wrong. One might claim that "only a relative change of location" is given and that what is seen can likewise be interpreted only in the same way—as, for instance, the motion of the train ***or*** of some objects outside it [*such as another train—Tr.*], moving in the opposite direction. This view has even led to the assumption that the basis of certain visible motions is that they are seen "relative to the border of the visual field"[140]—but the facts directly oppose this. One might claim that the thesis is conclusive because indeed one event actually appears first and then the other, under the same physical conditions, but this also is countered by the fact that in actuality it is by no means so arbitrary "whether to interpret a given motion in one way or the other." A number of factors play a role here, such as seeing one's own bodily position and other factors of the same kind. Using the type of haploscopic mirror experiments described on p. 52, for instance, it is easy
[p. 256] to generate the impression of one's own head moving back and forth in the mirror image, even with the head perfectly stationary. In purely optical cases, aside from the point of fixation and the direction of attention, the main point is what gets anchored on—and one's bare thoughts cannot change this arbitrarily from one moment to another. It does not

139. What kind of nystagmus might be involved in the spiral experiment?

140. Cf. Hamann, *Zeitschrift für Psychologie* **45**, p. 236.

depend simply on arbitrary choice. Significantly, even with the best of intentions, it is *not* always possible in some arbitrary way to switch immediately from one "way of seeing it" to the other. On the contrary, one is adjusted to one [*anchoring state—Tr.*] and cannot arbitrarily get to the other, until somehow the situation reverses—somewhat against one's own will—and now it is the other state that is vividly experienced again. This is the way it happens in actual experience. In general, if, physically, a relative change of location takes place between *x* and *y*, then it is just as valid to say that *a* is stationary and *b* is moving as to say that *b* is stationary and *a* is moving. But although this is true in physics, the discussion of the *φ* phenomenon, above, demonstrates that such a thesis is fundamentally untenable [*in psychological terms—Tr.*].

II. The experience of instability of spatial orientation and the uncertainty that "one no longer is, as usually, in a firmly anchored space" occurred similarly in experiments involving concentration on some static view when over a longer period of time no anchoring cues were available. Under those conditions, similar to the experiments described in paragraph III below, there arose a "swaying" of the visual scene, sometimes even apparent motions of significant magnitude. Most intensely, ghostly, but vivid motion sensations of great magnitude (so-called autokinetic motions) are reported in experiments requiring prolonged fixation of a small point of light in an otherwise dark room. Here after some time of steady observation, the point of light begins to perform quite considerable
[p. 257] motions[141] to the side, for instance, or large partial rotations. With these autokinetic motions too, the observers complained spontaneously about the "instability" of the spatial sense.

Other experiments likewise showed that, when anchoring cues are continually reduced in various psychological tasks on spatial perception, instability, swaying, and change of spatial orientation easily occur. The reason why in most of these experiments on spatial perception consistent results are obtained with respect to spatial position is probably that they are performed under conditions of set [*Einstellung*] and anchoring conforming to the normal spatial orientation. If these conditions are not maintained, the result is often spatial swaying and uncertainty, even in experiments with the horopter.

In the extreme, these findings are of course known (see below) from experiments where the participant sets the vertical, for instance, in a dark room with no anchoring cues at all. Also in the Aubert experiments,

141. Motions which, according to recent studies, cannot be traced back to fluctuations of fixation.

intended to investigate motion perception in an elementary way, there was the curious result that in the dark room about 50% of the observations were "errors" [*false alarms—Tr.*], that is, "motion" was reported when objectively there was no motion, and vice versa.

This demonstrates that the Aubert motion experiments were *not*, in fact, of an elementary nature. There were two confounding factors in play—the perception of individual motion, on the one hand, and effects and processes concerning "spatial position" [*the perception of the overall spatial configuration—Tr.*] on the other—which were inextricably intertwined in his results.

III. Recall the well-known experiments concerning the "apparent vertical" showing that, with the head tilted,[142] the apparent vertical is blatantly tilted [*in the opposite direction—Tr.*]. Here again one often experiences[143] an "instability," sometimes actually a visible swaying or rotation of the (objectively stationary) line. In these experiments the vestibular system is involved, although the same results can also be obtained purely visually through set [*Einstellung*].

[p. 258] I set up a mirror tilted so that the observer, looking into the mirror, saw the room with a good many "anchoring" objects such as a door, a chest of drawers, a chair, equipment, and windows all tilted at an angle of about 45° [*to the left—Tr.*]. At first there is a distinctly tilted view that looks quite strange and curious, when the observer sees how a person in that tilted room walks around, does things, sits down . . . and then at some point, in the door frame, a wide object is let fall slowly: a wide cardboard tube that, remaining level, falls in the doorway from the top of the frame to the ground. At first this appears as a very strange diagonal fall, in weird violation of the usual vertical direction. But after a few minutes, during which the observer continuously looked in the mirror and the person in the mirrored room continued to move around and do things, already there was a strong perceptual change. Now if the cardboard tube was let fall in the doorway again, then the observer no longer saw it fall diagonally, but rather properly vertically. The spatial orientation had already changed [*adapted—Tr.*]: The tilted room no longer appeared tilted, but normal,[144] and the distinguishing edges of the anchoring cues, such as the "vertical" and "horizontal" of the chest of drawers and door, had become *the* (new) vertical and horizontal of the spatial orientation for the observer.

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142. For instance, Nagel, *Zeitschrift für Psychologie* **16**, p. 173.

143. Nagel, ibid.

144. Analogous experiments with mirror goggles are well-known.

The same experiment—already known from experience—was done in a better controlled, more objective way: The observer had to adjust a plumb bob to the "subjective vertical" right at the beginning of the experiment, and likewise after prolonged looking in the mirror.

The observer sits in front of a wide tube, which conceals the mirror frame and peripheral objects, and looks in the mirror with head in a fixed position. In the mirrored room, a certain point is designated as a fixation point. This fixation point appears right at the midpoint of a plumb line, which can be adjusted to various slopes from behind by an assistant, [p. 259] against a black surface; specifically, in precisely such a way that, with the mirror momentarily removed, only the line is visible against the black ground.

The observer first set the vertical within the tilted room (or in the above arrangement after some exposure to the mirrored room) to the objective vertical—not the "vertical" of the tilted room, but the normal one [*to gravity—Tr.*]. After some time during which the observer saw the tilted room, in which a number of tilted anchoring cues were visible as described above, including a person walking around, the experiment was repeated; the observer had to adjust the "vertical" again. Now the result was analogous to that of the previously mentioned experiment with a changed head position, but here with an unchanged head position and steady fixation. There was perceptual instability, a tilted set [*Einstellung*] (the "vertical" was adjusted more or less to that of the tilted room) and apparent swaying. The adjustable plumb line, when objectively stationary, often appeared to be swaying gently and even rotating. It might first appear to be "vertical," and then "it rotated in a strange way, out of this orientation to an angle of about 30° tilted to the right."

This setting of the vertical was repeated, but this time when the tilted room was no longer visible, as in Nagel's experiment, with nothing in the visual field except the adjustable plumb line against a black field and the fixation point in the middle. Yet the aftereffect of the tilted room as reflected in the settings still produced the characteristic results.

* * *

Digression: One is accustomed to a certain conceptual framework, which requires strong "stimuli" to release one from "being anchored in a particular orientation." This release often brings about "instability," a sensation of swaying, similar to the early stages of dizziness (vertigo). Now this is the case not only with respect to spatial orientation. A similar

kind of set [*is effective—Tr.*] in normal depth perception.[145] A sudden,
[p. 260] very strong change, after long-lasting adaptation to normal depth, shifts abruptly to abnormally perceived depth, which in some people engenders similar momentary instability and even dizziness. These facts point to something more general:[146] If one is adjusted to a certain level: a change, an event, can work either as an event within that level or it can cause a change of level.[147]

Analogously, this appears to play a fundamental role in music. To be sure, there plainly are compositions which, through instability, their failure to "anchor" themselves at a particular level, and continual changes of the base level [*Grundlage*], introduce a swaying from here to there, which for many people brings about unpleasantly intense feelings of instability. But more generally, playing a tonal movement pattern [*Tonbewegungsgestalt*] within a particular "level" and providing sufficient anchoring cues for interpreting the tone steps within an enduring level, is one of the major principles of music. There is a whole number of technical principles taught in composition theory simply for furnishing cues suited to produce such "anchoring." And on the other hand, the laws of modulation theory provide a number of principles to enable clear and unambiguous transitions between levels. Indeed, it may be the most modern achievement of music to attain a steady, firmly and clearly enduring level *despite* the use of unfamiliar tones and harmonies. The rigor of "tonal character" allows even very unfamiliar harmonies to appear to be within
[p. 261] the clearly given tonal character, as in certain extreme cases with Reger.[148]

The furnishing of unequivocal anchoring cues also plays an essential role in fine art. It underlies the clear and compelling presence of a certain conceptual layout as well as the centering of *Gestalten* for which there are differences among different works, and even in the way in which certain ornaments work.

In all these areas, aside from strong compelling effects, there are considerable individual differences. Some people are quite insensitive in the

145. In a similar way, one is set for a certain distance, to a certain apparent size, etc.

146. The "absolute impression" of the "gigantically huge," the "tiny"; the "colossally heavy," the "feather-light" also points to similarities in the emergence of perceptual set [*Einstellung*].

147. Not only visually. Experiments with changes in level [*pitch—Tr.*] of a familiar melody are analogous. The failure to notice a change in level often occurs, similar to visual perception, because the events within the general level draw all attention to themselves.

148. Cf. Ernst Groeg, Die Kunst Max Regers, *Soc. Monatshefte* 1910, I. p. 47f.

face of suggestions inciting to a particular interpretation, or are so firmly "hooked" on one that only with difficulty can they be brought to appreciate a different one, even exhibiting faulty interpretations or blindness in face of new incitements. Some people at the other extreme can be influenced easily in this regard and, indeed, are labile with respect to anything new.

To summarize, with respect to the question of the spatial orientation, one is set [*eingestellt*] in a certain frame of reference. This set [*Einstellung*] can be loosened, and sets in other orientations can be achieved with effort. The "loosening" or impeding of a continuous anchoring can lead to instability and, in the extreme, to a purely visual vertigo. "Loosening" requires relatively strong distracting stimuli, such as prolonged viewing of motion without sufficient anchoring cues, or anchoring cues that work in the direction of a new orientation, or sudden large and salient changes, or prolonged observation of visual objects in the absence of any anchoring cues at all.

These facts point out the need for experiments to address specific problems in spatial perception. They indicate that, for a certain spatial orien-
[p. 262] tation to be present and for individual visual objects[149] to be perceived in a particular location, central factors in the visual domain are of fundamental importance.[150]

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149. Moreover, the displacement phenomena mentioned on p. 48 involve certain concerns that are beyond the present discussion. Consider, for example, the phenomenon in Figure X on p. 88, in which rotation around a fixed point was often seen, while the two corresponding points, in reality, had a certain separation from one another; furthermore that, under certain conditions, small differences between the positions of two objects were not noticed, whereas in the motion phase, motion was immediately perceived. And another strong phenomenon: if one arranges multiple parallel slider slits in repeating pairs, one under another, so that the even-numbered pairs of the stacked slits are lit up simultaneously, while the odd-numbered pairs are occluded, it often produces glaringly different ranges of apparent motion of the pairs. For instance, the first, third, and fifth rows together produce a much smaller ⇄ motion than the second with the third. This impression can be varied by occlusion of pairs.

‖ *a b*
‖ *b a*
‖ *a b*
‖ *b a*
‖ *a b*

150. Indeed, it may be said: excitation processes in individual cells are *not* isolated events within an otherwise dead region. They are received within, and in return affect, a living *organism*, whose characteristic individual nature determines the final outcome. More general processes concerning the characteristic transition in the whole may be responsible for the "instability" and, in the extreme, "visual vertigo." The factor responsible for the type of perception of individual visual objects can be tested through experiments on set [*Einstellung*] and anchoring.

Types of Slide Arrangements

The upper rectangle represents the fixed slide; the lower, the moving one.

Fig. I

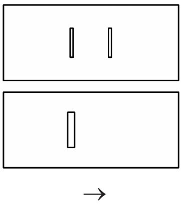


Fig. II

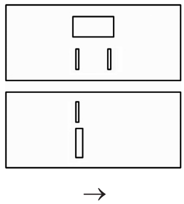
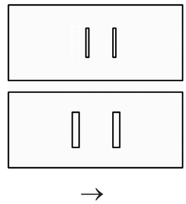


Fig. III



[p. 263] Fig. IV

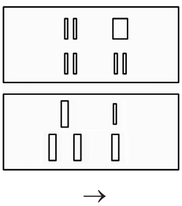


Fig. V

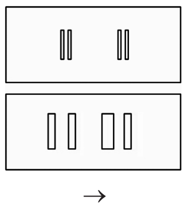


Fig. VI

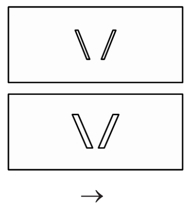


Fig. VII[151]

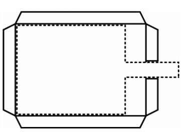


Fig. VIIIa

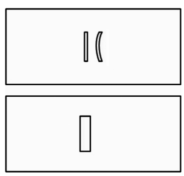


Fig. VIIIb

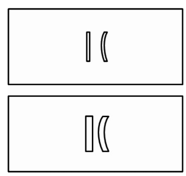


Fig. IX

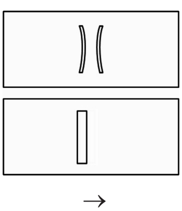


Fig. X

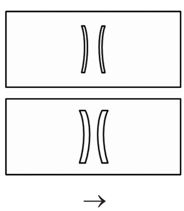
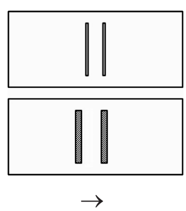


Fig. XI



151. [*The solid lines represent the piece in front, the dotted lines the one behind, which has a handle. The tabs of the front piece fold back to make a space within which the back piece can slide, thus generating relative motion between the front and back.—Tr.*]

Fig. XII

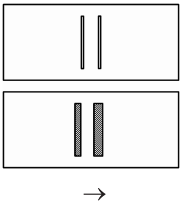


Fig. XIIIa

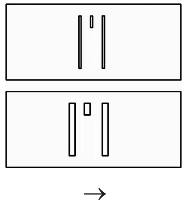


Fig. XIIIb

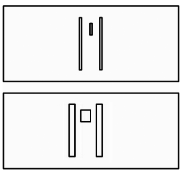
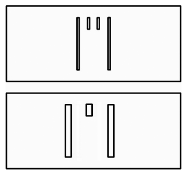


Fig. XIV



[p. 264] It is superfluous to supply here arrangements easily derived from those above.

Examples of Arrangements of Objects in the Exposure Fields of the Tachistoscope

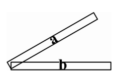
Fig. XV

Parallel arrangement. 

"the separation"

Variations: 1. In succession: *a b* ↓ or *b a* ↑
2. In separation
3. In overall positions (with both parallel strips horizontal, vertical, tilted)
4. Sliding one sideways relative to the other
5. In the size, shape, color, and brightness of the objects

Fig. XVIa

Angle arrangement. 

1. Variations: 1. In succession: *a b* ↘ or *b a* ↖
2. In angular separation (separation over an acute angle, a right angle, an obtuse angle)

3. In overall positions (pendulum, tilted, in various quadrants, and the like)
4. Sliding sideways
5. In the size, shape, color, and brightness of the objects
6. In vertex conditions:
   (a) *a b* touch each other at the vertex
   (b) the vertex parts are missing
   (c) a small circle replaces the vertex in one or both exposure fields

Fig. XVIb

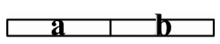


Fig. XVIc

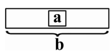


Fig. XVId

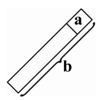
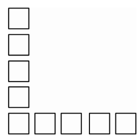


Fig. XVIIa



Rows of squares or circles are substituted for the strips; these are set under the full strips so that, as desired, the row of squares in question can be exposed in the place of one or both of the full strips, by taking away the strip.

[p. 265] Fig. XVIIb

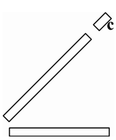


Fig. XIXa

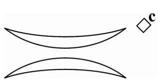


Fig. XIXb

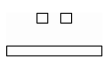


Fig. XXa

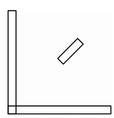


Fig. XXb

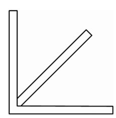
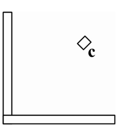
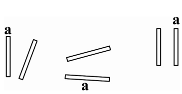


Fig. XVIII



In the visual field (within the motion field or outside it), a third object *c* is presented in one of the two exposure fields, or identically in both. For variations, see §10.

Fig. XXI



and similar successive exposures presented at the same time.

Fig. XXII

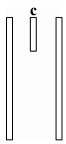
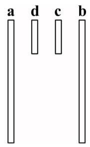


Fig. XXIII



a c and *b d* are each presented in the same exposure field.

Fig. XXIV

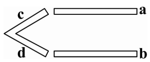
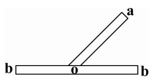


Fig. XXV



a, the shorter line, is presented so it can rotate around *o*, and is exposed at various angles to *b b*. Similarly with extension of *a* (two strips crossing), in other arrangements of *b b*, and so forth

Fig. XXVI

(Received 29 January 1912.)

Translated by Michael Wertheimer and K. W. Watkins

Synopsis of Max Wertheimer's 1912 Article

Viktor Sarris

> A physiological theory has, in my opinion, a dual function in connection with experimental research. On the one hand, it should unite the various individual results and lawful relationships and make it possible to deduce them. On the other hand, and this is the more fundamental function, the unification should serve scientific progress by . . . addressing specific experimental questions that first test the theory itself, and then penetrate further into the fundamental lawfulness of the phenomena.
>
> —Max Wertheimer (1912, p. 75)

Abstract

Max Wertheimer conducted and published his experimental studies on apparent as compared with real motion at Frankfurt's Institute of Psychology during 1910–1912, under the patronage of its director Friedrich Schumann (1863–1940). The main emphasis of this synopsis lies on Wertheimer's (1) apparatus, methodology and findings, (2) basic Gestalt theoretical concept, (3) neurophysiological theorizing, and (4) clinical-psychological observations. Today's readers might be interested to know that Wertheimer's paper immediately led to extensive follow-up work, including investigations by Wertheimer himself during the period 1911–1914 on the principles of perceptual organization (Wertheimer, 1923).

Wertheimer's 1912 article, after its *Introduction*, consists of 22 sections (§1–§22) including an interim summary (§18) plus an *Appendix* (§22) with more than 26 schematic illustrations of his apparatus.

Major Issues (Introduction and §1)

In 1910 Wertheimer saw the special significance of apparent motion (AM), a particular type of visual "illusion" in which the phenomenon of seen motion is generated by two stationary stimuli, as contrasted with real motion (RM). Although this type of illusory motion was already well-known, as in the then popular motion pictures, and already described in the published literature as early as 1875 by the physiologist Sigmund Exner (1855–1926), it was Wertheimer who first recognized its theoretical relevance for a new conception of the mind. He developed his own empirical research paradigm and psychological theory in Frankfurt, acknowledging earlier research by Exner, Karl Marbe (1846–1926), and Friedrich Schumann (1963–1940), his mentor in Berlin in 1901–1902. He also referred to Christian von Ehrenfels (1859–1932), his teacher at Charles University in Prague, specifically to his publication on "Gestalt qualities" (*Gestaltqualitäten*) in 1890.

The *Introduction* lists the major rival explanatory theories of apparent motion later to be rejected by Wertheimer, namely: a sensation theory, afterimage theory, eye-movement theory, and fusion theory. The paper proceeds with a brief description of the basic experimental setup using the Schumann tachistoscope, then the most precise time-measurement apparatus available. Using this equipment, the participants in Wertheimer's motion-perception studies—primarily Wolfgang Köhler (1887–1967), Kurt Koffka (1886–1941), Koffka's wife Mira Koffka-Klein, and himself—reported, for instance, a vertical line appearing to move from one location to another nearby, thus demonstrating Wertheimer's so-called "phi" motion (from the Greek term "*phenómenon*"), which occurs when two stationary lines *a* and *b* are successively exposed at an appropriate time interval—although in reality there is no physical movement of the stimulus lines whatsoever.

Experimental Methodology and Its Phenomenological Basis

In his studies on AM versus RM Wertheimer used, besides the Schumann tachistoscope, a variety of additional equipment such as, for instance, a slide projector (with slides or diaphragms), a shadow-casting epidiascope, a Zimmermann tachistoscope (with a revolving kymograph), and several simple cardboard cutouts, with one index card sliding relative to another. However, the most important procedure was the adaptation of the Schumann tachistoscope, enabling him to obtain quantitative data along with a large number of phenomenological observations.

Wertheimer was able to manipulate a multitude of relevant factors including the following: stimulus duration, interstimulus time interval, local stimulus distance, stimulus intensity, object form, object color, and object orientation. Additional conditions included a third object introduced into the exposure field and a long series of exposures presented in succession. In Wertheimer's own words, among the crucial AM factors are the following:

1. Observations during the transition from one of the three main stages [simultaneous, in motion, and successively stationary] to another, with variation of the time interval *t* between the exposures of the two objects, and variation of the exposure times.
2. Appropriate variations in the arrangement of the two objects, such as their position and distance from each other, their shape, color, and other variations of the objects themselves.
3. Variations in the observer's behavior: fixation, attention, and set (*Einstellung*).
4. Introduction of additional objects into the field of exposure, with complicating factors to be eliminated through appropriate control experiments.
5. Investigation of aftereffects. (§1, p. 6.)

The phenomenology of AM versus RM was studied with the help of a research design, known in today's literature as "yoked control design," whereby two AM and RM stimulus sets were presented simultaneously under comparable conditions.

Main Results and Discussion

Wertheimer discriminated among three stages of apparent motion: simultaneity ("*Simultanruhe*"), succession ("*Sukzessivruhe*"), and apparent motion (AM). For the latter he distinguished between optimal motion of an identical object moving from *a* to *b* (optimal motion, "*Optimalbewegung*"), when the unstimulated interspace is continuously filled in, and phi motion when there is only motion without perception of a moving object ("*objektlose Bewegung*," "*reine Bewegung*"). In addition, he described partial motion of one or both objects ("Singular"—or "*Innenbewegung*" and "*Dualbewegung*"). These partial motions do not obey the criteria of *identity* and *continuity* but represent transitional phenomena between the stages.

Two tables (p. 17f.) list the psychophysically obtained time measurements obtained for the different motion stages. Under the conditions of Wertheimer's experiments, optimal motion was perceived with an interstimulus interval of about 60 ms; with shorter intervals of about 30 ms, the two stimulus lines *a* and *b* were seen as "simultaneous"; with longer intervals of about 200 ms, they were seen as "successive." Importantly, Wertheimer states: "In most cases, the actual and the 'apparent' motions were entirely indistinguishable, even to (experienced) observers . . .

trained for months" (p. 13). In addition to the quantitative measurements, extensive phenomenological reports—in great detail—take up about two thirds of the paper. The following examples illustrate some of these qualitative findings (experimental phenomenology):

Temporal–spatial factors Crucial for the occurrence of apparent motion is, ". . . aside from the temporal conditions, the distance between the two objects. For instance, a smaller distance expanded the range of time intervals that enabled optimal motion (phi)" (p. 63).
Interocular transfer "In additional experiments it was confirmed that the motion could be seen even when one stimulus [*a*] was presented *to one eye, and the other stimulus* [*b*] *to the other*" (p. 64).
Negative afterimage ". . . It was confirmed that the percept of motion resulting from . . . successive exposures [of *a* and *b*] was followed by a *negative motion afterimage,* analogous to the afterimage phenomena experienced with prolonged viewing of real motion." (p. 65).

Gestalt Theory and Principles of Perceptual Organization

The paper contains only a few hints about what would later become Gestalt theory and the principles of perceptual organization (e.g., the principles of proximity, similarity, common fate, etc.). But there are at least three explicit references in this 1912 paper to Wertheimer's basic Gestalt thinking:

Gestalt arrangement of objects ("Gestaltanordnung") The Gestalt arrangement too may be considered relevant for apparent motion. This holds in particular if three or more stimulus objects *a, b, c* . . . are presented in a special spatio–temporal mode (see pp. 11, 43f., and 79; cf. figures XXII–XXVI, p. 91).
Law of the smaller separation ("Gesetz des kleineren Abstands") "As predicted by the principle of the smaller separation [proximity]," there is a particular type of apparent motion (p. 60; see also pp. 62f. and 76). This brief mention foreshadows Koffka's and Korte's later studies on the laws of motion psychophysics (see the Epilogue in this volume).
Nonarbitrary nature of Gestalt motions ("Gestaltbewegungen") Some of Wertheimer's findings speak for compelling Gestalt impressions (*zwingende Gestalteindrücke*): There are characteristic transverse and holistic brain processes which ". . . must play an important role, directly relevant for some factors that still need to be clarified psychologically. . . .

Other results as well point to something remarkable about compelling Gestalt impressions. . . . Experimental research will have to investigate the conditions that make for a compelling Gestalt . . ." (p. 79; cf. the "short-circuit theory" cited below).

In discussing the different theories as potential candidates for the explanation of the AM phenomena, Wertheimer convincingly rules out various alternative interpretations of his own findings. Importantly, he demonstrates that his own results are not consistent with Wilhelm Wundt's (1832–1920) and E. B. Titchener's (1867–1927) structuralism (element theory, "*Elemententheorie*") and the cognitive "judgment-illusion theory." Specifically, he argues on the basis of his experiments that neither peripheral effects such as afterimages nor eye-movement events or shifts of attention can explain the AM phenomena in question (cf. §20). Notably, near the end of the article, he refers to the phi phenomenon also in other sense modalities (e.g., melody "*Gestalten*" in the spirit of Christian von Ehrenfels, 1890), thus placing his conclusions from visual observations in a broader context: "While these are specifically visual φ phenomena, analogous topics are studied in other sense modalities. For instance, in the acoustic domain, the previously mentioned phenomenon of the 'living interval,' of 'tonal movement,' though different in principle, resembles a nonstatic type of directed experience." (p. 80). This observation is especially relevant because only a few years later Wertheimer investigated such auditory phi motions more fully together with Erich von Hornbostel (1877–1935).

Interim Summary (§18)

Wertheimer's preliminary summary—as condensed below—pertains to eleven areas listed in section §18 of his paper:

1. Optimal, i.e. pure, apparent motion ("*Ganzbewegung*"), with the indication of the major psychophysical conditions for its occurrence.
2. Long-term observation of successive stimulus-series presentations and the concept of phenomenological identity ("*Identität*") under the different experimental conditions.
3. Dual partial-motion impressions, with different motion impressions for different objects.
4. Motionless and motion impressions (partial motions) for two different objects presented at the same time.

5. The secondary role of attention in AM perception.
6. Various other partial-motion impressions resulting from a variety of experimental conditions.
7. The case of pure phi motion without any object being seen as moving.
8. Motion impressions under the condition of presenting three, instead of only two, objects.
9. Different motion impressions with variation of the stimulus duration.
10. AM impressions being indistinguishable from RM perception.
11. Negative afterimages being produced from AM as well as from RM perception.

Neurophysiological Theory and Clinical Observations

In section §21 Wertheimer suggests a neurophysiological hypothesis—revolutionary for his time—that might explain the irreducible motion phenomena via certain possible cortical processes in the human brain. Wertheimer argues persuasively that the phi phenomenon cannot be explained by peripheral sensory mechanisms, but only by taking into account higher-order brain processes (after all, among other findings, the stimuli *a* and *b* could be presented to the two retinas separately and still yield AM). Specifically, he elaborates on a neurological theory of Sigmund Exner (1875), at that time perhaps the most influential theory of brain functions.

Wertheimer suggests: "In this sense, let me here sketch out briefly, as a supplement, a basic physiological scheme that permits a unifying account of the experimental results. . . . It concerns particular central processes, physiological 'transverse functions' [*Querfunktionen*] of a particular kind that serve as the physiological correlate of φ phenomena [a physiological *short circuit* or *Kurzschluß*]. . . . According to recent neurophysiological research, one must assume that the stimulation of a central location *a* produces a physiological effect within a certain radial distance [*Umkreis*]. . . . If *t*, the intervening time between the emergence of the excitation in the two successively stimulated places *a* and *b*, is too great, then the spreading around *a* has already dissipated when the spreading from *b* emerges (succession stage). If the intervening time is shorter, such that the spreading from *a* is present when that of *b* arrives, perhaps at the peak of its temporal course, then the cross-over of excitation takes place. If *t* is very short, then the spreading of *a* and *b* occur too close to each other in time (or, rather, at the critical moment the one around *a* has not yet reached its sufficient height) to enable the directional short circuit (stage of simultaneity)." (p. 75f.). It is only when the two effects occur close enough together in time and space that the *short circuit*, and hence the perception of motion, occurs.

Wertheimer considers his neurophysiological theorizing merely a "*hypothesis*" which may serve as a potential explanatory basis for AM. In addition, however, he links this hypothetical account to a certain neurological disorder of Gestalt perception. Specifically, he refers to the careful examination of a female patient with severe impairments of both occipital lobes, who erroneously perceived a single moving light (RM) as a succession (sic!) of different stationary lights—in fact, she was not able to see any motion at all (cf. p. 75). Wertheimer examined this patient in 1911, together with Otto Pötzl (1877–1962), in the Vienna Neurological University Clinics (under the directorship of the later Nobel laureate Julius Wagner von Jauregg, 1857–1940). These clinical observations, made by the help of his tachistoscope apparatus to test for both real and apparent motion, led Wertheimer to conclude that a severe brain disorder interfered with this patient's Gestalt perception.

It should be stressed that Wertheimer developed his neurophysiological hypothesis and psychopathological reasoning well in advance of modern knowledge about brain processes and modern tools for studying them (e.g., EEG recordings, positron-emission tomography, or magnet-resonance imaging technology).

Appendix

The *Appendix* (§22, pp. 88–91) contains some 26 graphic apparatus schemata, with very brief descriptions of each, providing further details about the experimental variations and findings. It also summarizes Wertheimer's reasoning about visual space perception, relating to the phenomenological impression of depth effects with some additional experimental arrangements. Furthermore, the concepts of perceptual "frames of reference" ("*Bezugyssysteme*") and "anchoring" ("*Verankerung*") are briefly presented as well as a sketchy description of observations in a mirror-distorted room.

Acknowledgment

A longer version of this synopsis has been provided elsewhere (Sarris, 1987, 1989). Special thanks are due to Michael Wertheimer for reading and providing helpful comments on a draft of this synopsis.

Motion Perception: A Modern View of Wertheimer's 1912 Monograph

Robert Sekuler

Abstract

Max Wertheimer's 1912 monograph on apparent motion is a seminal contribution to the study of visual motion, but its actual contents are not widely known. This article attempts to clarify what the monograph did and did not contribute, emphasizing links between Wertheimer's principal findings and the results of subsequent investigations of motion perception, including currently active lines of research. The topics discussed include Wertheimer's experimental tests of explanations for apparent motion; his work with motion phenomena that lie between succession and optimum motion; his studies of the influence of attention on motion; explorations of various forms of hysteresis and motion transparency; and Wertheimer's work with a motion-blind patient.

1 Introduction

In 1912 Max Wertheimer published the first of the papers on which his reputation rests, a monograph entitled "Experimentelle Studien über das Sehen von Bewegung." In the course of little more than 100 pages Wertheimer described several dozen experiments and demonstrations, touching upon many issues that now occupy a central position in research on motion perception. Today there can be no doubt that Wertheimer's monograph was a seminal contribution.

My impression, which may be unjustified in its cynicism, is that this important paper is cited far more often than it is actually read. Of course, many papers have high cite-to-read ratios, so why remark on this particular case? There are four reasons. First, significant aspects of the monograph are not only ignored by secondary sources, they are actually misrepresented or distorted in the retelling. Second, the monograph is of continuing interest because it foreshadows issues in contemporary research on motion perception. Third, the ingenuity behind some of the questions and experiments offers valuable lessons for students of perception. Finally, Wertheimer's monograph illustrates how a thoughtful researcher can wring objective quantitative insights out of subtle phenomena without sliding into uninterpretable subjectivity.

Just as there are several reasons why the monograph should be read, there are also several reasons why this tends not to happen, despite the current high interest in motion perception. First, the field now uses what Teller (1990) terms 'special stimuli'—spatiotemporal displays designed specifically to test particular physiological linking hypotheses. In the domain of visual motion, special stimuli include second-order motion displays (Chubb and Sperling 1988; Pantle 1973), isoluminant gratings (Cavanagh et al. 1984), plaids (Adelson and Movshon 1982), and displays whose elements follow complex trajectories (Scase et al. 1996; Sekuler 1992). Although some of Wertheimer's experiments did use special stimuli for similar purpose, the stimuli in his experiments were inspired by a view of the nervous system that bears little connection to our current understanding. Second, Wertheimer attempted to communicate not only the results of his psychophysical experiments, but also the nuances of his subjects' experiences. As a result of this laudable effort the monograph contains many passages in which the language is opaque or obscure. As one translator put it, "This paper is particularly difficult to translate because of Wertheimer's deliberate use of words and phrases in a novel manner, i.e., as symbols of the event (e.g., 'stationary-position-character') rather than as simple names or descriptions" (Shipley 1961, page 1032).[1] Third, to my knowledge no complete English translation of the monograph has been published, though excerpts have been. For example, Shipley (1961) published a translation of about 70 pages; Herrnstein and Boring (1965) offered a fluid rendition of only 7 pages. Finally, although it is not a translation, Paul Kolers's book on visual motion (1972) devotes a full chapter to Wertheimer's monograph, and is also an excellent introduction to the topic.

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1. Shipley's translation has at least one serious, substantive error. On page 1081, footnote 48, it inverts an experimental result reported by Wertheimer. I first suspected this might be the case when I was unable to replicate the results as Shipley described them. Later, after reading the original, I discovered the reason for my apparent failure to replicate.

1.1 Caveat Lector

My goal here is not to provide a complete guide to Wertheimer's monograph; that task belongs rightly to the persons who prepare and publish a full translation into English. Instead, I want to call attention to aspects of the monograph that might benefit and stimulate research on motion perception. I would like to encourage more people to read for themselves what Wertheimer had to say.

The interpretation of history is colored by the interpreter's knowledge and perspective (Butterfield 1931/1950). The most familiar manifestation of such influences may be the 'Rashomon effect'[2] in which eyewitness observers diverge in their interpretation and report of some event. But the Rashomon effect does not exhaust the ways in which knowledge and perspective influence historical studies. The interpretation of written historical documents is not immune from the influence of one's background knowledge of events and developments subsequent to the document. When one reads an historical document, one tends to interpret ambiguous remarks in light of knowledge that comes from outside the text. With Wertheimer's monograph a reader is unavoidably mindful of Wertheimer's own later contributions, as well as of other subsequent developments in the field.

One may try to recognize and resist the tendency to re-interpret history, but success is far from assured. This general concern will be familiar to students of perception who, as well as anyone, recognize the contribution of top-down influences to perception (Gregory 1969; Gregory 1995). Perhaps this historiographic problem is another reason to read Wertheimer's monograph oneself.

2 What Wertheimer Did Not Do

Some secondary sources credit Wertheimer with discoveries that rightly belong to others. So, before getting to Wertheimer's actual contributions, it might be useful to identify several things he did *not* contribute. For example, long before Wertheimer people realized that visual motion could be generated by properly sequenced stationary targets. In 1824, Peter Roget, best known today for his thesaurus, presented a paper to the Royal Society describing his idea that visual motion arose from a

2. Named for *Rashomon*, a 1951 film by the distinguished director Akira Kurosawa. In the film, four eyewitnesses to a murder and rape report strikingly different versions of what they all saw.

succession of static images (Boorstin 1992, page 740). And, several decades before Wertheimer's monograph, Exner (1875) recognized that apparent motion could be important for understanding perception more generally. Exner, with whom Wertheimer did some postdoctoral study (Sarris and Wertheimer 1987), demonstrated that motion perception was not a mere parasite on the perception of space or time. In particular, Exner showed that apparent motion could be seen even though the two targets producing that motion were too close, in time or space, to be discriminated from one another. And, long before Wertheimer's monograph, researchers knew that variation in the timing of stimulus sequences carved out three perceptual domains, which we call 'succession,' 'motion,' and 'simultaneity.' Of course, the best-known application of apparent motion is its use in television and movies. Coincidentally, the word 'movie' was coined in the year of Wertheimer's publication. By that time, apparent motion was being exploited to good financial advantage by Thomas Alva Edison and others (Boorstin 1992).

None of these facts diminishes the importance of what Wertheimer did. His depth of understanding and persistent curiosity were extraordinary. He appreciated the rich theoretical implications of the very simple phenomenon he studied. He was equally aware of the phenomenon's experimental possibilities.

3 The Apparent Mystery of Apparent Motion

In the opening paragraphs of his monograph Wertheimer identified the most intriguing feature of apparent motion: Two static objects, presented in succession at different locations, produce motion—a perceptual attribute not owned by either object alone.

> If seeing motion is due to an "illusion"—if physically there was only a stationary event, and later a different stationary event at a certain distance from the first—then, based on the two sensations of stationary events, a subjective completion must somehow have occurred along with them, subjectively including the intermediate positions. The following investigation deals with impressions of motion that can be achieved by presenting two such successive events, even with considerable distance between them. (Wertheimer 1912, pages 162–163)

From prior work by others, Wertheimer collated several alternative explanations for apparent motion. Taking just two of these alternatives, apparent motion had been attributed to factors such as: (a) processes

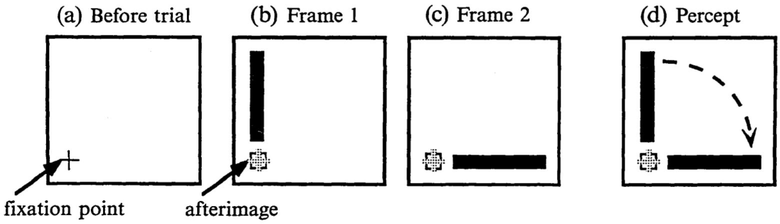

Figure 1
Schematic of the method Wertheimer used to detect subjects' eye movements. (a) At the start of each trial the subject fixated a small luminous cross. With the afterimage of the cross on the fovea, the subject fixated the spot where a small square would appear, and saw a (b) vertical bar alternate with (c) a horizontal bar. (d) Despite the stability of the fixation point relative to the small square subjects saw apparent motion.

associated with eye movements; and (b) cognitive inferences of the type "I saw X, I saw Y, therefore X must have moved to Y." Without the benefit of modern tools, such as eye-trackers and computer-generated displays, Wertheimer managed to address these explanations experimentally, usually offering several experiments to test each one of them.

Consider, for instance, some of the five experiments done to determine whether eye movements could explain apparent motion. Wertheimer (page 182) began by confirming that apparent motion could be generated with total exposure times below one-tenth second, considerably less than the reaction time of the oculomotor system. (Total exposure time is the sum of each object's duration, plus the interval between them.) Wertheimer went on to devise a method that allowed him to detect eye movements that might occur while subjects viewed the display (pages 183–184). At the start of each trial, the subject fixated a small luminous cross [figure 1, panel (a)]. With the afterimage of the cross on his or her fovea, the subject fixated the spot where a small square would appear during the motion sequence. Then the subject was given the sequence whose components are illustrated in panels (b) and (c). The resulting apparent movement is represented in panel (d). Subjects reported that the afterimage remained static at locus of fixation, suggesting that eye movements were either small or nonexistent. Just as important, subjects reported that the motion was the same as it had been in a control condition with no afterimage present. Another experiment used displays designed to evoke simultaneous opposite directions of motion. Such movements would rule

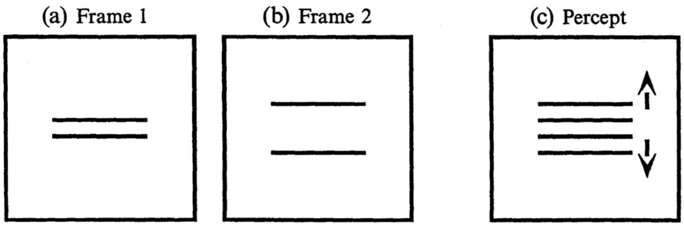

Figure 2
Schematic of display used to evoke simultaneous opposite directions of motion. In the movement space, the lines shown in panel (a) alternated with those in panel (b). The result—simultaneous opposite directions of apparent motion—is illustrated in panel (c).

out a causal role for eye movements, which could take only one direction at a time (pages 184–185). Figure 2 illustrates the successive frames of one such display, along with a diagram suggesting what subjects reported. Although scant details are given, Wertheimer commented that he could generate three or four disparate simultaneous impressions of motion. For example, he found that good motion was produced when some novel collection of complex objects (a small cage, a plant, and bunch of grapes) were presented for the first time. In such cases, the various objects could be made to move in different directions.

As I indicated above, Wertheimer also tested whether apparent motion depended upon some form of cognitive inference. In one experiment on this issue, Wertheimer presented apparent and real motion side by side. Observers who were ignorant of which stimulus was which attempted to distinguish the two.

> In most cases, the actual and the "apparent" motions were entirely indistinguishable, even to observers practiced in meticulous observation of momentary exposures in various tachistoscopic experiments performed over a span of months. In some cases, . . . the two types could finally be correctly distinguished from each other, not by designating one as motion and the other as nonmotion, but by stating a qualitative difference in the kind of motion perceived. . . . Very often there were statements like, "One motion looked different from the other in that it was so strong, energetic, the best motion of all," and this with regard not to actual motion but the apparent motion produced by two successive stationary stimuli. (pages 173–174)

This result—equivalence of real and apparent motion—depends upon careful choice of stimulus parameters. With most parameter sets, including most in the monograph, apparent motion is not likely to be confused with continuous motion, a point considered further in the next section.

4 Why Do We See Motion, and What Does the Motion Look Like?

Wertheimer was intrigued by the fact that nonmoving stimuli produced clear and compelling motion. Almost certainly part of the explanation of apparent motion lies in the limited spatial and temporal resolution of the visual system. The visual system is blind to spatiotemporal variations falling outside these limits, which Watson et al. (1983) designated the 'window of visibility.' This construct can be used to predict whether some time-sampled stimulus would be perceptually indistinguishable from one in which motion is continuous. Any time-sampled stimulus, like the one schematized in figure 1, can be represented on space-time frequency axes. Spectral components that fall outside the window of visibility would have a diminished effect or no effect on vision. This opens the possibility that two physically different stimuli could generate identical visual responses, and would therefore be perceptually indistinguishable from one another.

However attractive it may be as a simplifying heuristic, as an explanatory construct the window of visibility is deficient. First, the window of visibility ignores directional selectivity, one of the motion system's defining properties. Because it operates on spatiotemporal variations without regard to the directional characteristics of those variations, the window of visibility is silent about perceived direction of motion. It is also silent about subtle phenomena that depend upon the characteristics of directional tuning, for example the efficiency with which directional information is extracted from stimuli comprising many different spatially-intermingled directions (Watamaniuk 1993). Because it ignores directional properties, the window of visibility has nothing to tell us about the actual *appearance* of the sampled motion: It tells us *whether* a sampled stimulus will be distinguishable from a continuous one, but it says nothing about what either one will look like. In addition, predictions from the window of visibility ignore masking effects from spatiotemporal variations that lie just beyond the limits of visibility. Though such components are not visible themselves, they can influence (mask) the appearance of motion (Wandell 1995). The window's deficiencies are particularly important in connection to Wertheimer's monograph, which emphasized stimulus-related variations in the strength and clarity of apparent motion.

Exner (1875) was probably first to identify three temporal regimes of apparent motion: Long intervals between stimuli yield succession; short intervals yield simultaneity; and appropriate intermediate intervals yield apparent motion. This tripartite scheme now is familiar to even the most

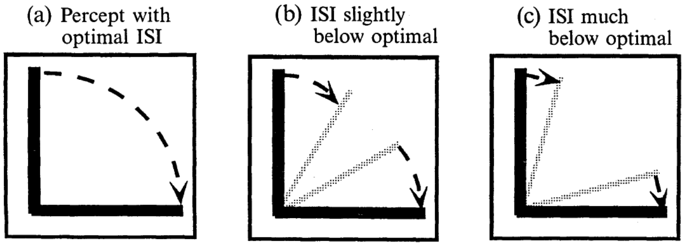

Figure 3
One form of partial movement studied by Wertheimer. The dotted line in panel (a) illustrates the complete movement seen with an optimal interval between the two stimulus components (ISI), a vertical bar and a horizontal bar. Panel (b) suggests the partial movement seen when the interval between the two display frames is shortened. Panel (c) illustrates the consequence of shortening the interval still further.

casual student of psychology. Wertheimer, however, realized that the visual system did not entirely respect Exner's scheme. In fact, he was intrigued by the percepts that lay between stages. Wertheimer asked (1912, page 166):

> How does the optimal motion stage arise? How does it develop out of the simultaneous and successive stages? How does it decompose into them? What is perceptually given in the interstices among these three stages? Are there qualitatively distinct, characteristic impressions of intermediate stages that might shed light on the qualitative development and psychological nature of the optimal impression of motion?

With painstaking care Wertheimer explored motion's in-between stages. Changing the interstimulus interval in very small steps,[3] he would present a stimulus and record the observer's report. Typically, two minutes elapsed before the next stimulus presentation. This leisurely pace allowed him to do some necessary calculations and also allowed any residual effects from the preceding trial to dissipate. Among the subtleties revealed by this effort was partial movement *(Teilbewegung),* in which the elements move only part way toward one another, and singular movement *(Singularbewegung),* in which only one of the two elements appears to move (Wertheimer 1912, pages 191–196). Figure 3 schematized one form of

3. I am not reporting the numerical values given by Wertheimer because those values would vary considerably with actual stimulus conditions; I do not want to encourage misleading overgeneralizations, such as "the boundary between good motion and succession occurs at so-and-so many milliseconds."

partial movement. This stimulus sequence in each panel of that figure was the same as in figure 1, a vertical object followed by a horizontal one. The left panel shows that when the interval between the two frames is optimal the resulting motion seems to cover the entire space between the objects: The vertical object rotates all the way to horizontal. When the interstimulus interval (ISI) is made slightly shorter, though, subjects report that the vertical moved only part way [panel (b)]. If the ISI is shortened further, without reaching the point of simultaneity, partial movements become even shorter (as illustrated in the right panel of figure 3). Note that these effects do not lend themselves to easy quantification by ordinary psychophysical methods. Subjects can be encouraged to map these variations in the character of motion onto response categories of "motion" and "no motion," but only at the cost of obscuring phenomena that may be significant theoretically, however inconvenient they may be in data analysis. DeSilva articulated this point with particular clarity (1928, pages 553–555).

Wertheimer explored several factors that favored partial motion, or promoted partial motion into full blown motion. One particularly potent factor was attention, to which I next turn.

5 Attention Influences Apparent Motion

In several experiments Wertheimer showed how the characteristics of apparent motion are altered by shifts in observers' attention (pages 208–211). Generally, the appearance of motion is favored in a place to which the observer is attending. For example, Wertheimer presented a red horizontal stripe followed by a similar blue (or green or white) stripe located below the red one (page 209). He found an ISI that produced good (but not optimal) motion from the red stripe to the blue. He then encouraged subjects to concentrate attention on the first stripe, for instance by presenting that stripe alone several times. Now subjects reported that the attended-to stripe moved part way toward the non-attended stripe, which seemed not to have moved at all. When subjects attended to the lower stripe, the upper stripe (presented first) seemed to be stationary, while the blue stripe moved clearly and distinctly into its lower position.

Figure 4 illustrates another of Wertheimer's experiments on attention (page 211). A short vertical line was followed by a longer horizontal line. When attention was positioned in the vicinity of the left end of the horizontal line, the observer saw motion toward the left; positioning

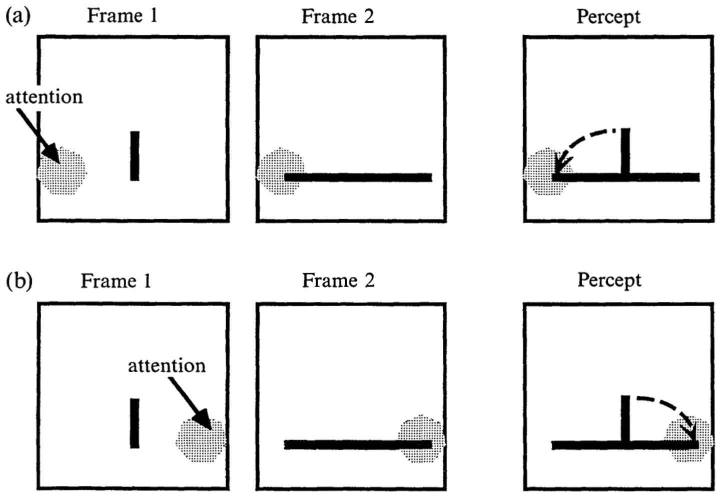

Figure 4
Schematic result of one of Wertheimer's experiments on attention. A short vertical line was followed by a longer horizontal line. (a) When attention was positioned in the vicinity of the left of the horizontal line, observers saw motion toward the left. (b) Positioning attention at the other side of the horizontal line produced motion toward the right.

attention at the other side of the horizontal line produced motion toward the right.

In recent years many researchers have explored the impact of attention on perceived motion, though none seems to have acknowledged Wertheimer's pioneering work in this area. One example of such influence is the motion-induction effect. Here an observer is shown a spatially extended stimulus, such as a horizontal line, and movement is seen within the stimulus in a direction *away* from the end of the stimulus to which the observer attends. For example, Hikosaka et al. (1993a, 1993b) found that a briefly flashed horizontal line appeared to be drawn either left to right or right to left, depending upon the side to which the observer attended: When the subject attended to a spot at the left side of the to-be-drawn line, the line appeared to grow outward from the attended spot. This effect is most likely caused by enhanced processing speed within the attended region (von Grünau et al. 1995), which could also describe Wertheimer's original observations. All of these, in turn, are related to the generalization known as the law of prior entry (Reber 1995, page 597): "Of two simultaneously presented stimuli the one upon which one's attention is focused will be perceived as having occurred first."

6 Perceptual Inertia: Hysteresis

Earlier I commended Wertheimer's caution in allowing two minutes to elapse between trials in some experiments. A similar caution led him to keep subjects uninformed, wherever possible, about the details and purpose of an experiment. This was especially important because his three main subjects (Wolfgang Köhler, Kurt Koffka, and Mira Klein-Koffka) served repeatedly in the studies, and during the course of these experiments Wertheimer, Köhler, and K. Koffka "saw one another daily, and actually discussed everything under the sun" (Koffka, quoted in Sarris and Wertheimer 1987, page 483).

6.1 Hysteresis of Motion

Into some experiments Wertheimer inserted catch trials—a maneuver that kept observers honest and also led to one intriguing result (page 217). A horizontal and a vertical line (as in figure 1) were alternated several times at a rate that produced good to-and-fro motion. Then, without the observer's knowledge, Wertheimer omitted the horizontal line, while continuing to present its vertical partner at its own appropriate time (page 218). The result was that for two or three presentations observers reported that they continued to see the motion, although the motion was partial and grew smaller with repeated presentations. By the third or fourth cycle no motion at all was seen. Bear in mind that the observer did not know that one of the lines had been omitted. This intriguing form of perceptual preservation was studied in more detail by DeSilva (1929), who not only omitted an element without warning the observer (page 282), as Wertheimer did, but also examined the effect of suddenly reversing the direction of motion, again without warning the observer (page 287). In both cases DeSilva found that for a short time after the stimulus changed observers continued to see the original direction of motion.

6.2 Hysteresis of Stimulus Orientation

Figure 5 illustrates a related effect which Wertheimer examined quantitatively. The upper two panels suggest what happens when a short oblique line is followed by a horizontal line: The resulting apparent motion takes the shorter of the two possible paths, either rightward (top panel) or leftward (middle panel). After establishing these baseline results, Wertheimer gave an observer several successive presentations of the sequence shown in the top panel. As expected, each presentation produced motion to the right. Now, while continuing to present this stimulus, Wertheimer

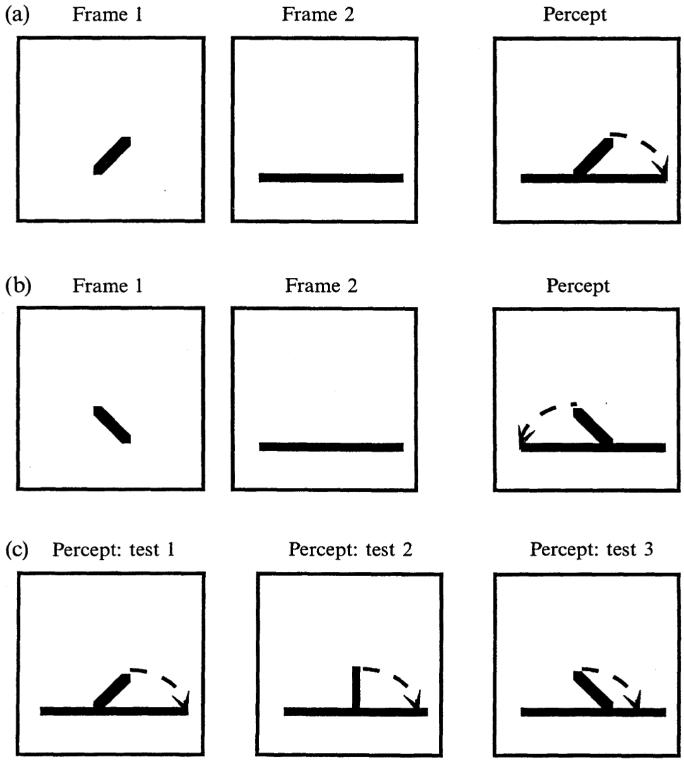

Figure 5
Hysteresis: Exposure to a stimulus that produces motion in one direction biases the response to a subsequently seen stimulus. The upper two panels, (a) and (b), show the result when a short oblique line is followed by a horizontal line. The resulting apparent motion takes the shorter of the two possible paths, either rightward (a) or leftward (b). After several presentations of the sequence illustrated in the top panel, any of the sequences in panel (c) produced motion to the right, which would not have happened in the absence of the conditioning exposure.

interspersed single presentations like those illustrated in the bottom panel of figure 5. The first test resulted in motion to the right, which is what would have been produced in the absence of the conditioning sequence. The second test produced a similar result—motion toward the right. And the same result even occurred in the third test, which previously would have produced motion to the left. Exposure to a stimulus that produces motion in one direction biases or primes the response to a subsequently seen stimulus. To quantify this phenomenon Wertheimer measured the orientation at which perceived direction reversed. The effects of the biasing motion were very substantial, shifting the critical orientation by as much as 35° or 40°.

6.3 Hysteresis of Stimulus Timing

Wertheimer reported another demonstration of hysteresis, by examining the interstimulus intervals (ISIs) at which good apparent motion could be seen. Far from being a fixed value (even for constant spatial conditions), the range of ISIs for good motion varied with the preceding exposure conditions. For example, exposures to an optimal ISI allowed a subsequently presented non-optimal ISI to evoke good motion. Thus, exposure to 'good' ISIs allowed subjects to see good motion at an ISI that ordinarily produced poor motion (pages 194–196). The converse also held: Starting with a 'poor' ISI narrowed the range of ISIs that could produce good motion.

In recent years hysteresis in motion perception has become an important theoretical issue because hysteresis is one sign of nonlinear cooperative interactions among visual mechanisms. Similar interactions may contribute to other perceptual domains, but the relatively extended time scale of motion perception makes motion a particularly sensitive index of nonlinear neural interactions. And several researchers have demonstrated hysteresis using random-element cinematograms, comprising spatially intermingled motion vectors in various directions (Chang and Julesz 1984; Nawrot and Sekuler 1990; Williams et al. 1986). But random-element cinematograms obviously differ from Wertheimer's stimuli in a number of ways, and results from the two kinds of stimuli may not be completely commensurable.

Recently Hock et al. (1996) quantified the hysteresis that can be generated by stimuli much like those used by Wertheimer. Hock and colleagues devised a display in which the luminance values of two nearby dots were simultaneously exchanged on alternate frames. Under favorable conditions, despite its physical simultaneity, this interchange produced a clear percept that the dots had moved from one position to the other. Hock et al. found that the threshold for seeing such movement depended on the relative luminances of the two dots (Lj and *L2*), on their mean luminance (Lm), and on the background luminance (Lb). These variables were expressed in the ratio $(Lx - L2)/(Lm - Lh)$, which Hock et al. call background-relative luminance change (BRLC). Note that in this ratio the numerator holds the time-varying properties of the stimulus, and the denominator holds those stimulus properties that do not vary with time.

Ordinarily, values of BRLC > 0.5 promoted seeing motion; values < 0.5 promoted seeing the dots stationary (simultaneity).

Hock et al. found that once either percept—motion or no motion—was established, it resisted change: The percept persisted despite changes in BRLC that favored the alternative percept. Eventually, when BRLC became sufficiently unfavorable to the current percept, the rival percept emerged. This resistance to change is an index of hysteresis which Hock et al. attribute to recurrent facilitatory influences among motion detectors. Note that although these influences show up as 'errors' in subjects' perceptions, outside the laboratory such influences would ordinarily benefit their owners by stabilizing perception in the presence of noise.

Hysteretic effects in motion recall Newton's first law of motion: A physical object moving at uniform velocity in one direction will persevere in its state of uniform motion unless acted upon by an external force to change that state. Based on their own observations of perceptual inertia, Ramachandran and Anstis (1983) suggested that, because the visual system evolved to process information from a world in which Newton's law holds, it is not surprising that vision exhibits a parallel perceptual version of Newton's law.

7 Transparency

In the natural world various circumstances can cause one surface to appear to move across another. For example, as you jog along a country road, your shadow moves across the road's surface, producing perceptual transparency. And, when a speedier runner passes you, her or his shadow moves transparently across your own more slowly moving body. In terms of the flow field of the stimulus, motion transparency arises from a discontinuity in the distribution of local velocities. In recent years, vision researchers have been quite interested in perceptual movement of one object or surface relative to another (Qian and Andersen 1994; Stoner and Albright 1994; Zohary et al. 1996). This psychophysical work and its physiological counterparts (Qian et al. 1994) seek to understand how the visual system manages to represent multiple motion vectors within a single region of visual space.

Although Wertheimer did not write about 'velocity distributions' or about 'multiple neural representations,' his motivation for studying transparency was not too different from the motivation that drives current research. He wanted to know what actually transpired when a target was seen to move (apparently) from position *x* to position *y*. Did the motion trajectory induce some measurable visual perturbation in the surface or objects over which it passed, or was the motion transparent to the surface or objects? He wondered about this, particularly for what he called pure phi, when motion, but no moving object *per se*, was seen. Because the term 'phi' is so often misused, a brief clarifying digression may be in order before proceeding. Today, the terms 'phi phenomenon' or 'phi movement' are sometimes used to signify apparent motion that is optimal, that is apparent motion that is perceptually compelling. This usage is certainly not what Wertheimer intended. To him, 'ϕ' meant objectless motion, as can be seen by Wertheimer's description of what happens when the successive presentation of two stimuli, a and b, produces apparent motion:

> The psychological circumstances can—without any bias—be designated $a\phi b$ . . . , where ϕ represents what is there in addition to the perceptions of *a* and *b*; what occurs in the space between *a* and *b*; what is added to *a* and *b*. (Wertheimer 1912, page 186)

It may help to note that ϕ has a more familiar counterpart in continuous motion. For example, when a small ribbon snake moved rapidly through the grass in a meadow, my friend Florence Harris remarked that she could "see the slithering, but not the slitherer." This observation vividly communicates that there was a clear sense of motion, but that the moving object itself was not seen.

To study transparency Wertheimer inserted various objects into the path of apparent motion (page 221 and following). In one case the interposed object was consonant with the objects that produced the movement. Would the movement passing across the interposed object summate with that object? Against a black background, a white vertical stripe, a, alternated at an optimal rate with a white horizontal stripe, b. Then, when b was presented, a short white oblique stripe, c, was also presented, in the middle of the two other stripes. Wertheimer wanted to know whether c gave any evidence of the passage of the longer stripe. For example, would the interposed line appear to lengthen or brighten? Subjects saw the motion across the field, but there was no sign that the interposed stripe was affected. The interposed bar did not, for instance, appear to lengthen, as one might expect had the interposed bar summed with the passing stripe. Five decades after Wertheimer's monograph, Kolers (1963) measured such interactions with greater precision. Kolers briefly flashed a small target in the path of a moving line. He adjusted the intensity of the light flash so that, when it was presented alone, the flash could be detected about nine times of every ten. He then allowed the line to move across the position in which the flash would occur. The motion of the line was either apparent or continuous ('real'). Although motions from the two sources were similar perceptually, they had disparate effects on the threshold for the interposed flashed target: A continuously moving line diminished the target detectability, but a line in apparent motion had no effect. The transparency of apparent motion accords with Wertheimer's original report.

8 Physiology of Motion Perception

Near the end of his monograph Wertheimer turned to the physiological underpinnings of apparent motion. Drawing on the observations of Exner and others, including haploscopic observations, Wertheimer strongly endorsed the proposition that seen motion draws on processes "which lie beyond the retina" (page 246). For him the contributions of attention and experience which he had investigated further strengthened this endorsement. Now it is taken for granted that the perception of apparent motion depends upon activity in several centers in the human cerebral cortex, including the middle temporal area (MT). Although many diverse studies have contributed to the development of this hypothesis, the work of Newsome and his colleagues has been especially influential (Newsome et al. 1986). One of their studies triangulated on the substrate of apparent motion, with the same stimuli used to study the responses of single cortical neurons in macaque visual cortex, as well as psychophysical responses in both macaque and humans. From careful systematic variation in the temporal and spatial parameters of the stimulus, Newsome et al. identified detailed parallels between motion sensitivity at the single neuron level and sensitivity measured psychophysically both in macaque monkeys and in human observers.

8.1 Physiological Short Circuits and Isomorphism

Wertheimer attributed apparent motion to a physiological short circuit, a lateral spread of excitation across adjacent centers of activity in the brain. (These centers of activity were set up by the presentation of the stimuli.) The short-circuit hypothesis is both well-known and wrong, so I will not discuss it here, except to note that it asserts an isomorphism that later was expanded and formalized by Wertheimer's colleague and experimental subject, Wolfgang Köhler (1920).

Note that the assumed isomorphism is not between stimulus and brain activity, but between brain activity and perception. As a result the theory could accommodate non-stimulus influences, including the influence of attention. For example, Wertheimer suggested that attending to one component of a motion stimulus increased the excitability of the cortical representation of the attended locus, thereby enhancing the likelihood of a physiological short circuit (pages 248–249). Although the physiological details were wrong, the overall approach seems to foreshadow contemporary accounts of exogenous influences on motion perception (O'Craven and Savoy 1995; Sekuler 1995).

8.2 An Early Report of Motion Blindness

Wertheimer's monograph contains a long footnote that resonates strongly with current research interests:

> A recent pathological case, with an affliction of both occipital lobes, appears to speak to the central basis of seeing motion. In *Wiener Klinische Wochenschrift* 24, p. 518, No. 14, 1911, Dr. Pötzl[4] reports of the afflicted patient: "If one presents a strong light in slower or faster motion to her, then she seems not to perceive the motion of the object; she characterizes what she sees as multiple lights. . . ." On the strength of this, I contacted Dr. Pötzl in May 1911, and in the course of the summer of 1911, I had the opportunity to test the patient repeatedly, with various real motions as well as with slider experiments. Stringent observation suffered somewhat from the impaired intelligence of the subject, but her deficiency in the seeing of motion was definitely confirmed time and again, even though she could recognize colors. When helped by acoustic impressions (rustling, etc.), she did speak of "fluttering back and forth." Meantime she recognized the color of what objectively moved past. (Wertheimer 1912, pages 246–247)

Wertheimer realized that the patient's impaired cognitive state muddied the interpretation of her results. And the absence of anatomical details, such as one would have with autopsy or with modern brain imaging, makes it impossible to know the precise site and extent of the damage, further reducing the scientific value of this case (Zeki 1991). With both these caveats firmly in mind, we should acknowledge Wertheimer's priority among researchers who have made psychophysical measurements in motionblind patients.

For his part Wertheimer was eager to learn whether Pötzl's patient, who had trouble seeing real motion, would also fail to see apparent motion, which she did. Wertheimer's comment that the patient, despite impaired motion perception, could still recognize the color of the moving object is consistent with what has been seen in recent cases of akinetopsia. The reduced visibility of both real and apparent motion is also consistent

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4. The paper to which Wertheimer referred was actually published by Pötzl and Redlich, not by Pötzl alone.

with recent findings, including those with patient L. M. (Zihl et al. 1991). Like many modern psychophysicists who have studied patients with akinetopsia, Wertheimer's goal was to exploit Nature's experiment to understand motion perception, particularly the physiological basis of various forms of motion perception. Today, of course, researchers use more diverse and sophisticated stimuli to test motion-impaired patients (Nawrot and Rizzo 1995; Zihl et al. 1983). Of particular theoretical importance have been demonstrations of selective losses to one type of motion coexisting with preserved responses to other types of motion (Vaina and Cowey, 1996; Vaina et al. 1990).

9 Gestalt Influences on Motion

Max Wertheimer is known as one of the founders of Gestalt psychology —a perspective that insisted on the primacy of perceptual organization. In empirical research, such perceptual organization shows itself in two distinct, but related, guises: demonstrations that the perceptual whole is different from the sum of its parts, and demonstrations that configural relationships among stimulus elements shape various perceptual phenomena (Rock 1995). Clearly, many of the phenomena in Wertheimer's 1912 monograph confirm the first of these points. Time and again Wertheimer noted that under optimal conditions subjects saw not alternating static objects, but pure disembodied movement—perceptual wholes different from their constituent parts. But Wertheimer's monograph contains only a few observations that foreshadow his later work on configural factors in perception, such as the Gestalt principles of perceptual organization. Those few observations that do relate to configural factors involve a two-stage experimental approach (section 10, pages 201–204). First, Wertheimer assessed the movement generated by alternation of two elements presented by themselves. Then he reassessed this movement after other elements had been introduced into the display field. Varying the identity and position of these added elements revealed a variety of figural effects, though the monograph does not make much of them.

Figure 6 shows some stimuli that Wertheimer devised for this purpose (page 202). Two horizontal stripes, separated by a gap, were presented with timing arranged to produce poor or no movement [panel (a)]. After confirming that this arrangement did indeed reliably produce poor movement, Wertheimer inserted an additional figure into each of the two alternating displays. As panel (b) suggests, these additional elements formed an angle that seems to link the horizontal lines perceptually. When a

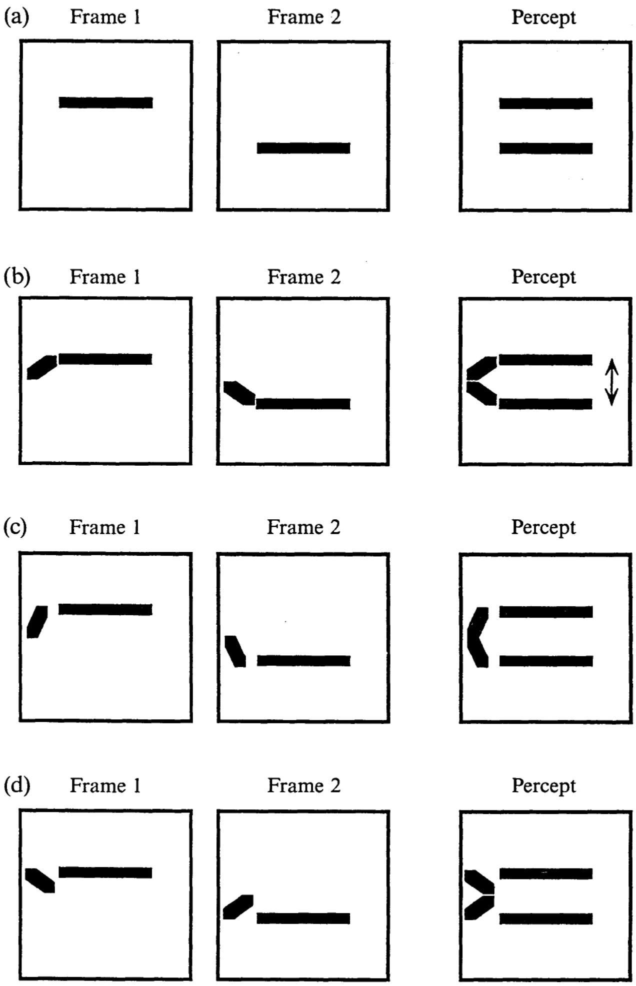

Figure 6
Movement between two elements is influenced by the presence and configuration of other, neighboring elements. In panel (a), two horizontal stripes, separated by a gap, were presented with timing that produced poor movement. As panel (b) suggests, other elements were added to form an angle that seems to link the horizontal lines perceptually. When the frames were alternated, temporal conditions that previously yielded poor motion or no motion at all produced good movement: The horizontal lines were seen as moving back and forth. Panels (c) and (d) illustrate other stimulus sequences in which the extra components stood in different figural relations to the original elements. Many such arrangements failed to produce apparent motion.

frame containing one added element was alternated with a frame containing the other added element, temporal conditions that previously yielded poor motion or no motion at all now produced good movement: The horizontal lines were seen as moving back and forth (based on figure XXIV, page 265 of the monograph).

Wertheimer suggested (page 202) that the angle altered the effective separation between the horizontal stripes (i and ii), thereby creating a stimulus that was better suited to produce movement with the existing timing. To test this general idea, Wertheimer devised several variants of iii and iv (the components producing the 'angle'). Most of these variants, some of which are shown in panels (c) and (d), failed to promote perception of movement. Note that the drawings shown in these panels are based on Wertheimer's scant verbal descriptions of what he did (page 204).

These observations show that the movement between two elements is strongly influenced by the presence and configuration of other, neighboring elements. Recently such phenomena have attracted considerable interest in connection with occlusion, image segmentation, and the integration of motion signals arising from adjacent or spatially separated regions (Braddick 1993; Nakayama and Silverman 1988a, 1988b; Stoner and Albright 1994). Perhaps new research will one day show that Wertheimer's results (figure 6) are determined by factors that promote propagation of motion signals from one region to another—or inhibit such propagation.

Whatever their explanation may be, it is natural to wonder how such observations relate to the work that Wertheimer would do later, on Gestalt principles of organization. For example, one wonders whether the observations in the 1912 monograph were inspired by some nascent vision of the importance of figural factors in perception. But, in my opinion, the monograph gives little support for this idea. In fact, Wertheimer's observations on adding a third element to the basic movement sequence were motivated less by an interest in figural effects per se than by an interest in the effects of attention on movement. Several paragraphs in the 1912 monograph allude to Gestalt influences, but such allusions are few and scattered, for example, on page 211 and in footnote 134 on page 251.

As Sarris (1989) points out, over the next two decades Wertheimer's doctoral students, including Wolfgang Metzger (1934) and Josef Ternus (1926), published important work on Gestalt influences on motion. Both these students examined the maintenance or loss of figural identity of moving objects. Of the two, Ternus's work (1926) is better known today, having provoked at least a dozen studies of group and element motion, beginning with Pantle and Picciano (1976). A small section of Ternus's paper is available in English (1938), but not even a partial translation of Metzger's has been published. Despite this lack, one portion of Metzger's work appears to have stimulated a valuable line of modern research (Bertenthal et al. 1993; Goldberg and Pomerantz 1982). Even a cursory reading of Metzger's paper reveals several phenomena that will interest and challenge contemporary motion researchers, for example Metzger's work on the perception of multiple targets that traverse irregular or unpredictable trajectories.

10 Conclusions

This look back at Wertheimer's monograph shows how far we have come in understanding apparent motion. For example, today we have a reasonable picture of the key neural events that probably underlie the basic, early phenomenon of apparent motion (Newsome et al. 1986). The monograph reminds us also of how much remains beyond our grasp. Wertheimer posed, or at least hinted at, many significant questions that remain unanswered. He noted the complex interactions between Gestalt (form) factors and the variables that govern motion. Such interactions quite likely reflect neural events in several different regions of the brain. How are these distributed events bound together to generate a unified multidimensional percept?

The transparency phenomena described by Wertheimer comprise another enduring puzzle. Such phenomena imply that multiple contradictory objects can be assigned the same location in visual space, though usually in different depth planes. This possibility seems to conflict with computational rules that have been assumed to operate in other domains, e.g., the one-to-one matching rules from which the visual system has been assumed to generate element correspondences over successive frames of random element cinematograms. Obviously, we need to develop a deeper understanding of the coordination of multiple representations.

As I mentioned earlier, in many of Wertheimer's experiments special attention was paid to conditions that produced partial or otherwise suboptimal movements. These sub-par movements are an interesting challenge to any theory that aspires to present a complete account of apparent motion. These phenomena require that a theory predict not only the existence of perceived motion and its direction, but also variations in the clarity and extent of motion as spatiotemporal parameters change.

A final set of unanswered research questions comes from Wertheimer's experiments on hysteresis. These effects, which seem to be nearly ubiquitous in visual motion, create some obstacles as well as opportunities. Clearly, experiments on visual motion must be designed in a way that takes account of such effects. Wertheimer had the good fortune to allow significant time to elapse between successive trials in his experiments, but most modern researchers do not. Can we say how much experimental noise is added by our (necessary) haste? Finally, we need to understand hysteresis itself, particularly how it relates to the kinds of learning, fast and slow, that are currently being explored in research on visual motion.

Acknowledgements

I thank Allison B. Sekuler for helpful comments on a much earlier version of this manuscript. Preparation of the manuscript was supported by the M. R. Bauer Foundation. I thank Viktor Sarris, University of Frankfurt am Main, for inviting me to deliver the Max Wertheimer Memorial Lecture in 1995 which stimulated this article. I am indebted to James R. Lackner who made available to me an unpublished verbatim translation of Wertheimer's monograph, to Howard Hock for allowing me to describe his unpublished data, to Mark Hulliung for pointing me to Butterfield's historiographic work, and to Stuart Anstis, Oliver J. Braddick, and Michael Wertheimer for excellent suggestions during the review process.

Published in *Perception*, 1996, vol. 25, pp 1243–1258. Reprinted with permission from Pion Limited, London.

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Investigations on Gestalt Principles

by Max Wertheimer

with 56 illustrations in the text

[p. 301] I stand at the window and see a house, trees, sky.

For theoretical purposes, I could now try to count and say: There are . . . 327 brightnesses (and color tones).

Do I "have" 327? No; I have sky, house, trees. Having the 327 as such is something no one can actually do.

If, in this droll reckoning, there happen to be 120 shades of brightness in the house and 90 in the trees and 117 in the sky, then at any rate I have that grouping, that segregation, and not, say, 127 and 100 and 100; nor 150 and 177.

I see it in this particular grouping, this particular segregation; and what nature of grouping and segregation I see is not simply a matter of my whim. I can by no means just get any other pattern of coherency I like at will.

(And what a remarkable process it is, when for once something like that visual integration succeeds in happening. What astonishment when, after looking for a long time, after considerable efforts with a very unrealistic set [*Einstellung*], I discover that there at the window, sections of the dark frame, together with a smooth branch, form a capital letter N.)

Or: I see two faces cheek to cheek. I see one of them, with, say, its theoretical "57" brightnesses, and the other, with its "49," but not partitioned into 66 plus 40 nor 6 plus 100.

Theories claiming that I see "106" exist only on paper; what I see is two faces. Yet this is only a matter of the nature of the grouping and the integration; and that, at any rate, is determined in this particular way. Only this state of affairs—modest but theoretically not unimportant—is handled here to begin with.

Or: I hear a melody of 17 tones with its accompaniment of 32 tones. I hear melody and accompaniment, not simply "49" or at least certainly not normally, nor purely at my whim, 20 plus 29.

This is also true when the stimulus is discontinuous. It is true when, for instance, the melody with its accompaniment is played on an old-
[p. 302] fashioned music box in the form of short, individual little bell tones or, visually, in figures, Gestalten composed of discontinuous components such as dots, each separate from the others against a homogeneous background. It might be easier to achieve other types of grouping in these cases than in the previous ones; nevertheless, for the most part there is still a normally expected, "spontaneous," "natural" type of perceptual grouping and segmentation evoked. Indeed, only rarely, under particular circumstances, can something else result or, still harder, be artificially evoked via special means.

In general, if a number of stimuli are presented to a person simultaneously, generally that person does not experience an equally large number of individual *givens*, one and another and a third and so on. Rather, the person experiences *givens* of larger scope, with a particular segregation, a certain grouping, a certain division. And whatever one's theoretical interpretation might be, whether or not one travels far from the straightforward findings and assumes for theoretical purposes a basis in the sum of the "327. . . sensations," nevertheless there remains a straightforward factual problem:[1]

Are there principles that govern the nature of the resulting perceptual grouping and division? What are they?

If stimuli *a b c d e* . . . are active together in a certain configuration, what are the principles whereby the typical grouping is perceived as *a b c* / *d e* . . . and not, say, *a b* / *c d e* . . . ?[2] This question applies whether the first grouping is what regularly results and in fact a certain other cannot be achieved, or the first grouping is merely the normally expected, spontaneous, "natural" one while the second is also quite possible, but only artificially or under special circumstances, and perhaps more unstable.

Because of the present prevailing theoretical state of affairs, the following discussion starts with configurations of discontinuous stimuli.

One can seek to identify and isolate the effective factors that govern perceptual segmentation and grouping in a variety of experimental

1. C. Stumpf says ("Erscheinungen und psychische Funktionen," Abhandlungen der Königlichen Preussischen Akademie der Wissenschaften 1907, p. 24), "Through careful study of single sensory areas one will arrive at laws of grouping. . . ." Here "the last word must rest with experimental psychology, and so far it has still hardly said its first."

2. Cf. G. E. Müller in "Gesichtspunkte und Tatsachen der psychophysischen Methodik" in "Ergebnisse der Physiologie" (Asher-Spiro) Part II, Year II, pp. 237, 238; 1904.

[p. 303] arrangements.[3] We will come back to several experiments at particular points in what follows, but for purposes of demonstrating the most essential factors, it would suffice to present a series of simple, specifically chosen examples. The following confines itself to selecting a few essential principles. (This will also involve consideration of certain problems that have hitherto been overlooked.)

It would be instructive to begin by imagining the principles which, according to conventional theoretical assumptions, might explain perceptual grouping. We will return to this in detail later; for now there is only one point to be emphasized:

If it were actually the case that for a certain configuration, one type of grouping is the normal one, the more "natural" interpretation, then of course this is an observation based primarily on experience. But what does a basis in experience mean, in the strict sense of the customary usage? Suppose that this grouping, for instance: *a b c* has often been presented together, without *d e f*, and likewise *d e f* in turn has often been presented together (perhaps with these two "associative complexes" also associated each with a word as well). Hence when *a b c d e f* appears, it is obvious that the grouping *a b c* and the grouping *d e f* would be expected to be perceived, rather than *a b* and *c d e f*, which had not been experienced together frequently. In the example mentioned at the beginning of this paper, the complex "house" and the complex "window" are

3. The investigations communicated in what follows originate principally in the years from 1911 to the beginning of 1914 (except for §§42 and 50). Concerning what is already available in the literature, aside from individual citations in the text, use the general references here: see the mention of the factors that arise for the "degree of coherence" in the remarks of G. E. Müller, loc. cit., p. 238; cf. the visual investigations of Schumann, Bühler, and Benussi, among others. I also refer here in general to the frequent material agreement with the beautiful investigations published meanwhile by E. Rubin ("Die visuelle Wahrnehmung von Figuren," VI Congress for Experimental Psychology 1914, p. 60; "Visuell wahrgenommene Figuren" Danish 1915, German 1921; "Psychologische Geometrie," VII Congress for experimental psychology, and "Zur Psychophysik der Geradheit," *Zeitschrift für Psychologie* 90, p. 67f., 1922). See also W. Fuchs' recently published work from the years 1912/14 (*Zeitschrift für Psychologie* 91, p. 146f., 1923), "Untersuchungen über das simultane Hintereinandersehen auf derselben Sehrichtung," particularly pp. 168f.; A. Gelb, "Versuche auf dem Gebiet der Zeit- und Raumanschauung," VI Congress for Experimental Psychology, p. 36, 1914; Gelb and Goldstein, Psychologische Analysen hirnpathologischer Fälle I, Leipzig 1920. For the principles for §§42 and 50 in particular, see W. Köhler, "Die physischen Gestalten in Ruhe und im stationären Zustand," 1920 (in detail particularly pp. 183f).

very familiar, as is the complex "tree," each associated with its verbal name as well. But the perceptual grouping that I "extracted" only with difficulty, integrating parts of the window with parts of the branch, might never have occurred before. Hence such a grouping arises only with a chance wandering of attention, under very special circumstances, with greater difficulty, in cooperation with the familiar complex that is the letter N. This is how the theory of "associative predispositions" might explain perceptual grouping.

In the following we will deal chiefly with discriminating among groupings in the sense of *a / b c* as opposed to *a b / c*. For this question, what would a salient [*prägnant*] example look like? Here is an example of that kind of association: I am standing together with a certain Herr Tahör from India, and someone calls out, Herr Tahör! That is how I hear it, whereas I would have heard the same spoken sequence very differently if [p. 304] I weren't standing with this gentleman, and had never heard such a name under these circumstances, and if there were a girl by the name of Hertha in the room. [*"Herr Tahör!" is an instance of a / b c, while a b / c would be "Hertha, hör!" (Hertha, listen!)—Tr.*]

This is the sense in which an explanation purely by experience should be considered if the customary meaning of the term "experience" is taken seriously. (Cf. §39f.)

Furthermore, the mere invocation of words like "past experience" or "conditions of attention" does nothing to explain exactly how they supposedly accomplish the perceptual grouping: Each observed perceptual grouping phenomenon would have to be explained explicitly by the theory of association, and compared with alternative explanations for those same phenomena.

I [Proximity]

1. Present a series of dots in an otherwise homogeneous field, with alternating distances, for instance, d_1 = 3 mm, d_2 = 12 mm.

1: • •   • •   • •   • •   • •   • •   • •

Such a series of dots is normally seen spontaneously as a series of small groups of dots in the pattern *a b / c d* and not, say, in the pattern *a / b c / d e* . . . . Seeing the second grouping (*a / b c / d e* . . .) simultaneously across the whole field is completely impossible for most people.[4]

4. To begin with we concentrate here on this simple formulation of the question. We are dealing with only these two possibilities at first. Initially it is crucially necessary to contrast the most basic differences in results. If a certain grouping such as the current example is not compelling for a certain subject, then one

2. To be sure, what is meant here is seeing, not merely intending to see, a grouping. This may be clearer for series of dots like this:

2a: 

One sees a series of diagonal groups , slanting from lower left to upper right, in the pattern *a b / c d / e f . . . .* The opposite pattern, *a / b c /*

---

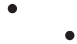
should not begin by getting lost in a discussion of why that grouping failed to appear, but rather seek first to strengthen the conditions (for instance, by increasing the number), in order to see whether the question at issue is testable with this subject. The investigation of the numerous beautiful features which can be generated in such experiments in addition to those intended here, and the resulting variations generated with different perceptual set [*Einstellung*], different distribution of attention or fixation, and so on, must be studied separately and, again, under experimental conditions that are as pure for that purpose and as salient [*prägnant*] as possible. This is discussed later.

It is necessary to concentrate on resolving one of the questions under consideration, on isolating one factor in the experiment. For instance, if the thought arises concerning rows 2a and 2b that, owing to experience with handwriting, the diagonal from lower left to upper right might be more favorable than the one from upper left to lower right (cf. §38f.), one should not confuse the issue, but rather should check at the outset (with enhanced patterns, say) whether the original factor prevails in the present case. It is typically easy to show that it does, just by suitable alteration of rows 2a and 2b.

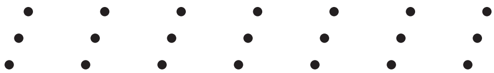
[p. 305] These remarks on scientific method are necessary only because in psychology one is often accustomed to lose oneself in handling a multitude of details simultaneously, with special value placed on "subjective arbitrary preference," rather than on posing rigorous, decisive questions and seeking a pure resolution. ("Individual differences" too can and should be handled with strict scientific rigor.)

One technical point remains: one must carry out this kind of study under pure experimental conditions. For instance, one should not imagine that one has already fulfilled the experimental conditions for all cases of "a row of black dots on a homogeneous white field," by presenting such a row and then another just like it, but 2 cm higher, or by using a configuration characteristic of a certain apparatus or frame (cf. §22). One must beware of the tacit justification that the original is really all that is intended or should be paid attention to, is all that comes into question for this experiment. . . . The common piecemeal approach [*Einstellung*] of psychology makes it all too easy to conduct experimentation under conditions that are impure or disregarded in this sense.

Consider also Heinrich Hertz's humanly very instructive remark (in his "Untersuchungen über die Ausbreitung der elektrischen Kraft," Leipzig 1892, Introductory synopsis, p. 10) about his "Untersuchungen über die Ausbreitungsgeschwindigkeit der elektrodynamischen Wirkungen." He had detected faster propagation of electricity in the open air than in the wire but says, "In conducting these experiments, I did not in the least suspect the neighboring walls of having any influence. I remember, for instance, that I ran the live wire only 1.5 m from an iron furnace."

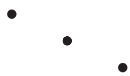
[p. 305] *d e . . .* , the series of  long diagonals, is much harder to perceive. Indeed, for most people it is impossible to see such a configuration clearly simultaneously across the whole field. If one does, with difficulty, succeed in seeing such grouping, it is a great deal less reliable and much more unstable than the first—for instance, in face of eye movements and shifts of attention.

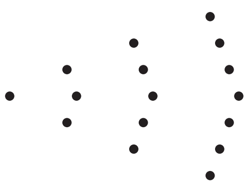
In other examples:

2b: 

One sees a series of small diagonal groups , slanting from lower left up toward the right; thus, the grouping *a b c / d e f / g h i . . .* , designating the dots from left to right:

```
  c      f      i      l       o
 b      e      h      k      n      etc.
a      d      g      j      m
```

But the opposite grouping, , that is, *c e g / f h j / i k m . . .* , is not seen, and is impossible for most to see simultaneously across the whole pattern.

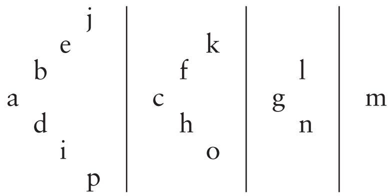
2c: 

```
                        j
             e            k
       b       f            l
a        c       g            m
       d       h            n
             i            o
                        p
```

[p. 306] In 2c, one sees:

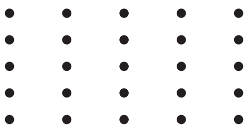
```
     |     |     |  j
     |     |  e  |    k
     |  b  |   f |      l
a    |   c |    g|        m
     |  d  |   h |      n
     |     |  i  |    o
     |     |     |  p
```

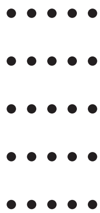
but not (or only with difficulty, hard to see, and unstable) the corresponding other pattern:



2d:

One sees the triplets *a b c* / *d e f* . . . and not any of the many other theoretically possible groupings.

2e: 

2f: 

In 2e one typically sees the verticals, in 2f the horizontals.

3. If the configuration contains few dots, then the respective opposite grouping is easier to perceive. The result is no longer so unequivocal; the condition is in general entirely more unstable.

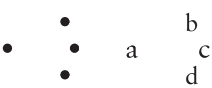
For instance, if one reduces series 1 to

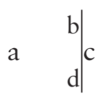
3a:

then one can readily perceive the grouping *a* / *b c* / *d e* / *f*; similarly, with 2a,

3b: 

one can get the grouping *a* / *b c* / *d e* / *f* with the two long diagonals . Similarly, with 2c:

3c: 

one can get the pattern 

(the angle of the long diagonals).

[p. 307] However, although with few dots the outcome sometimes is not unequivocal, it is often still possible to determine that there is a stronger tendency for one grouping. For instance, in an experiment similar to that in §45, with rhythmic alternation in perceiving the two groupings at will, often still one grouping appears clearly as the more difficult, more uncertain, more unstable.

4. In series 1, 2a, and 2b, the conditions for the two patterns under discussion are not yet completely equivalent. With the second pattern, "leftover" dots result. That in itself exhibits a special, important factor (cf. part VII). Now, with respect to the leftover dots, series 2c, for instance, is similar; so is the other series if one arranges them in the form of a closed circle rather than a straight line. If the series are long (or distributed all over the surface, as on wallpaper) and are not observed right at the edge, then the leftover factor plays practically no role.

5. It would be wrong to conclude from the conditions in §3 that the larger the number of dots, the more combinations there are, and thus the harder the perceptual grouping. In reality although an unnatural, artificial grouping is harder to perceive with a multitude of dots, the natural pattern is not. An increase in the number of dots to the point of immensity—dot-patterned wallpaper—does not in the least make the naturally resulting pattern more difficult to perceive. Indeed, such arrangements do not tend at all to support the argument that groupings with larger numbers of dots are harder to perceive.

Although it is mathematically and theoretically the case that the more dots there are, the more possibilities of combination are conceivable, the facts do not support this at all. Actually, larger numbers of dots in the stimulus tend to promote fewer perceptual groupings; indeed, such configurations are often unequivocal under normal circumstances. With configurations of fewer dots, there are considerably more alternative grouping possibilities.

This has to do with a very general tenet: Proceeding from a few individual stimuli does not "self-evidently" produce a simpler, more stable, more elementary percept. The theoretical supposition that the simplest stimuli produce the simplest perceptual groupings is not at all warranted. With configurations like these, it is quite the opposite; the fewer the number of dots and the "simpler" the configuration, the more uncertain and ambiguous the resulting grouping.

[p. 308] 6. In all the cases under discussion, a first simple principle can be seen: Dots separated by small distances group naturally. Perceptual grouping of dots with large separations does not arise, or does so only with great effort, and is less stable. In a provisional formulation: All else being equal, perceptual grouping tends to form more easily across smaller separations. (Factor of proximity.)

This is a most general and ubiquitous principle of perceptual grouping, and is not confined to visual grouping, nor even spatial experience. Continuous tapping rhythms, for instance, in the pattern of series 1

• •   • •   • •   • •   • •   • •   etc.,

or in the pattern of series 2d

• • •   • • •   • • •   • • •   etc.,

show the effect under discussion in a most definite way.

7. Now one might argue: It must, of course, be quite self-evident that "it is easier to form associations across a smaller distance." But it is premature to jump to such apparently "self-evident" conclusions.

On the contrary, one must ask further, concretely:

Is this a matter of the absolute distance between stimulus elements? Or is it more a matter of the relative separation? Can a function be established here at all? What kind?

Also, does the principle apply formally, in detail, in the same way in different domains? For instance, what if one uses parallel lines or surfaces rather than dots? What more precisely are the relationships among successive Gestalten as compared to those among simultaneous Gestalten? What about when they occur in, say, the acoustic domain rather than the visual?

Indeed, is it certain yet that applying the principle to the individual dots and the distances between them really does justice to the facts?

We will see that it is possible to determine particulars here. In the course of scientific development, the supposed "self-evidence" of a fact has often concealed the real problem for a long time. But first, consider a brief characterization of some other factors.

II [Similarity]

8. Present a configuration of equidistant dots in pairs of different color on a homogeneous field: for instance, white and black in a grey field, in the schema:

8a: O O • • O O • • O O • • O O • • O O • •

Or, better, fill a surface with this schema:

[p. 309] 8b: 8c:

```
O • O • O • O • O • O •     O O O O O O O O O O O O
O • O • O • O • O • O •     • • • • • • • • • • • •
O • O • O • O • O • O •     O O O O O O O O O O O O
O • O • O • O • O • O •     • • • • • • • • • • • •
O • O • O • O • O • O •     O O O O O O O O O O O O
O • O • O • O • O • O •     • • • • • • • • • • • •
O • O • O • O • O • O •     O O O O O O O O O O O O
O • O • O • O • O • O •     • • • • • • • • • • • •
O • O • O • O • O • O •     O O O O O O O O O O O O
O • O • O • O • O • O •     • • • • • • • • • • • •
```

Or 8d: O O O • • • O O O • • • O O O • • • O O O • • • etc.

One generally sees the grouping in which similar elements group with each other: in 8a, *a b / c d* . . . ; in 8b, the verticals; in 8c, the horizontals; in 8d, *a b c / d e f* . . . .

It is generally impossible to get the alternative grouping to appear simultaneously and clearly across the whole pattern: in 8a, . . . / *b c* / *d e* / . . . ; in 8b, the horizontals; in 8c, the verticals; in 8d, any of the groupings *c d e / f g h* . . . or the like.

If the number of stimuli is decreased, then the other patterns also become possible, like those in §3, but they generally prove to be more difficult and more unstable.

This leads to a second principle, which might provisionally be formulated this way: If several stimuli are presented together, then—all else being equal—they tend to group together in patterns in which similar stimuli appear to be combined. (Factor of similarity.)

9. A similar grouping is perceived, for instance, with continuous tapping rhythms (if they are not too slow) with strong and weak tapping in alternation:

analogous to 8a: . . ! ! . . ! ! . . ! ! . . ! ! etc.
analogous to 8d: . . . ! ! ! . . . ! ! ! . . . ! ! ! . . . etc.

In the first series, one hears *a b / c d / e* . . . ; in the second, *a b c / d e f / g h i* . . . . Even if one attempts to maintain persistently an opposing pattern—an attempt which moreover is generally quite arduous—nevertheless it usually soon "flips" perforce back to the first, natural pattern; cf. §22.[5] On the peculiarity of such successive Gestalten, see moreover §17.

5. In auditory patterns such as these, tapping along with it is very characteristic. Indeed, providing a continuous series of taps can produce the strong result of a series of motions.

[p. 310] This also works with musical pitches:

analogous to 8a: *C C G G C C G G C C G G C C G G* . . .
analogous to 8d: *C C C G G G C C C G G G C C C G G G C C C* . . .

With such series, it is important to pay particular attention to crisp, clean stimuli. Preferably, the notes are pure staccato beats (we will have to deal with the psychology of the "legato" later) and, with regard to "musical" factors, use European intervals. Intervals on the Appunn tonometer [*a table apparatus that produces specific tones by blowing air past metal reeds, on the same principle as a harmonica—Tr.*] are particularly suitable.

Influences from certain modes of conduct can counteract this, just as can objective cues; but even these are not subjectively arbitrary. Since one preferably starts with supposedly elementary, tacitly obvious cases with few simple components, in psychology one has frequently become accustomed to viewing all this from the standpoint of subjective modifiability, in the sense of genuine "arbitrariness." It is disconcerting in itself, that this can be the case in artificial examples having few components with a laboratory set [*Einstellung*], but it is another thing when listening to salient [*prägnant*], good, musical melodies in a musical setting.

10. In cases 8a and 8d, the conditions for the opposing "patterns" are not quite equivalent. Aside from the "leftover factor" (cf. §4), the group sequence itself also exhibits a change in direction, in the more remote or impossible pattern.

With 8a: O O • • O O • • O O • • O O • • O O • •, the *b c* group is O •, but the *d e* group is • O. Or with the rhythm . . ! ! . . ! ! . . ! ! . . ! ! . . , *b c* is weak → strong, but *d e* strong → weak. This indicates a particular factor [*see §11—Tr.*].

This complication can be remedied by continuing the increase. In the tapping series, let two strong taps follow the first two weak ones, then still stronger ones, and so on, in the schema:

10a: • • 10b: • • •
• • • • •
• • • • •
• • • • •
• • or • • •

(with vertical distance indicating the intensity).

A corresponding visual series would be (on a green background) white, white, light grey, light grey, medium grey, medium grey, dark grey, dark grey, black.

Correspondingly for musical pitches:

[p. 311] analogous to 10a: C C E♭E♭F# F# A A C C . . .
analogous to 10b: C C C E♭E♭E♭F# F# F# A A A C C C . . . .

11. In the form discussed so far, the regularity treated here presents only a special case. Not only similarity and dissimilarity, but also greater and lesser dissimilarity within a certain range still work in the same way.

With musical pitches, pure series such as

11a: C C# E F G# A C C# . . .
11b: B C D D# F F# G# A B C . . .
11c: C C# D E F F# G# A C# C C# D . . .

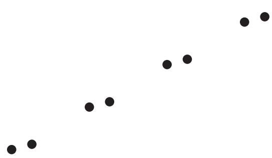
normally result in the pattern *a b / c d / . . .*

a b / c d / e . . .
a b c / d e f / . . .

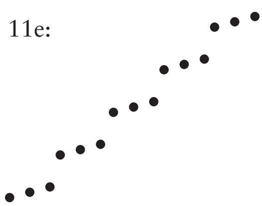
that is, the groups that span the smaller distances.

This also works with corresponding simultaneous series of brightness and series of color, in the schema

11d:



11e:



If one considers this principle of the size of the difference interval along with that of proximity (I), there appears the possibility of a more general principle that encompasses them both, and to a certain extent encompasses the spatial, temporal, and qualitative domains as well. Specifically, if it turns out that distances of intensity and qualitative characteristics can be coordinated with a general regularity concerning the spatiotemporal ones—an assertion which certainly must be carefully tested, but which can be tested experimentally—then the cases discussed above can be considered as cases of the principle of proximity.

Thus domains that until now were psychologically segregated and heterogeneous can be compared quantitatively with respect to their regularity.

III [Combinations of proximity and similarity]

12. What happens when two such factors exist together throughout a stimulus configuration?

One can let the two factors work with each other or against each other. For instance, if the one is set to favor the tendency toward *a b / c d* . . . , then one can set the other to favor either the same pattern or the opposite (. . . / *b c* / *d e* / . . .).

This is similar to the way in which, through change in the distance relationships within the law of proximity (cf. §45), one can weaken or strengthen an existing tendency.

[p. 312] For instance, in series 12a, the factor of proximity works in the pattern of *a b* / *c d* / . . . . With the lesser number of stimuli, it is not as unequivocally compelling as in a continuous row. The pattern *a* / *b c* / *d e* / . . . results very rarely here in pure spontaneous experiments; nevertheless, some people can get it to happen, although with more difficulty.

12a: • •   • •   • •   • •

In series 12b, the factor of similarity (with that of §10) also works in the pattern *a b* / *c d* / . . . . Perceiving the opposite pattern *a* / *b c* / *d e* / . . . here is much harder than in 12a, and is impossible for most people.

12b: • •   O O   • •   O O

In series 12c, the factor of similarity is set in the opposite pattern from that of proximity. In spontaneous experiments with this series, *a* / *b c* / *d e* / . . . results more frequently than *a b* / *c d* / . . . . Aside from that, the series typically appears easily "confused." Artificial production of the pattern *a b* / *c d* / . . . simultaneously across the whole pattern is relatively difficult.

12c: • O   O •   • O   O •

But the examples 12a, 12b, and 12c are not simple in the sense of §§3 and 4; so we will go on to others.

13. What is intended may be clearer to some people in more obviously unequivocal relationships.

The series below are of course to be exposed to observation individually; cf. §22.

13d: 

13e: 

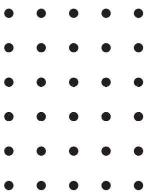
13f: 

13g: 

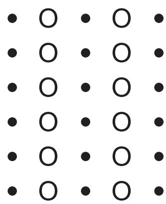
13h: 

13i: 

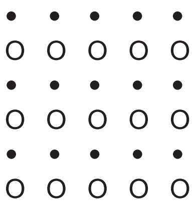
[p. 313] 13j:



13k:



13l:



In the original series, 13d, the distance relationships are selected so that the factor of proximity already works to some extent in the pattern *a b / c d / . . .* , though not as strongly as would be the case with a larger difference in the distances (cf. §45). The short diagonals • • slanting from upper left to lower right are perceived more readily, while the opposite pattern of the long diagonals • •, slanting from lower left to upper right, is distinctly rarer, more difficult, and more indefinite.

With 13e, in which proximity and similarity work toward the same pattern, the result is the short diagonal grouping, less ambiguous and more definite. The opposite pattern is generally impossible to perceive, or leads at best to confusion.

With 13f, in which proximity and similarity work against each other, the factor of similarity typically wins: One sees the series of long diagonals • •. A clear pattern of short diagonals is impossible for most.

Series 13g, 13h, and 13i show much the same thing.

With 13k, in which factors of similarity and of proximity work toward the same pattern, the verticals result. With 13l, the factor of similarity, set up in opposition to proximity, wins; the horizontals result.

14. Through systematic variation of the distance relationships in the original series, one can seek to determine the region in which, with the similarity factor set up in opposition to proximity, similarity wins; and thereby one can seek to test the strength of the tendencies more precisely (cf. §45f.).

15. This also works with tapping rhythms. If one starts from a series in the pattern of the schema

15a: . . ! ! . . ! ! . . ! ! . . ! ! . . ! ! . . etc.

here the factor of similarity works toward the pattern of *a b / c d / . . . .* In an ongoing series, not too slow, one now lets the factor of (temporal) proximity work in the same or the opposite pattern. With both working in the same pattern, there results strengthening of the *a b / c d / . . .* tendency; if proximity opposes that pattern in similarity, there is weakening of that tendency or eventual dominance of the opposite pattern *. . . / b c / d e / . . . .*

15b: . .   ! !   . .   ! !   . . etc.
15c: . !   ! .   . !   ! .   . ! etc.

16. This also works with pitches (staccato series):

16a: C C F F C C F F C C F F C C F F . . .
16b: C C   F F   C C   F F   C C . . .
16c: C   C F   F C   C F   F C . . .

[p. 314] Likewise with use of differing intervals in place of similarity and dissimilarity:

16d: C C# E F G# A C C# . . .
16e: C C#   E F   G# A   C C# . . .
16f: C   C# E   F G#   A C   C# E . . .

17. If one operates with systematic variations of the spatial and temporal distance relationships opposing the factor of similarity, then the results soon show a clear disparity which indicates one of the differences in the laws of simultaneous as against successive Gestalten. In simultaneous Gestalten the factor of similarity appears to work differently than in successive Gestalten, in general much more "strongly."

If in simultaneous series, one starts with original series as in §13 (the factor of proximity by itself), then introduction of the factor of similarity in opposition to it proves it to be very strong. With parametric variations one can easily achieve complete dominance for the pattern favoring similarity. Conversely, if one starts with series having equal distances (the factor of similarity by itself), then it is hard to attain dominance of the factor of proximity working in the opposite direction.

If in successive series, one starts with original series as in §15 and §16 (the factor of similarity by itself), then introducing the factor of (temporal) proximity in opposition easily leads to dominance of the latter. Contrariwise, if one starts with series of the same stimulus (the factor of temporal proximity by itself), then introducing the factor of similarity in opposition, it is not so easy to attain dominance for the latter. Here binding via similarity means something more, something different, for simultaneous structures than for successive structures.

18. A principle of proximity is also known to apply in stroboscopic motion: Movement is normally[6] perceived chiefly across the smaller (spatial) separation.

●● ●● ●● ●● ●●
18a: *a b* *a b* *a b* *a b* *a b*
→ → → → →

Successive exposure of all the *b* dots after the simultaneous exposure of all *a* as a rule produces movement from *a* to *b*, from left to right, in the pattern of the smaller spatial separation and not—simultaneously across the whole pattern—the movement b ← a, from right to left.

If one has set up such a configuration in a "slider," showing first the *a* and then the *b* for five pairs of dots with distances of, say, 5 and 15 mm, then via simple variation of the conditions, factors in the pattern of §4 and §10 prove to be effective in quite a powerful way. For instance, if one covers the first dot *a* on the left, then aside from the left-to-right motion of the dots in the small distance, one also typically sees motion at *a* from the right (in the large distance). If one covers them all, up to the second, third, or fourth *a*, then the right-to-left motion in the large distance typically still occurs.

A principle of similarity applies here too. All else being equal, motion is perceived chiefly among similar items:

6. See, more generally, Korte, Kinematoskopische Untersuchungen in Beiträge zur Psychologie der Gestalt, edited by Koffka. Leipzig 1919, p. 183f.

	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
[p. 315] 18b:	O	O	•	•	O	O	•	•	O	O
	→		→		→		→		→	

Here the spatial distances of the stimuli are the same, but their featural quality is different. There results chiefly a motion from left to right, not from right to left like this:

← ← ← ←

Here the factor mentioned in §10 definitely comes into play again. With the latter motion, the qualitative transition in the groups would alternate [*O* ← •, •← *O*—*Tr.*]. Thus a pure experiment, as above, would use not pairwise alternation in quality, but rather an increase. Other commonalities and differences relative to the regularities of simultaneous-φ and motion-φ will be reported later.

18c: If one introduces the factors from 18a and 18b together in the same pattern, then that produces strengthening of the common tendency. Each, more equivocal in itself, becomes more unequivocal. If one introduces the factors in 18a and 18b together in opposition to each other, then one would have to search for the spatial conditions which overrule the factor of similarity, and those which are just barely defeated by the factor of similarity. I do not yet have on hand sufficient experiments on this question; but it appears that here too, when the effects of spatial distance and similarity are in opposition, the factor of similarity proves to be very strong.

IV [Common fate]

19. If the configuration 2d is present, clearly in the grouping determined by the factor of proximity:

•	•	•	•	•	•	•	•	•	•	•	•
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*

If there is now, unexpectedly to the subject, a joint alteration among its component parts before the subject's eyes, such as a sudden small upward displacement of several dots at once, then the effects of two principal types of action can be clearly distinguished from each other:

I. "Structurally consistent" changes, which are consistent with the objectively pre-existent groups: For instance, *d e f* shift upward slightly (or *d e f* and *j k l*).

II. "Structurally inconsistent" changes, in which the common fate in the change is contrary to the pre-existent grouping: For instance, *c d e* simultaneously shift upward slightly (or *c d e* and *i j k* or *h i j*).

[p. 316] Shifts of the second kind occur "not nearly as smoothly" as those of the first. Often the first are easily just "noticed," while with the second there is a characteristic process that usually occurs. It is as if there were a special (much stronger) "resistance" against such changes. A jolt occurs, possibly disorder, confusion in the series, often a flip-flop: The component parts affected by the common fate (in opposition to the law of proximity) end up combined. With shifting of *c d e i j k l*, the series no longer has the grouping *a b c / d e f / . . .*, but rather the grouping *a b / c d e / f g h / i j k /*.[7]

This holds objectively as well. The threshold for the perception of such changes seems to be different for types I and II. But this will be dealt with later.

20. Let us tentatively designate this factor under consideration as that of "common fate." The cases mentioned in §19 are only special cases of its effectiveness.

It is important here that what comes into question is not necessarily only common identical changes. Something similar shows up with piecemeal, individual, very different changes, such as diagonal shifts of three dots in a pattern of type I or type II, or "rotations" such as *c f i l* downward, *e h k* upward (cf. part VII). This also works with qualitative changes as well.

This principle too has a very wide area of application; how wide will not yet be dealt with here.

V [*Prägnanz*]

21. Set up a batch of series as follows: a starting series like

Example 1: • •   • •   • •   • •   • •
a b   c d   e f   g h   i j

---

7. Here is an experiment which results in particularly striking observations: Using a series of vertical lines, or even just three of them, with the distances: • •   •, saliently [*prägnant*] set up *a b / c* or *a / b c* and perform joint horizontal shifts with two lines: smaller and larger; structurally consistent and, for comparison, structurally inconsistent. Characteristic phenomenal events are observed, especially by people with strong visual dispositions, including the perception of "surfaces"; cf. §48.

Make the distance between *a* and *b* (likewise between *c* and *d*, etc.) d^1 = 2 mm, and the distance between *b* and *c* (likewise between *d* and *e*, etc.) d^2 = 20 mm. Now set up other series, in which the location of dots *a*, *c*, *e*, *g*, and *i* remains unchanged, keeping $d^1 + d^2$ constant, but systematically permitting variation in the location of *b* between *a* and *c* (and of *d* between *c* and *e*, etc.). For instance,

[p. 317]

Series A	d^1 = 2 mm	d^2 = 20 mm	$d^1 + d^2$ = 22 mm
B	5	17	22
C	8	14	22
D	11	11	22
E	14	8	22
F	17	5	22
G	20	2	22

This is the schema. But it is necessary to operate with a larger number of series (with smaller stages of variation). Vary the number of dots (groups) in a series as needed.

This also works with more unequivocal series. For instance, starting with the configuration

```
               c        f        i        l
Example 2:   b        e        h        k
            a        d        g        j
```

leave the locations *b e h k* unchanged, but systematically vary the positions of the *c f i l* dots in stepwise shifts to the right, and those of the *a d g j* dots by identical shifts to the left (cf. §45, examples I–IV).

If one has set up a large number of such series and now presents them individually (in a single pure experiment), what happens is the following.

This is not just a matter of a bunch of steps that have psychologically similar weight. Primarily, three distinctive kinds of impressions become prominent. Using example 1, they are

- The *a b* / *c d* / . . . grouping, most unequivocally, most definitely, most undeniably in configurations patterned according to the beginning rows of the table above;
- The / *b c* / *d e* . . . grouping, in configurations in the pattern of ending rows of the table above; and
- In the middle (series D), the equalized "uniform series": a third grouping that is characteristic in itself, equally remote from either of the others. This corresponds with the form of five points arranged in a cross in example 2. Cf. §45, example IV.

This is the way it works in single pure experiments. We will see that there is a way in which objective factors can work in opposition here.

In a single pure experiment, there are often intermediate series, lying between these distinctive regions: not unequivocal to the same degree, not quite as salient [*prägnant*], "less definite" in their character, less pronounced, and often more easily seen in terms of one grouping or the other.

Each of the three kinds of impression, most pronounced in a certain region, has its own range. Thus intermediate series near the middle one are typically seen in a single pure experiment as "not quite equal," even if the difference in distance is quite clearly above the threshold.

[p. 318] This can be illustrated by another example. The multiplicity of angles from 30° to 150° (with one leg fixed horizontal) is psychologically perceived not simply as a multitude of equal psychological steps, as numerous as the ability to distinguish among them may suggest. Rather, the primary, distinctive impressions are the acute angle, the right angle, and the obtuse angle; these three qualities become prominent more or less purely from the outset.[8] The prototypic right angle, for instance, has its own range: An angle of 93° typically appears as a—somewhat imperfect—right angle. Intermediate angles have a "less salient" [*unprägnanter*] character; they might be seen most easily in the pattern of one or the other salient steps [*Prägnanzstufe*]. If one concentrates further on these shapes, the initial number of three salient angles [*Prägnanzcharaketere*] can increase, with new intermediate steps [*Prägnanzstufen*] developing in between.

It is of great importance here that a shape close to a salient step [*Prägnanzstufe*] appears primarily as a somewhat "poorer" version of it. An angle of 93° is not perceived chiefly as this actual angle. What a forceful interaction with the material is required in order to have such a form as a characteristic one! Rather it is perceived psychologically as an "imperfect" right angle. This is clearly proven in the experiment, most blatantly in the regularity of the tendency toward the salient [*prägnant*] shape. In

8. The following experiment is an excellent illustration: Start with this configuration

and generate a series of variants from it, in which the two dots on the left remain unchanged, but the dot on the right shifts downward in small steps. Under appropriate conditions for surveying the entire pattern, characteristically distinctive shapes are perceived: the initial right triangle; the very different isosceles triangle, tilted; the isosceles triangle with its base vertical on the left; and further correspondingly. In this experiment a variety of Gestalt factors are beautifully comprehensible, as are other conditions of "combining" also. This will be dealt with later.

tachistoscopic presentations, even in the case of considerable deviations, the observer often sees simply a right angle, by assimilation to the salient prototype [*Prägnanzform*].

This is evident in other circumstances as well: Forms that are close to a salient shape [*Prägnanzstufe*] often result in an impression of "not quite right," of a "poor" salient shape [*Prägnanzform*], "somewhat askew," "somewhat wrong," without it really being possible to indicate in what direction the "wrongness" lies. Indeed, such deviations have certain types of qualities. For instance, in tuning a violin, a "not quite right fifth" often seems clearly wrong, without one being able to judge whether it is too high or too low. This quality is typical whether the fifth is too sharp or too flat. All this must be dealt with later.

[p. 319] In general, if one varies a component, such as the location of the *b* between *a* and *c* in example 1, in systematic steps, then the resulting impressions are psychologically not a mass of individually characteristic impressions consisting of evenly balanced matched steps. Rather, particular salient steps [*Prägnanzstufen*] occur, each with its range; the progression shows breaks. Intermediate steps typically appear as related to one of the salient forms [*Prägnanzformen*].[9]

VI [*Einstellung* or set]

22. One should distinguish sharply between the objective conditions discussed in §21 and those under which a single pure experiment does not set forth one of the established variants. In the latter case, one continually varies what is in front of the subject's eyes or, comparably, operates with particular sequences or with simultaneous presentation of such series.

If one observes the series in example 1 (§21) one after another in order, preferably with rhythmic transitions from one to the next (for instance, following a metronome set to one beat per second), a new factor soon emerges: the factor of objective set [*Einstellung*].

If one starts with series A and goes successively to G, or conversely from G to A, it emerges that the initial perceptual grouping—starting from A, the grouping *a b* / *c d* / . . . ; from G, the grouping *b c* / *d e* / . . . —persists longer, very often past the middle series D, until finally, often only for one of the last series, it flips to the opposite characteristic group-

9. Something similar also occurs in the purely qualitative domain, for instance, with respect to the qualities that actually occur in the multiplicity of shades between white and black and likewise with chromatic colors. In creating salient steps [*Prägnanzstufen*], how much farther must a painter go to develop so many more!

ing. With experienced subjects and pure experimental conditions, the region of this flip is a readily available quantitative measurement; cf. §46.

Thus a given configuration, for instance, series C, creates different results if preceded by series A and B than if preceded by G, F, and E. This is the case with visually continuous displacement, but it is also already the case with only a single preceding series.

In short, if a series is a component of a sequence (or part of another combination), that is generally decisive. A configuration that results in a particular grouping in one sequence results in another particular grouping in another sequence. Moreover, a configuration which, when presented
[p. 320] by itself, would produce ambiguous results, or results in something unclear or imprecise, results in a regularly specific grouping when presented in a sequence.

This factor of set [*Einstellung*] is very strong. Through its operation, even configurations that when presented alone are typically unequivocal can lead to a different grouping.

It is customary to attribute such effects to purely subjective conditions, which makes it easy for them to display the familiar characteristic of ambiguity. But this is actually a matter of regular, objective factors from the outset. Here, whether a particular series is a component of a combination with a certain other series depends from the outset on the objective configuration. Exposing a series M immediately after series L, or with it, is objectively different from exposing series M after series N, or separating the exposures by a time interval of several days.

If one opposes this by claiming that, in considering this set of series all at once, of course one could choose one sequence or the other entirely by subjective whim, or even choose to observe a specific one together with the next higher or next lower, one thereby misses the point; such a thing is possible only if the stimulus configuration (what is objectively presented) specifically allows just such ambiguity and so does not force a certain combining. That is a very particular special case, which, quite strange to say, is usually seen as the fundamental one. Besides, as we will see later, even in such cases, purely subjective factors typically are not at all "arbitrary" in the common meaning of the term, but have their own characteristic regularity.

It is clear that one must take this factor into account very carefully in experiments.

It should be noted that, apart from such successive set [*Einstellung*], there is also a simultaneous set that works in a comparable way.[10] Also,

10. See footnote 4.

more generally, certain conditions of the "field," along with the set, are essential in deciding the matter.

VII [Good continuation and closure]

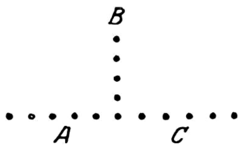


Fig. 1

Fig. 2

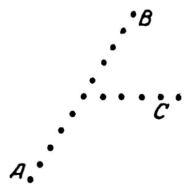


Fig. 3

23. If, for each individual dot, one takes into account all of the individual distances between dots, then theoretically, according to the law of proximity, in figure 1: The dots in the left half of the horizontal line (group *A*) are closer to the dots in the vertical line (*B*) than to those in the right half of the horizontal line (*C*). Likewise, the dots in *C* are geometrically closer to those in *B* than to those in *A*. Yet the result is "a straight line on which a vertical line is standing"; that is, / *A C* / *B*. Theoretically, figure 1 is not all that simple. In terms of the distances between dots, / *A B* / and / *B C* / should be equally favored over / *A C* /. But according to that reasoning, / *B C* / in figure 2 should be favored over both / *A C* / and / *A B* /. Nevertheless, the result of spontaneous experiments with figure 2 generally is not *A* / *B C* /, but / *A C* / *B*—"a horizontal with a diagonal line."

[p. 321]

Similarly, /*B C*/ should be favored in figure 3, but what typically results is /*A B*/ *C*—"the slanted straight line with the short horizontal."

One sees this effect more strongly and more compellingly in configurations such as figure 4.

Here, geometric consideration of all the individual distances between dots would result in /*C D*/ favored over /*B D*/, /*F G*/ over /*E G*/, etc.

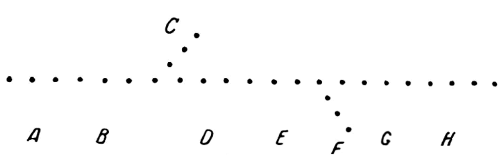


Fig. 4

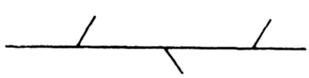


Fig. 5

Instead one typically sees /*A B D E G H* . . . / and *C* and *F*, that is, a long straight line with short slanted lines.

In place of these configurations of dots, we could even put objectively continuous lines (figure 5). For the theoretical situation under consideration here, the results remain the same.

24. One can also ask why in, say, the series

c f i l o
b e h k n etc.
a d g j m

[p. 322] it is so difficult to produce the pattern /*c d e*/, /*f g h*/, /*i j k*/ . . . that even in configurations with smaller distances, it does not result spontaneously across the whole series.

Likewise, in configurations in the form of zigzag lines (figures 6a, 6b), one can ask why there typically results a zigzag configuration of the straight component segments.

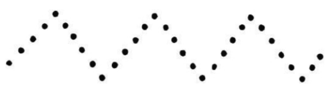


Fig. 6a

Fig. 6b

And similarly in figure 7.

Fig. 7

25. Here again one can even set up the factor of similarity at the same time as that of proximity (as, by using different coloring and different distances between dots) to take effect in either the same or opposite directions and, thereby, strengthen or weaken or overcome the effectiveness under discussion.

26. What is happening in §§23 and 24? The "continuous straight line" is favored, the "group in one direction." True, one could immediately

think up certain very special theoretical possibilities here. But it is nonetheless significant in itself that what happens here does not appear to be limited to the visual domain. For instance, figures 6 and 7 in §24 are demonstrably similar in principle to experiments in the acoustic domain with series of tones or even continuous tonal glides, such as

C D E F G F E D C D E F G F E D C . . . etc.
C D E F G G F E D C C D E F G G F E D C . . . etc.

In such series, even if there is some characteristic difference as well, the result typically corresponds with that of the series in §24, figures 6 and 7.

27. But is only that which is continuously straight favored like this? Only the configuration of one direction, just on the basis of many identically aligned distances between dots? No. Instead of the straight course along a series of identically aligned individual distances, one can set up very different configurations:

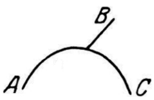


Fig. 8

Fig. 9

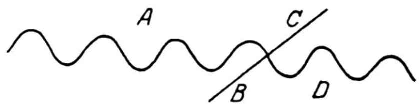


Fig. 10

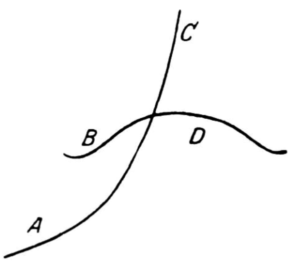


Fig. 11

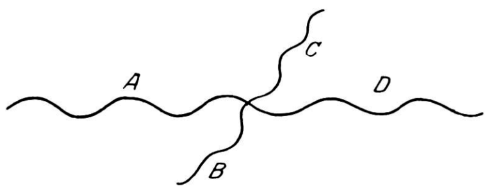


Fig. 12

[p. 323] Figures 8 and 9 typically occur as */A C/ B*, not */A B/ C* or *A /B C/*.
Figure 10 occurs as *A D / B C* and not, for instance, *A B / C D*.
Figure 11 occurs as *A C / B D* rather than *A B /C D*.
Figure 12 occurs as *A D / B C* rather than *A B / C D*.

In figure 13, just try for the pattern *a b e f i k / c d g h j* as opposed to the natural *a c e g i j l / b d f h k*!

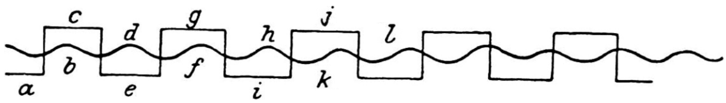


Fig. 13

28. One might think that it is simply a matter of the angular conditions at the critical point of intersection: 180° at the intersection point would be more favorable than acute or obtuse angles. Certainly such an angle is often an important factor in contrast with the course of the straight line, etc., as a form of inhomogeneity in the course of an important factor (cf. §50). But that does not yet capture what is essential here, as seen in examples like figures 14, 15, 16, and 17:

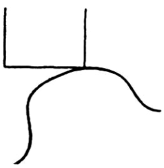


Fig. 14

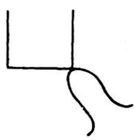


Fig. 15

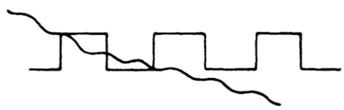


Fig. 16

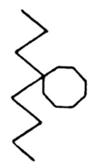


Fig. 17

29. At this point one can pose a general experimental question. As one of many instances, take a curved arc *A* and add the two pieces *B* and *C* to it, as in figure 8, with systematic variation of *B* and *C*. Which appears to group with A and which appears to be separate from *A*? Which presents the continuation of *A*, appears "at one" with *A*?

If *C* "wins"—that is, the result is that *A C / B* is more obvious than *A B / C*—then one can replace *C* with a C_2 and see whether it too wins out over *B*; etc.

Likewise one can replace the "defeated" *B* which does not appear to be the continuation with a B_2 and see whether it too is defeated relative to *C*, then with a B_3, B_4, and so on.

Clearly, posing the question in this way requires extremely broad experimentation. For purposes of illustration, let us single out a quite simple case: Typically figure 8 results in *A C / B*. *C* appears to be the continuation of *A*, to group with *A*. One can now vary the arc in many ways
[p. 324] without really changing that result. Figure 18 also results in *A C / B*. The same is often true even if one sets up C as a straight line on a tangential course, as in figure 19.

Fig. 18

Fig. 19

Fig. 20

Fig. 21

Fig. 22

Fig. 23

If one sets up tangents and circular arcs, as in figure 20, the result is somewhat less unequivocal, although in most cases the grouping of the arc wins. Here the length of *B* and *C* also plays a large role.

It works much the same way if one sets up two "arcs" as in figure 21.

Alternatively, one can set up the tangents to be constant and vary the third piece, as in figures 22 and 23.

30. What happens in experimenting with such different ways of posing the question?

Certain cases stand out: "distinctive" cases resembling salient [*prägnant*] steps, cases of especially strong "continuations," particularly unequivocal "winners," "intermediate" cases that deliver less unequivocal results.

Overall it is soon clearly obvious what matters. When systematically varying one constituent piece, one can soon predict with great certainty what the result will turn out to be from the pattern of the layout. As a preliminary formulation, one might say it is a matter of "good" continuation, of "fitting the curve," of "inner belonging together," of resulting in a "good Gestalt" that exhibits its own particular "inner necessities." This may suffice as a very preliminary designation. For the purpose of a truly scientific comprehension of what is presented here, there are several methods of penetrating further into the present regularities, including methods that do not involve the question of "grouping." More about this later.

For now, just a few brief points:

(a) Consider a certain curve with a mathematically simple regular course, large enough that by itself it makes the character of that course vividly
[p. 325] clear—a straight line, part of a circle, a sine curve, etc. If one attaches in one case a curved piece with a clearly disparate regularity, and in another case a curved piece that presents the identical principle, that is, the mathematically regular ("logically required") continuation of the main curve, a curved piece that is demanded just like this, in this place, by the

mathematically uniform course, then in general the first case is preferred to the second, to get a result that is "at one" with the initial piece.

(b) But this is not a matter of mathematical "simplicity" in every sense of that word, nor of just any arbitrarily consistent regularity of the pieces. The mathematical formula for constructing the pieces can be quite complicated. The issue here depends less on simplicity of the course of the smallest components and much more on simplicity with respect to the course of larger components (subwholes), with respect to attributes of the whole.

(c) A certain type of salient [*prägnant*] attributes of the whole plays a distinctive role in this matter: attributes such as "closure," "symmetry," "inner equilibrium." For these purposes clearly symmetry, for instance, is by no means simply an "equality" of components. Logically, it can be correctly grasped only from the viewpoint of the whole, as an attribute of the whole.[11]

What is indicated here can become more strictly precise only with further study. It is clear that certain problems in pure mathematics and in set theory must be considered, particularly the problem of attributes of the whole in contrast with mere regularity among pieces.

Later we will deal with cases in which what is discussed here can be formulated in quite a simple way, relatively speaking.

31. Furthermore (figures 24, 25, 26):

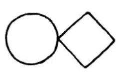


Fig. 24

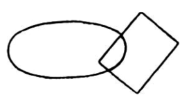


Fig. 25

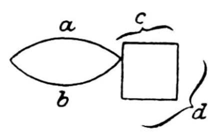


Fig. 26

32. The cases in §31 involve another factor that is quite important in itself, the factor of closure.

To formulate it quite generally: Given *A*, *B*, *C*, and *D*, if *A B* / *C D* generates two closed progressions (running back into themselves), but *A C* / *B D* generates two unclosed (open) ones, then *A B* / *C D* is favored.[12]

11. Something like this also occurs with temporal succession (with a different kind of characteristics, due to the directionality of the time vector).

12. It should also be mentioned briefly here that experimentation shows that two mutually concave curves that close one another are favored to some extent over two curves that lie convex to one another.

[p. 326] For instance (figures 27, 28),

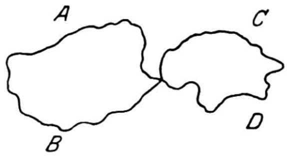


Fig. 27

Fig. 28

The factor of closure, though, can be isolated from the factor of the "good curve," the "good Gestalt." Figures 29 and 30 below, for instance, typically do not result in three closed forms, but in those determined by the "good curve." Here the factor of the "good curve" dominates over that of closure. This is clearer still when the lines and curves are extended past the starting and end points of contact.

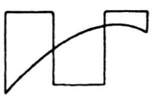


Fig. 29

Fig. 30

33. Here is something else to try in this connection: Take two outlined figures such as two black squares, or figures like those below. On a homogeneous ground, lay them next to or overlapping one another. In which configurations does one clearly and compellingly observe the duality of the two figures? In which not? Which typically and compellingly result in something entirely different: the existence of a kind of new unity?

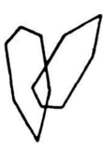


Fig. 31

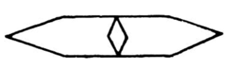


Fig. 32

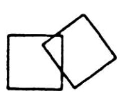


Fig. 33

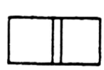


Fig. 34

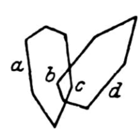


Fig. 35

A very rough indication of the results of such experimentation, performed systematically, appears in this simple example: The placement in figure 31 favors the result of the two six-sided figures, but the placement in figure 32 typically produces something entirely different: one long hexagon with a smaller quadrangle in the middle. A corresponding pattern in the first placement is extraordinarily unusual, impossible for most people to see.

It works the same way with two squares: The placement in figure 33 favors the result of the duality of the two squares; by contrast, the placement in figure 34 typically results in an oblong with a transverse strip in the middle.

[p. 327] This demonstration is not restricted to outline figures. One can get results with surfaces also, with strong consequences. Compare Fuchs's investigations on transparency 1911/1914.[13] By methodical application of the regularities discussed in this section, these investigations achieved extremely strong results, for instance, with respect to the colors seen.

What primarily is the situation here? Experiments posing the question like this very soon show what is decisive, in a very salient [*prägnant*] way. For linear combination as well as surfaces, the tendency toward the "good whole Gestalt" is completely in accord with the preceding discussion:

Figure 35 labels the four parts of the outline in figure 31, from crossing point to crossing point, with the letters *a*, *b*, *c*, and *d*. Using these labels, what are the circumstances?

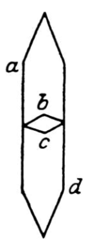


Fig. 36

(a) Linearly, in detail: /*a b*/ would result in a bad, inconsequential, "senseless" outlined figure with eight or nine sides which, only after this comment, probably the reader might now be able to see—not without effort. The same is true of /*c d* /. By contrast, /*a c*/ is a much better Gestalt than /*a b*/:[14] *c* corresponds much better than *b* with what is adjacent to *a*. Indeed, *c* is what is "required." The fact that the *c*-parts join up with the *a*-parts in the favored straight line especially plays a role in this. The corresponding situation occurs with /*d b*/.

(b) Regarding the surfaces: The surfaces enclosed by the lines /*a b*/, /*c d*/, /*b c*/, /*a d*/ would result in bad surface figures. (The reader might try to grasp these surfaces as whole surface Gestalten.) By contrast, the surface

13. *Zeitschrift für Psychologie* 1923.

14. Cf. §§30 and 39f.

enclosed by the lines /*a c*/ is a much better whole surface Gestalt; likewise the one enclosed by the lines /*b d*/.

And so figure 31 results in the pattern *a c* / *b d*, and not in the pattern *a b* / *c d*.

But in figure 36 (the same as figure 32, with labels) the emphasized cues are characteristically different. Linearly and in terms of surfaces, /*a d*/ and /*b c*/ (which would result in poor forms in figure 31) are favored.

The situation is still simpler if we use differently colored chunks of surface, as in figure 37.

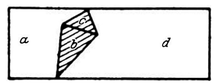


Fig. 37

One sees a slanted deltoid in a long oblong; if we label the surface chunks from left to right as *a*, *b*, *c*, [p. 328] and *d*, then one typically sees /*a d*/ as a whole oblong, with /*b c*/; never spontaneously /*a b*/, /*c d*/. (The reader should try to achieve this: on the left a six-sided figure whose lower right tip is dark, on the right the longer six-sided figure whose upper left tip is dark.) Again it works as above.

With curves, very much as above, it is a matter of the tendency to result in a "good" Gestalt. To some extent this seems to be theoretically easier to comprehend than above. For instance, there is a tendency here for a whole surface to result in uniform (more homogeneous, more centrally symmetrical, etc.) coloring. Thus the law of similarity becomes a special case of that of the good Gestalt.

34. For these purposes, it is very instructive to try the following as well:

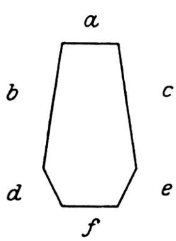


Fig. 38

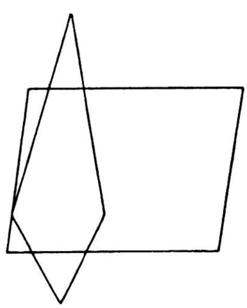


Fig. 39

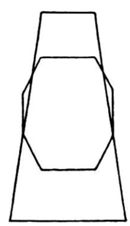


Fig. 40

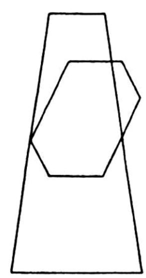


Fig. 41

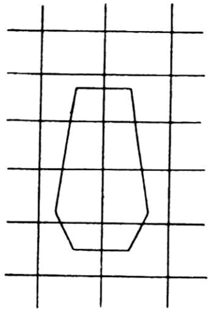


Fig. 42

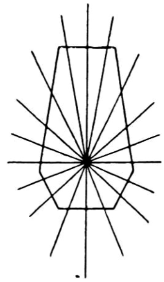


Fig. 43

Start with a given configuration (figure) and ask: What additions, what extras, what field is capable of ruining the Gestalt? What can one add to be quite sure of getting a spontaneous experiment to result in a pattern which is not at all the same pattern which is there without these additions? [p. 329] It soon becomes apparent that a superb means of achieving this is to complete subdivisions of the figure into "good Gestalten," especially when there is "structurally adverse, poor" subdivision of the figure. And rigorously so: Whether more or less is added in a piecemeal sense, other additions do not have this consequence.

Label the lines in figure 38, the original figure, as *a*, *b*, *c*, *d*, *e*, and *f*. In a spontaneous experiment, figures 39, 40, and 41 typically come out as something different from the original. Schematically expressed, figure 39 comes out as *a*, *b*, *f* . . . /*d*, *e*, *c* . . . ; figure 40 and figure 41 come out as . . . *a*, *b*, *c* . . . /*d*, *f*, *e* . . . ; and figure 42 and figure 43 typically come out as the original figure.[15]

If we designate the initial figure as *A*, the additions of the first kind (the destructive ones) as *B*, and the last, nondestructive ones as *C*, what emerges is: One part, or partial configuration (*A*), alone or as part of a particular configuration (*AC*) results in something different than as part of a different configuration. What configuration it is part of is crucial to the nature of the result. Even if at first this formulation is concerned only with the formal condition of the "combining" within *A*, nevertheless it is also much more generally valid. The same is true for other formal cues, and, as we shall see later, for qualities as well.

15. Except, characteristically, in pathological cases that belong in the realm of mental blindness, or in cases of so-called alexia; see Gelb and Goldstein, loc. cit., p. 23.

Using the method indicated, one can make a person effectively blind to what is shown, even when in itself (alone or in another configuration) it is very clear and natural. This has consequences for recognition and indeed even for perceivability, on which we will report later.

35. One might think that what is meant by a "good curve" in the preceding paragraphs is based on an extraordinarily regular relationship among the individual component parts (the "elements" of the configuration), such as the exact same direction followed by the individual spaces between dots in the case of a discontinuous straight line.

But that is not the case. Variations quickly show that it is not primarily a matter of the location of the individual dots, nor of the direction mutually followed by the individual spaces between dots. Rather, in essence it is a matter of what is happening on a large scale. What is at issue is properties of the configuration "from above, seen in terms of the whole," "major stretches," and attributes of the whole, even though in detail the formation may happen irregularly and perhaps indeed lawlessly in the smallest pieces.

[p. 330] To see this, one need only replace the straight lines and curves of the figures with configurations of dots which show the character of the curve in question in their overall course, yet meanwhile are variable in detail, possibly disorderly or irregular. Not a single individual interval needs to lie correctly on the curve; and this deviation can be strongly above threshold. Or one can crinkle the curves.

It is precisely the opposite of a matter of the placement of individual elements: What is primarily of importance, indeed what is first seen and grasped in such configurations, is what is happening on a large scale, the overall distribution. This is shown especially clearly in tachistoscopic experiments to be discussed later.

This does not have to do with piecemeal relationships of "elemental pieces" to one another, nor of the "degree of coherence" of stimulus pairs and of stimuli "from the bottom up." Consider figures 14–17 in §28. If two "pieces" display a tendency to appear "together," to result in "one unit," that does not seem to be an attribute that belongs to this pair of pieces as such. The same two pieces placed side by side piecemeal in other Gestalt configurations display other tendencies, including the opposite one; and this does not happen in a way that makes it likely that simply summing two simultaneous tendencies algebraically would bring it about. More on this later.

36. There is something further to point out here. A problem area already alluded to in §19 is closely connected with this matter.

Consider a configuration with clearly articulated structure, such as a Gestalt whose division into subparts is determined by one of the factors already discussed (as in figure 7). Then a second factor comes into question. Now we have to do with a distinction between the "structurally appropriate" and "structurally inappropriate" application[16] of this second factor. This distinction works entirely consistently with the tendencies under discussion, in important ways that are clearly experimentally testable.

Under certain clearly comprehensible conditions, the two factors together, applied differently from each other, can still cause a "good" Gestalt. Beyond that, the cases of structurally appropriate and structurally inappropriate operation can be clearly distinguished.

37. The principle dealt with here, of which §§23–36 tentatively present only a part, has fundamental epistemological consequences. It makes genuinely sensible predictions possible, in a salient [*prägnant*] way, in contrast with the predictions of Hume and of traditional logic. More about this shortly in another connection.

[p. 331] VIII [Past experience]

38. Another factor affecting whether a certain grouping and segregation will result is familiarity or "past experience."

In its simplest formulation, this principle asserts that if *AB* is familiar, and *C* is familiar, but *BC* is not; if they happen to be associated with something else (spoken names, etc.); or if *AB*/*C* is familiar, but *A*/*BC* is not; then there is the tendency for *ABC* to result in the familiar, frequently experienced, learned, trained pattern *AB*/*C*.

In contrast with the description in the paragraphs above, it is characteristic of this principle that fundamentally it has nothing to do with the contents, the combination, or any objective data about the configuration. In principle, which pattern will result depends only on objectively arbitrary habit or drill.

Here is the sort of thing that happens:

1. One will see figure 44, not according to the pattern of figure 45, but as *j u r y*.[17]

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16. From this there also arise beautiful relationships to what the musician, for instance, calls "senseless phrasing" or accentuation, and even "illogical" phrasing.

17. [*In the original German this word is* juni, *the name of the month of June.—Tr.*]

2. One will see 314 cm in the pattern *a b c* / *d e* and not in the pattern *a b* / *c d e* or *a b c d* / *e*; thus as 314 cm, not 31/4 cm, not 314 c/m.

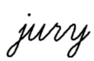


Fig. 44

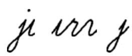


Fig. 45

Fig. 46

3. Someone accustomed to reading Greek will see figure 46 on a white ground partitioned into sigma and gamma, inherently a duality. But someone accustomed to the Latin alphabet will see it as a large ornamented V.[18]
4. Everything said in the earlier paragraphs also has beautifully fruitful relevance to production and "doing things in one's own way." If the alphabet drill in school is in the rhythm a b c, d e f, g h i, j k l . . . , it could just as readily be in another rhythm, such a b, c d, e f, g h . . . ; but when recitation resumes, the drilled pattern will result. The same is true for finger exercises on the piano.

[p. 332] 39. This works. Leaving it undecided here whether something like this really applies in general, to a great extent one can obtain extremely arbitrary patterns in arbitrary material through sufficient drill. Habit, past experience, will to a great extent determine the pattern or, in any case, frequently correspond with the pattern.

Even in these cases, it remains undecided here whether the fact of arbitrary items having "been there together" (been paid attention to at the same time), through drill of the pattern of connections, really covers the essence of the process.

Some scholars with a very common mindset [*Einstellung*] might basically be inclined to see everything that has been dealt with so far, but especially the circumstances in part VII, blandly in terms of the "fundamental" factor of "past experience." From this there follow not only merely theoretical conclusions, but unfortunately also this: Rather than seeing the positive tasks which these circumstances open up for research

18. Saliently [*prägnant*] seen, these two compositions look very different. The attempt to produce them alternately on purpose may already make it evident that, aside from the bare issue of "combining," entirely different Gestalt factors come into question, such as the function or role of a part in its whole, orientation to the main layout, level, and centering. But this will be dealt with later.

(and here fruitful exploration is possible), one casually shuts off these problems through such a thesis and believes them disposed of through the bland phrase “past experience.”

Various theoretical approaches to the regularities under consideration are not discussed experimentally until later sections, but because of the importance of this one problem, a bit of that discussion is anticipated here.

One might think that the circumstances of part VII signify nothing other than that familiar complexes are favored. Aren’t the “straight line,” the “right angle,” the “circular curve,” the “square” familiar complexes in a very favored way?

And with regard to the earlier paragraphs: Aren’t we very familiar with breaks between items to be distinguished? In print, don’t the letters to be grouped together in words stand close together, while there are larger distances between words? What a thousandfold past experience! Doesn’t past experience drill us to group together that which is the same color, for instance, in the displacement of things relative to each other when we are walking? And doesn’t past experience drill us to group together that which has common displacement, common change?

All this, casually put forth, sounds very self-evident. But one must be firm in not believing that one has disposed of such important questions so casually. Based on the thesis of past experience in the above sense, one would surely be obliged to demonstrate concretely the specific past-experience drill cues in question for each of the circumstances discussed, and its regularities. One must also show concretely that alternative [p. 333] groupings in fact have no—or a correspondingly inferior—basis in past experience, and also that, for gaining the past experience, the assumed “arbitrariness” by itself is actually sufficient. As soon as one really takes these problems seriously, it quickly becomes evident that all this is not by any means as blandly obvious as the answer deceptively implies.

This applies even in cases in which the situation initially appears to be very clear. As an example, consider the right angle, which is in fact favored. Think of tables, cabinets, windows, corners of rooms, houses. Isn’t the right angle already there for the child thousands of times in experience? As self-evident as this sounds, one should go into it more closely. To begin with, is the environment of the child filled only with things made by humans? In nature aren’t there a great many other angles, for instance in trees with their branches, surely not fewer in past experience? Of course this would have to be estimated quantitatively somehow. But still more important: In the sense of merely being there piecemeal in past experience, in the sense of the reception of sensory stimuli, is it actually true that the cabinets, tables, and so on present right angles a thousandfold? No; only in the extremely rare cases where these are in an effectively frontal–normal configuration. When the child looks at the table or cabinet, the most frequent cases by far are those where the stimulus-moderated experience is in fact not right angles at all. And if one wishes to apply, not the stimulus-moderated experience, but already the phenomenal, doesn't the problem arise all over again?

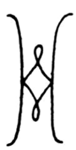
40. Even for a basis in "past experience," possibilities arise that are very different from piecemeal experience that has an arbitrary character in principle, in the sense of random pieces or groupings merely having been there often. But ignoring whether or not one wants to look at the circumstances in part VII as somehow determined by "past experience," the question nevertheless remains clear: In the circumstances discussed, are there objective regularities or not? If so, which ones? Just what is the regularity, in greater detail? These are research questions which cannot be disposed of by the word "experience."

For research, the question of objectively regular tendencies must be clearly distinguished from the kind of cases in which it is already well-known that one really is dealing with arbitrarily established connections.

Can one try to decide these things experimentally?

If the grouping *a b c* on the one hand and the grouping *d e f* on the other hand are highly familiar, and now I set them next to each other, presenting *a b c d e f*, does *a b c* / *d e f* unequivocally result?

For this I select a domain in which enormous past experience is unequivocally present thousands of times.



[p. 334] **Fig. 47** **Fig. 48**

Figure 47 is nothing but a very common W and a very common M set next to each other. Typically, though, one does not see them, but rather the looped form in the middle between the symmetrical curves left and right, which is thoroughly unfamiliar (not drilled). Thus if the W from left to right is made up of the parts *a b c* and the M of the parts *d e f*, one typically sees not *a b c* / *d e f* but *a d* / *b e* / *c f*, or / *b e* / between / *a d* / and / *c f* /.

This is stronger still when multiplied, as in figure 48. Very typically, instead of the four Ws and the four Ms, what is unequivocally seen is the group of four comical, unusual little loops and the closed curves. Who sees here, strictly simultaneously, the four Ws with the four Ms?

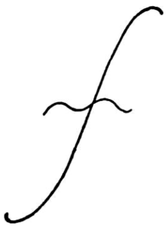


Fig. 49

Fig. 50

Fig. 51

Fig. 52

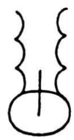


Fig. 53

Figure 49 is a J and an L; figure 50, an L and a J. Figure 51 is a p and a q and another p and another q, and so on. Figure 52 is a q and a b. Figure 53 is a 3 and a 4 and an E and an S.

Experimentation with very simple resources is already instructive in this matter. Place a mirror horizontally above or below a row of letters, or to the right or left next to letters or numerals written in a vertical column. One often sees very peculiar forms produced, entirely consistent with what is considered above. This also occurs with the plane of the mirror placed slightly oblique to the direction of the line of letters, and with other similar variations.

41. The experimental discussion goes further. Here is a bit more of that discussion, by way of example.

Just what is the state of affairs in question? One might initially believe that complex *A* is familiar and so is complex *B*, like the M and the W
[p. 335] in figure 47, but AB arranged in this way is not familiar, nor is *A* or *B* familiar in /*AB*/; and that is why *A* / *B* does not result. But it would be an error in reasoning to think that this "explains" the situation. At most it

might explain why *A* / *B* does not result, but it does not at all explain what does result. Aside from that, though, experimentation can test the assertion more precisely. For instance, in figure 54 too *AB* is not familiar, yet *A* / *B* nevertheless results more readily; and one cannot assert that this grouping would be less unfamiliar. It is equally likely never to have come up.

Fig. 54

Fig. 55

Fig. 56

One might say, in figure 55, which is the same as figure 47, but with labels, it is true that *A* (= *a b c*) is familiar and *B* (= *d e f*) is familiar, but so are *a d*, *c–f*, *b–e*, and even *a d* / *c f*. One might say this quite casually, but concerning *b–e* it is false. Can one really believe that the grouping *b–e* has actually been there in real past experience more often than *b* in *a c* and *e* in *d f*? With *a–d* and *c–f* it is different. One can quite rightly assert that such groupings have very often been there, and more often as *A* and *B*, so more strongly. But in figure 56 is not the tendency to result in *a d* / *b e* / *c f* very distinctly still there? Yet one cannot assert that the / *a d* / and / *c f* / of figure 56 are at all familiar to the necessary extent.

These cases are singled out for discussion. Systematic experimentation, including variations in the relative location, shows furthermore that the configurations are "sensitive" in a very characteristic way: always in conformity with the strength and salience [*Prägnanz*] of the pertinent objective factors.

But also, what is going on with the formation of the individual letters themselves? In a certain sense, they too are historically "arbitrarily" established formations. What is going on—and very much from the beginning—with their variability, their range of "acceptable," immediately recognizable variations? We will come back to this problem in another context. Here we just remark briefly that these formations too are very sensitive to certain variations and can collapse into something strange or even unrecognizable; yet other variations, which introduce much more modification with respect to the sum of the individual parts and their locations, disrupt nothing at all, but rather yield the "same" formation, blandly recognizable, in the same pattern. This does not by any means work in the sense of averaging the experience abstracted [p. 336] piecemeal. With such historical formations, psychologically one does not have to do with complexes of summative habit. Rather, they too are psychologically essentially determined by structural regularities, corresponding closely with those of part VII.

42. Does one not also see things like the figures in §40 here and there in reality?

In the moonlight I come upon a still, dark body of water. What is that wondrous luminous form there across the way? It is a small pale suspension bridge which is reflected in the water; but what does it look like? Bridge and reflection together exhibit a wondrous whole, entirely different from anything that is familiar in real experience. Who could imagine such a peculiar figure over there? The way it looks is totally improbable. Even though I know it is a bridge and its reflection, and the form, as I see it, is as improbable as possible, that simply does not help at all: Grouping and partition do not occur according to "bridge" plus "reflection," but completely differently, according to the regularities that have been discussed, according to what has symmetrical closure. And of course it is not in the least the case that somehow past experience of reality would actually favor symmetry in this way.

And likewise the peculiar figure over there? A group of trees, right at the water's edge, together with its reflection. How this form occurs against all experience! And even the individual tree over there with its branches above and below!

Is it an answer to say that these are unfamiliar conditions?

As a rule, in natural life, the pattern corresponds with reality. Must that be interpreted to mean that piecemeal, summed-up, individual past experiences are always the basis of it all? One relatively seldom sees anything like the sights mentioned above. Conversely, could not this be due to biological regularities at work in receiving information, regularities typically quite adequate in our world, but which under rare, biologically atypical conditions regularly lead to "false interpretations"? Biologically, is it not very generally true that there are regular, general kinds of organization, modes of operation quite adequate under their biologically regular conditions, which are "defective" under atypical conditions? Nature does not at all seem to work in arbitrarily summed-up individual adjustments, but rather in the emergence of inherently regular, biologically typically adequate forms and methods of functioning.

The nervous system has developed under the conditions of the biological environment. It is no wonder that the Gestalt tendencies devel-
[p. 337] oped thereby correspond with the regular conditions of the environment. One certainly should not think of this development in terms of the emergence of some special kind of mechanical devices.

IX [Further considerations]

43. Other factors will be dealt with later; here, in connection with §7, we only want to pursue a bit further the experimental discussion of the factor of proximity in visual configurations, in a brief sketch of the larger-scale results.

For the factor of proximity, is it (a) the absolute magnitude of the distances, or (b) the difference in the distances, or (c) the relationship of the distances that is decisive?

(a) Consider a series (schematically)

● ●   ● ●   ● ●   ● ●   ● ●   ● ●   ● ●

which appears to be in the grouping *a b* / *c d* / . . . , and in which the d_2, the larger distances of 7 mm, represent the "pauses." One can easily generate a second series in which distances of the same size as d_2 function as the relatively smaller ones[19] (schematically):

●   ●   ●   ●   ●   ●   ●   ●   ●   ●

This is vividly more unequivocal for cases of diagonal configurations, as in §2.

The individual absolute distance, the absolute separation between two dots, is simply not what is decisive in any case.

(b) Starting with an initial series, generate a number of series which all have the same difference in the distances, even though each series has different absolute distances. Also generate a number of series which have the same relationship of the distances, again varying absolute distances.

Already in simple observation, but especially with the systematic attempt to perceive the opposite pattern in each series, it becomes clear that in the series with identical difference, the relationships for the *a b* / *c d* . . . pattern and for the / *b c* / *d e* / . . . pattern in the various

19. Cf. Köhler, Die physischen Gestalten in Ruhe und in stationären Zustand, p. 188.

series are extraordinarily different, corresponding with the large difference in the form of the series.

For instance, suppose that the difference is small in absolute terms, and the series with very small distances are unequivocally *a b / c d / . . . .* Then the series where the distances themselves are large, and the difference is therefore a relatively small one, are no longer as unequivocal, even if the difference itself is quite above threshold. They soon incline toward an [p. 338] approximately equal impression (cf. §21); neither *a b / c d / . . .* nor */ b c / d e / . . .* is then especially favored.

(c) By contrast, in the series with identical distance relationships, corresponding with the vivid similarity in the form of the series, the results of experiments with the individual series are relatively much more similar. If the initial series favors a pattern of, say, *a b / c d / . . .* , the same is also true with quite wide variation. The conditions for generating the opposite pattern remain largely the same, and much more equal in any case than in the series with identical differences.

More precisely, the same change of the initial distance constitutes much more of a change for our purposes, much more strongly alters the strength of an existing tendency toward a pattern, in the series with identical differences than in the series with identical relationships.

Moreover, the series with identical relationships are not even fully equal. This is true even disregarding the different conditions for surveying the entire pattern, which depend on "augmented series" containing fewer constituent parts or groups in the same space, or the same number of constituent parts or groups in a larger total space.

With series that are varied like this, one has to do with series of very different total length. To exclude this variable and be able to make comparisons across the same lengths, one proceeds as follows: Start with an initial series in which $d_2 = d_1 + \Delta$ (difference). Series with the same difference in the distances will have the differences d_x and $d_x + \Delta$; series with the same relationships, the distances nd_1 and nd_2. Now, in order to achieve the same total length, we must have $2d_x + \Delta = nd_1 + nd_2$. Thus $2d_x + \Delta = 2nd_1 + n\,\Delta$, and hence $d_x = n\,(d_1) + \Delta\,((n - 1) / 2)$.

For instance, if in the initial series d_1 is 2 mm and Δ is 4 mm, then d_x is $4n - 2$.

If one varies n, one gets two series of equal length for each n, one with the same difference as the initial series, the other with the same relationship of the distances.

Sample values of n	Difference series		Relationship series		Sum of the two distances
	d_1	d_2	d_1	d_2	
n = 3	10 mm	14	6	18	24
n = 5	18 mm	22	10	30	40
n = 7	26 mm	30	14	42	56

Now if one compares the series of each such pair with one another and [p. 339] with the initial series, with regard to their distinctness and the strength of the tendency to result in a particular grouping, it turns out that, as n increases, the difference series very soon lose the distinct character of the initial series, but the relationship series do not. This is only the crudest outcome of this experiment; we will come back to other aspects of the results later.

44. In arrangements like the examples cited in §§1 and 2, the results were to a great extent unequivocal. The "natural" grouping occurs a great deal, and the corresponding opposite grouping hardly ever arises spontaneously, simultaneously in the whole. In efforts to generate that opposite grouping artificially, very characteristic difficulties arise: The observer often finds it necessary to grasp a successive synthesis of the grouping, pair by pair. Then, during the laborious further synthesis, already synthesized parts often "fall apart" again or topple back into the natural pattern. If somehow the pattern really does manage to succeed eventually, then its generation very often takes a considerably long time.[20] Time measurement in such experiments very often yields blatant results, for instance, if one first sets this task and then the task of "generating" the other (natural) grouping, which latter is usually present in a sudden toppling over.

Often, with the effort to generate the desired grouping, jumbled forms arise instead.

In such an experiment, if getting the opposite grouping really does finally succeed clearly and simultaneously across the whole pattern, then it

20. The well-known finding of the "Gestalt time," that is, the span of time "necessary to produce a Gestalt," is erroneously viewed as a feature in producing a Gestalt at all. Such time spans crop up primarily if one is dealing with producing a Gestalt that is not unequivocally determined by the configuration and is not compellingly advanced by the objective relationships. In fact it is not true that there is first a sort of "sum," and only out of that is a Gestalt produced, which takes time.

turns out to be very unstable. Mostly it topples over very quickly by itself. Indeed, the slightest disruption, the slightest relaxation of concentration, and the strained "will" typically has toppling over as its consequence.

In experiments of the earlier paragraphs, it is generally unnecessary to take conditions of fixation point, eye movements, placement of attention, or distribution of attention into special account. On the one hand, it is of course true that these features depend secondarily on the presented configuration (of which more later). On the other hand, regarding our question about results in the entire series, they are largely irrelevant in these designs. Even if one sets them up in an opposing, unnatural way, for the most part this changes nothing essential. The natural grouping still clearly [p. 340] remains the favored one. In experiments on systematic "generation of the opposite" with natural and opposing groupings, once again distinct differences between the two appear. To be sure, when setting up the opposite, often some of it changes individually, but typically only in individual domains of the series, which leads to "unevenness" in the series. The exception is with subjects who, having been drilled with many laboratory experiments in generating arbitrary distributions of attention, possess an unusual ability to generate unnatural "modes of interpretation."

Experiments are also less unequivocal with observers who have been drilled in the European set [*Einstellung*] for scientific experiments of ascertaining all the details individually, each in itself. With such as these, one must try more rigorous experimental conditions. Nevertheless, it is not at all the case that experiments with such observers result in opposite instances, contrary to the distinction between the natural and the more unlikely grouping. Mostly one gets neither one grouping nor the other, but rather a thoroughly wretched enumeration of individual details.

In the effort to penetrate deeper into the regularities at hand, if one turns to less compelling arrangements, such as series designed with less striking dissimilarities in the distances, one enters a domain where the outcomes naturally show a much larger range of variation. One must then take "subjective approaches" into account individually and be concerned about consistency. One must seek average values, taking the factor in §22 strongly into account, because of the necessary massing of trials. If one is careful to maintain pure experimental conditions in this regard, then once again unequivocal outcomes occur with various methods.

Even without such special experimental precautions, it becomes evident that one of the two groupings is the more "natural," more obvious one. Even with these less compelling configurations, still the opposite grouping rarely occurs to the observer. If what is favored does not result, then it is usually a maximal "indistinctness" and uncertainty, a tendency toward a "jumble" or for "undifferentiated forms."

If one sets the task of generating the opposite or of generating the two opposing groupings in turn, then here too the unnatural one turns out to be distinctly more difficult, as shown by such factors as the spontaneous report of the subject, the time it takes to generate them, their lability, and the ease of disrupting them.

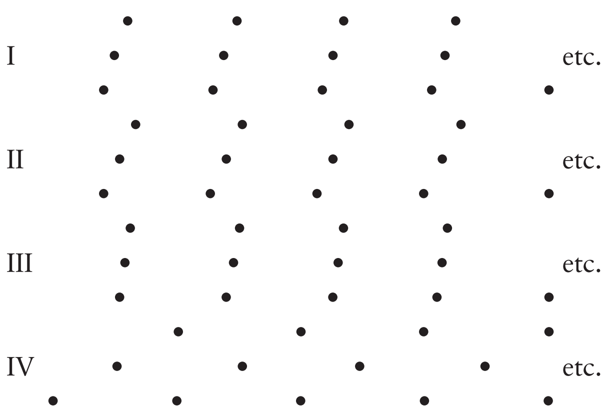
Fatigue, sniffles, numbness, lack of ability to concentrate or of "stick-to-it-iveness," and difficulties in understanding the instructions strengthen the favoring of the natural simple (though perhaps more chaotic) grouping as against the more unlikely one.

[p. 341] Technically, the most important factor here is the different strength of such configurations, as opposed to setting up other factors such as objective set [*Einstellung*] along with them.

45. If one wishes to go deeper into the problem of setting up the function of the law of proximity, there are various methods that deliver clear resolutions.

Here is an illustrative selection from a variety of experimental series.

Does the strength of the law of proximity differ with different-sized difference of distances? If so, in what way? Consider this schematic illustration of four configurations from the slanted-group series.



(a) One observes one of the four configurations individually and attempts to generate the contrary interpretation of the long slanted groups. If it turns out to be impossible with various subjects, one must try different allotments of the number of dots and the like.

I select the slanting-group series as an example here because with them it is possible to establish much more clearly whether unpracticed subjects really get the opposing grouping. The distinctions between the two patterns are more vividly evident and make surer confirmation more readily possible.

If one does the experiment for each series with maximal exertion of will and with consistency in the range for simultaneously surveying the entire pattern, then distinct differences of difficulty emerge for the individual series. The generation and clear simultaneous retention of the opposite pattern typically succeeds more easily and also more quickly with II than with I or even III. Toppling back into the natural grouping [p. 342] also shows the corresponding effect. Soon there emerges an order of difficulty of the series corresponding with the law of proximity: from the most difficult, III, through I and II to IV. For finer ranking of the series, one must sometimes work with specification of fixation and of the domain to which attention is directed.

It was possible to confirm this more precisely with the following tasks.

(b) One of the series is exposed, with the long slanting pattern to be generated. When it is clearly there, the short slanting pattern is to be generated, and so on. The observer gives a sign each time the specified pattern is there; the times are measured.

(c) Similarly, but alternating the patterns according to the beat of a metronome.

(d) Best of all, with direct use of the factor of objective set [*Einstellung*]:

One observes one of the four series, generating the contrary pattern. When it is clearly there, one switches suddenly to a certain other of the four series, with the requirement to see this too in the contrary pattern, immediately. When using practiced subjects in such experiments, the results were as follows:

If the contrary pattern, that is, the long slating grouping, was achieved in I and one switched to II, in the great preponderance of cases the contrary pattern was clearly and immediately successful in II as well. On the other hand, if one began with the contrary pattern in II and switched to I, then against the observer's will, in the great preponderance of cases the normal grouping of the short slant was there, or it appeared jumbled. With the sequence II → I, an immediate result of the contrary in I was only rarely attainable.

In a methodical experiment

Going from a contrary pattern in	I	to	II	mostly produced	long slant
	II		I		short slant
	II		III		short slant
	III		II		long slant
	III		IV		long slant
	IV		III		short slant
	I		III		??
	III		I		??
	II		IV		long slant
	IV		II		short slant
	I		IV		long slant
	IV		I		short slant

That is, in this experiment the difficulty of attaining the intended contrary pattern increases unequivocally from IV through II to [I and III]. Thus, the greater the differences in distance, the more strongly the factor of proximity operates.

For initial experiments it is naturally good to begin with large step-by-[p. 343] step differences, but with a bit of practice in consistency of approach, it is quite possible to transition to series with more finely graduated steps.

Only in the cases of I → III and III → I did a large scattering occur, with no unequivocal result. But these are cases which in themselves are already very hard to get in the contrary pattern; and the two cases are objectively, quantitatively much more like one another than the other pairs.

Thus not only is the contrary pattern more difficult than the natural grouping, but also under the conditions of this experiment the difficulty of the contrary grows with the difference between the two distances. This is valid to a large extent, but—and this is of considerable importance for theory—it is not simply valid in general (cf. §47).

46. Among other methods that make a quantitative exploration possible, let us mention only the following.

Generate tables of systematic variations of an initial series, as in §21. The series are observed individually, switching from one to the next according to beats of a metronome, in systematic succession from the top, from the bottom, or from the middle. Look for the place where the "toppling over" occurs, that is, a sudden change into the other pattern or into a jumble, while attempting to retain the originally grasped natural grouping, or while attempting to retain the artificially generated contrary grouping when going from the middle. With pure experimental conditions, the region of the toppling over exhibits sufficient consistency and thus produces a quantitative criterion.

Now vary different aspects and compare the outcome of different tables. For instance, one table might contain systematically varied series as in §21 with a constant $d_1 + d_2$, thus with a constant specific distance of the *a-c-e-f* . . . dots in the straight rows of dots. Now generate other tables with a different specific $d_1 + d_2$ distance, and vary that systematically. Also proceed with tables of series that have a constant d_1 and a varied d_2. Also vary the number of series between the same initial and final series in a table and, thus, the number of steps. A somewhat different procedure would be to present the systematic sequence not from the top to the bottom and vice versa, but rather the top, then the bottom, then the second from the top, the second from the bottom, etc., and conversely going outward from the middle.

Even though in such experiments the strength of the factor of proximity and that of the factor of set [*Einstellung*] are tested at the same time, nevertheless confronting the outcomes yields insights into the mode of operation of the law of proximity.

From the results of such experiments so far, it should only be noted briefly here that they seem to give rise to a functional formula for the law of proximity, in which the relationship of the distances plays a decisive role, but not entirely alone.

[p. 344] 47. One more point should still be emphasized. One might suppose that the contrary pattern would generally become easier if d_2, larger in itself (in our simple example in §21), is decreased; *b c / d e /* . . . would arise more easily, as the distance *b-c* grows smaller (relative to the still smaller *a-b*).

Start with an initial series of four pairs of dots horizontally. Give it a small d_1 and large d_2, such as $d_1 = 2$ mm and $d_2 = 10$ mm. Set up variations that hold d_1 constant while decreasing d_2 in steps. For instance,

series I	$d_1 = 2$ mm,	$d_2 = 10$ mm
II	2	7
III	2	5
IV	2	4
V	2	$3\frac{1}{2}$

One might expect that the contrary pattern would become easier from I to V. But that is not the case, and in a very characteristic way: Though it goes quite well with I, most people can achieve the contrary pattern clearly and simultaneously across the whole field with IV and V only with difficulty, if at all. (Here one can usefully allot different numbers of series to different subjects.) The progression in this experiment often leads maximally to "jumbling" in the series or to a kind of impoverished evenness. And if the contrary is achieved at all, it is still much less clearly, specifically, distinctly, plainly there than with I. This points to something fundamental; we will come back to it.

48. One can replace the dots in the series of §1, and similarly in other series, with

A. Several dots closely one above the other (series of vertical rows of dots);
B. Vertical lines;
C. Additional horizontal rows of dots going through the top and bottom of configuration A, closing it off; and corresponding continuous horizontal lines at the top and bottom of configuration B.

Here too the factors discussed above are effective in principle: the factor of similarity,[21] and likewise the factor of proximity, as can easily be tested.

For instance,

Series A five pairs of dots, d_1 = 5 mm, d_2 = 15 mm
Series B at the same distances, vertical lines, say, 20 mm high
Series C the same series as B, but with a continuous horizontal line at the top and bottom of the verticals' ends.

But if one compares the result and the generation of the contrary pat-
[p. 345] tern in these cases with the simple series of dots, the "contrary pattern" */ b c / d e /* . . . appears much more easily, more specifically, more distinctly, more surely in B and C than in A. (Here again one can try allotting different numbers of series and different distances to different subjects.) Also, in cases where generation of the contrary in A is already very difficult, indeed is impossible to achieve across the whole field under the existing conditions, this grouping arises incomparably more easily in C or

21. Besides, it is easy to see here that the law of similarity is a special case: not only identical items but also those that lie symmetrically to one another, are correspondingly different, or the like are favored.

B. It looks “very salient [*prägnant*],” often arises remarkably suddenly (“with a snap”), and indeed results spontaneously under specific, characteristic, objective circumstances, and even is favored over *a b / c d / . . .* or at least achieved more easily.

It was very easy to make the contrary grouping actually impossible with the simple groups of dots discussed. If one wants to do the same here, one must try very forceful configurations. Indeed with some subjects one must set up the factor of similarity, of the simple Gestalt, in the same time, in the same way.

Why is this? What is happening here?

If one does such experiments, one quickly sees that although posing the question in the form of a / b c / d e / . . . as against a b / c d / e f / . . . was quite suitable to begin with, at bottom it was actually only a meager abstraction.

49. What do the groupings of §48 really look like? Does one truly describe the essence of what is obviously clearly presented if one speaks of “*a b / c d / . . .*” and “*a / b c / d e / . . .*”? In all these cases, are we really dealing with “sequences” or “quantities” of the pieces *a*, *b*, *c*, *d* . . . in a particular “combining of pairs”?

Let us start with C. What does the contrary, the pattern *a / b c / d e / . . .* actually look like? Typically, like this: There is a long horizontal oblong with four wide vertical strips or vertical oblongs. The pattern *a b / c d / . . .* is five narrow vertical strips between two parallel horizontals, and likewise with other forms.

And in B? Here too, with the contrary, there are typically four wide vertical strips between two bordering lines; and—are the two bordering lines really just “leftovers,” “unpaired”? No; together they shape “the border.” And here again *a b / c d / . . .* are the five narrow strips.

And A? Even if it is not as saliently [*prägnant*] markedly there, nevertheless here too there is initially the articulated horizontal series with partitions (subgroups). With a successful contrary, here too again it is not simply that the first and last dots are “unpaired” or “left over.” Rather, the four long ranges are between the two, which again shape “the border.” And the grouping *a b / c d / . . .* typically does not yield pairings of two pieces each or the like, but rather here too a horizontal whole with (small) subforms, subwholes.

In C very often there are not mere contour figures, but rather oblong surfaces, strips of surface. It is imperative to distinguish between these
[p. 346] two forms. There are specific regularities, to be dealt with later, for result-

ing in one or the other: pure contour figure or actual surface figure (cf. Fuchs, loc. cit.). These are regularities in simultaneous φ forms of line and surface.

For people with a strongly visual disposition, the same thing is also clearly the case with A and with B. Thereby there often occur in B the characteristic border events of the generated strips of surface mentioned by Köhler.

Very striking events of this kind appear in the experiments mentioned in footnote 7. People with a very strongly visual disposition see characteristic, regular events. The "surface" stretches as if it is elastic. Thereby the subjective border curves change in a regular way above and below; the "surface" tears and disappears; a new, different one forms; and so on.

It is the same with A as well. For visually disposed people, the pattern *a b* / *c d* / does not contain just "*a* and *b*" as a simple pair. The space between *a* and *b* is not simply empty, "merely space between," the way the space between *b* and *c* is.[22] Also "subjective lines" often crop up.[23]

From here there is a very characteristic connection to outcomes of tachistoscopic experiments, even for people who are not visually disposed. In experiments with heterogeneous dot configurations at brief exposures at distances that in themselves are well above threshold, preferably with configurations that are more profuse and not merely individually linear, it appears very plainly[24] that typically the relationships are initially grasped as an overall whole. Subwholes of greater range become prominent, with their subdivisions unclear. Often, indeed, subwholes consisting of relatively closely spaced dots do not in the least appear simply as configurations of these and those dots. Rather, their common surface becomes prominent, without subarticulation at first, often as "overall an irregularly colored, dark domain." Everything seems to point to this: We are not dealing here with a principle that makes its appeal primarily to distances and relationships between the individual pieces. Rather, it is primarily a matter of the resulting of whole forms and of articulation into
[p. 347] subwholes. It works not "from the bottom up," not from the individual pieces step by step to higher forms, but the other way around.

22. Cf. "dead interval"; but even for that it is so simple.

23. These lines are not merely straight, but also variously curved, according to the objective circumstances.

24. Except with unnaturally practiced setting [*Einstellung*] of the attention on a small range, which leads to poor recognition anyway.

In the present cases one might want to ask further: More precisely how are the "lines" as well as the "surfaces" there?

In C, if one saliently [*prägnant*] has the contrary version, with the four wide oblong surfaces, what do the five narrow interstitial spaces look like? Are they "five interstitial spaces"? No; typically there is just one field, one surface, whether it happens to be the surface of a horizontal whole long oblong or the surface of the paper. It is one continuous surface; or at the least it is not the "interstitial spaces" that are bordered by the lines so much as the strips between *b* and *c*, etc. The vertical lines have a one-sided bordering function. Line *b* very specifically acts as a border to the left, but not so much so to the right.[25]

This can be shown experimentally with extreme rigor. With suitable designs, the figural form of the interstitial spaces is not seen as such in the least, to the point where one is often "blind" even to very familiar forms of such surfaces. One cannot find them at all when asked to do so, and does not recognize them—unless indeed one topples into the opposite pattern, here *b c*, much as with puzzle pictures.

Hence one has not in the least to do with pieces (and so still less simply with pairs) and interstitial spaces, but rather with surfaces within a surface. One extremely important special case of a surface Gestalt within a surface Gestalt is the case of a background with a figure on it. For these relationships and their consequences there are clear regularities.[26] It remains only to mention briefly that similar phenomena also occur in nonvisual domains, for instance, in the acoustic.

Here we can usefully supplement our three cases at the beginning of §48 with a fourth: We change C, not by putting more lines in a homogeneous field, but by making the strips *a b*, *b c*, . . . alternately different-colored surfaces, such as blue and yellow. And hereby we seem to have arrived at the case that is, theoretically, the most fundamental, if in doing so we also bring the whole visual field into consideration.

X [The *Ganzfeld*, and further observations]

50. We will go into the more detailed regularities of the last-mentioned circumstances only later. Here we just want to attempt a brief sketch of what seems to matter fundamentally overall for the key point in §49. In §§35 and 47f., among others, something came up that speaks against a theory of working primarily outward from the individual dots, the indi-

25. Cf. Rubin, loc. cit. here and for the following discussion.

26. Cf. Rubin, Fuchs, loc. cit.

vidual distances that are juxtaposed. (We will later come to know something else that is still more important for this.) If one surveys the situation, [p. 348] then a different kind of theoretical formulation proves to be more appropriate. What seems to matter in essence is sketched here in very preliminary propositions.

If we take a good look at salient [*prägnant*] cases of the kind last discussed, the following theses arise:

1. Certain stimulus distinctions (inhomogeneities) are required in a homogeneous field for it to divide up in some particular way, for some particular forms to crop up in it somehow and stand out in it.

A homogeneous field appears as a whole field [*Ganzfeld*]. It resists disintegration or tearing up or disruption. Relatively strong inhomogeneities are necessary for this, and are especially disposed to be favored for it.

This holds good not only for homogeneous fields, but also for fields that display a simple regular progression (for instance, centrally symmetrical) of brightness or the like. To some extent it holds for fields that appear inhomogeneous in a variegated irregular way, as a disorderly, mottled, chaotic *Ganzfeld*.

Even in cases where the stimulus conditions only approximate this, there is generally a tendency to appear as a *Ganzfeld* in this way.

The same sort of thing happens with certain subwholes that regularly appear as whole surfaces or as "single surfaces" (simultaneous φ surfaces). This is especially easy to test in contrast with experimental conditions that produce "dual" results.

2. The most salient [*prägnant*] case of a form resulting in such a *Ganzfeld* occurs if a closed simple surface form in the homogeneous *Ganzfeld* is homogeneously differently colored. It is plainly different and favored: more compelling.

If this surface part is enclosed by the otherwise homogeneous *Ganzfeld*, then typically there does not result a duality of surface form and frame form. The contour of the enclosed field essentially has a bordering function only for the former. It does not demarcate the "ground" so much. In salient [*prägnant*] cases the ground "goes through."

As a rule, such a surface part results in a surface figure in or on the field surface,[27] as a complete part, a subwhole. But the same is also the case if this partial surface with its homogeneously different color is replaced by

27. With certain cues, a rarer counterpart results in a "hole" in the surface.

a domain that stands out through its regularly simple distribution of brightness, or even one that has a more or less dense different coloring than the *Ganzfeld* only discontinuously. For the simplest case of this, replace a homogeneous black surface figure in a white field merely with discontinuous black dots in the surface figure, or a continuous black line [p. 349] in a white field with a series of dots. Such a form stands out above all as a whole whose domain, its location and span, is in the *Ganzfeld*.

3. What is indicated here is repeated, theoretically secondarily, within this part-whole. Discontinuities and the occurrence of subwholes and subdomains can be generated within the part domain, for instance, in a straight line of dots where denser subgroups of dots are sundered from one another by relatively greater distances. The characteristic partitioning of the whole into subparts "from the top down"[28] is theoretically primary here as well.

4. The factors in part VII, especially §35, are of essential significance for resulting in such forms and partitions from the top down. There we see the conditions for the emergence of regular, characteristic, simple events primarily in broad outlines. Several such distributions together simultaneously tend not toward a coordinated "and"-juxtaposition, but rather toward a hierarchy of fewer main forms or main stretches, except in the cases where, on the contrary, a jumbled *Ganzfeld* is produced.

5. Under natural conditions, distribution of attention, fixation, and the like tend to be secondarily determined by the relationships in the configuration as a whole, above all by the main partitions in broad outlines. In principle one must distinguish between arbitrary, artificially intended

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28. This also has extensive epistemological consequences. The psyche and the psychophysical organism of sensory reception do not react primarily like a mirror or receptive camera apparatus which, upon sensing the individual stimuli, employs all kinds of operations on and among them to construct larger forms from the bottom up, via further complication based on the sensed "and"-sum of the individual impressions. Rather, what comes into question is primarily a type of overall partition in the sense of the factors in part VII. In contrast with the concept of a primarily piecemeal mechanical sensory apparatus, what emerges here is the concept of an apparatus (though already that word is not adequate for the situation in the least) which is as useful as possible for grasping internal necessities. At some point one should ponder, in contrast with a piecemeal mechanical apparatus, how to conceive of this apparatus in principle: one that is as well adapted as possible for grasping inner connections, parts, data, and qualities caused by an inner principle. One of the most direct possibilities arises if pieces are not sensed primarily as such to begin with at all, but rather the reception itself is already caused by characteristic whole relationships ("from the top down").

modes of attention and those demanded by the structure. Under certain circumstances, an artificially produced shift in the range of attention sets up new, different field conditions.

6. In going from the top down as sketched here, from the conditions of [p. 350] the whole down to the subwholes and parts, the individual parts ("elements") do not come under consideration primarily as pieces in an "and"-sum. Rather, from the outset they are parts of their whole.

From this there follows a principle for observing the situation, even in cases where at first it theoretically appears that the primary foundation lies in individual presentation of pieces in an "and"-sum, such as in some approaches in the visual domain, and in pure succession in the acoustic domain.

In the acoustic realm too there is much that corresponds with the above. As an example, consider a motif emerging out of a confusion ("*Waldweben*"), setting itself off from the background of an "accompaniment," even the phenomenal "breaking through the silence." In individual sequences of tones as well, a deeper investigation of their phenomenal nature shows a complete correspondence. The typical presentation of pieces is as parts.

Briefly, here is a tentative note about that.

Isn't there a huge distinction phenomenally between hearing the first three tones of a melody as such, in anticipation of what follows, as a beginning that flows and goes onward, and, by contrast, hearing the "ending," such that I have the three tones as a whole motif? Indeed, isn't this already so with the first tone, which is there as a starter or preparation (as the leading tone), or in some other way is different from the tonic? This is not something "tacked on," but rather the essential flesh and blood of what is there. If one really wants to grasp the nature of phenomenal presentation, it becomes evident that the individual tones in the melody are clearly, saliently [*prägnant*] presented as parts. If, before going farther, in the situation where one really cannot know in the least yet how or whether the melody continues, one seeks to grasp the nature of what is presented, then something beautifully characteristic occurs. The character of the tones is definitely not yet quite complete. The tones have a more indefinite, still unstable character (and what peculiar experiences occur if one performs this experiment in a pure form!). They are complete, firm, and definite only when the last one is there as the "closing tone," and hence everything becomes firm. Indeed, in various cases like this using the same objective stimuli, more precise experiments show that the intensities and even the pitch of the tones typically seem to differ on the basis of certain Gestalt regularities. Correspondingly in the visual realm, typically what is presented is there primarily as a part or as the whole. This last is also possible for so-called "elementary" parts; and the fact that a certain epistemological mind-set [*Einstellung*] views such a grasping of the elementary parts as the "scientifically primary obligation" may well explain in part the customary, principally piecemeal approach to everything psychological.

(Submitted 10 April 1923.)

Translated by Michael Wertheimer and K. W. Watkins

Synopsis of Max Wertheimer's 1923 Article

Viktor Sarris

What is indicated here can become more strictly precise only with further study. It is clear that certain problems in pure mathematics and in set theory must be considered, particularly the problem of attributes of the whole in contrast with mere regularity among pieces.

—Max Wertheimer (1923, p. 154)

Abstract

This article, affectionately known to researchers since its first publication as the "dot study" (*Punktarbeit*) for its numerous examples of dot patterns in various arrangements, helped to define a central problem in perception. For most of a century, researchers have asked how the differential stimulation of a mosaic of discrete sensory elements, such as light-sensitive cells (photoreceptors), is transformed into perceived units, figures, and wholes distinct from one another and from their background: What are the principles that govern perceptual organization? We do not notice that some receptor elements are more activated than others; we perceive objects in relation to one another in space. He describes his work on the Gestalt laws, or principles, of perceptual organization, performed mostly during the period 1911–1914 in Frankfurt. He shows how these principles generate emergent properties of form perception in vision (as well as in audition): (1) Wertheimer develops these principles not only for stationary stimulus patterns but also for dynamic events (e.g., motion perception and recognition of a melody). (2) His studies aim eventually at a quantitative theory, but they are worked out mostly on a qualitative basis. (3) The theoretical conclusions are based mainly on compelling demonstrations and phenomenological evidence, rather than on a firm body of systematic psychophysical data.

Wertheimer's 1923 article, the second of his two major early publications on Gestalt psychology, consists of fifty sections (§1–§50) divided into ten parts (I–X). Wertheimer wrote this article during his first period in Frankfurt, in the years from 1911 to the beginning of 1914 (except for §§42 and 50) (p. 129). He cites Carl Stumpf (1859–1931), his former mentor in Berlin, to whom this paper was dedicated: "Through careful study of single sensory areas one will arrive at laws of grouping." Here it is necessary that "the last word must rest with experimental psychology, and so far it has still hardly said its first" (p. 128). Thus the reader is told that the experimental basis of psychology—including the entire Gestalt theoretical approach—was still in its infancy at the time.

Gestalt Principles of Perceptual Organization

Wertheimer's introduction, a unique prelude to the main text, is based on a number of examples supporting the claim that all perception is organized into meaningful configurations ("wholes," or Gestalten), not in a summative ("piecemeal") way as proposed by the leading psychologists of his time. His illustrations stem mostly from vision, but also from audition, including face perception and melody recognition. For example: ". . . I see two faces cheek to cheek. I see one of them with, say, its theoretical '57' brightnesses, and the other, with its '49'; but not partitioned into 66 plus 40, nor 6 plus 100. Theories claiming that I see '106' exist only on paper; what I see is two faces . . . . Or: I hear a melody of 17 tones with its accompaniment of 32 tones. I hear melody and accompaniment, not simply '49' [tones] . . . , nor purely at my whim, 20 plus 29 [tones]" (p. 127). These opening illustrations are convincing but are also caricatures in that they ridicule the mainstream psychologists' "structuralist" (element-theory) point of view like that of Wilhelm Wundt (1832–1920) or Edward B. Titchener (1867–1927). The conflict arises from the juxtaposition of the orthodox "piecemeal" view and Wertheimer's experimental phenomenology as a basis for the new Gestalt theory. The radical Gestaltists' credo is that the "whole" (Gestalt) is different from a mere sum of its parts and is epistemologically prior to its parts.

Based on his many laboratory and classroom demonstrations in Frankfurt, Wertheimer describes the Gestalt "from above down" (top-down), that is, "from the whole to the parts," not the other way around (bottom-up). He phenomenologically demonstrates the principles of perceptual organization—namely, the following:

• *Proximity*, the general tendency according to which single items are integrated or segmented ("grouped") as Gestalten according to their distance from or proximity to one another;
• *Similarity*, which describes the perceptual tendency to group items together as Gestalten according to their similarity to one another (in respect to such features as shape, color, or texture);
• *Common fate*, which describes the perceptual tendency according to which stimulus objects that change together in location or that move together group into Gestalten;
• *Good continuation*, the tendency that parts that create coherent continuity are grouped together; and
• *Closure* or *completion*, which refers to the perceptual tendency to unite incomplete or partially interrupted figures.

Good Gestalten, Prägnanz, and Additional Key Concepts

The concepts of good Gestalt or Prägnanz—that is, the tendency to perceive symmetrical wholes and the tendency for percepts to be as "good" as the prevailing stimulus conditions allow—play a key role in Wertheimer's thinking. So does his concept of figure–ground organization by *segregation* and *segmentation*. Also, there is the principle of set (*Einstellung*), i.e. the tendency to perceive a particular pattern in accordance with instruction and past experience: "This factor of set (*Einstellung*) is very strong. . . . It is clear that one must take this factor into account very carefully in experiments" (p. 148; cf. also §22, and §§21 and 46).

Note that Wertheimer's definition of *past experience* is not identical with such set; rather the factor of experience involves the influence of earlier events on subsequent perceptions. In Wertheimer's words: "Another factor affecting whether a certain grouping and partitioning will result is familiarity or 'past experience.' In its simplest formulation, this principle states: If *AB* is familiar, and C is familiar, but *BC* is not; if they happen to be associated with something else (spoken names, etc.); or if *AB/C* is familiar, but *A/BC* is not; then there is the tendency for *ABC* to result in the familiar . . . trained pattern *AB/C*" (p. 160). According to Wertheimer, there can be no doubt that some of our apprehensions are determined in this way after sufficient "drill." Figures 47 and 48 (p. 163) are vivid phenomenological demonstrations of the relative unimportance of past experience, namely, the perceptual disappearance of the familiar letters "M" and "W," when placed in a certain pattern or configuration, rules out any dominant role of past experience; at the same time, these two simple figures constitute special cases of camouflage in perception (hidden figures). All the Gestalt principles mentioned above determine the way in which objects are perceived as integrated wholes ("*Ganze*") and subwholes ("*Teilganze*," "*Unterganze*"). The 1923 paper thus definitely suggests an innate origin of perceptual organization. Note that many of the themes discussed in this article already occupied Wertheimer in 1912, while he was still working on his apparent motion paper in Frankfurt.

Wertheimer's Dot Tasks

Much of Wertheimer's treatment of the Gestalt principles consists of dot-pattern tasks, which provide easy-to-grasp illustrations and do-it-yourself demonstrations for the reader. He starts with patterns illustrating the principle of proximity. For example, in Wertheimer's own words (§1, along with figure 1): "Present a series of dots in an otherwise homogeneous field, with alternating distances, for instance, d1 = 3 mm, d2 = 12 mm. . . . Such a series of dots is normally seen spontaneously as a series of small groups of dots in the pattern *ab / cd* and not, say, in the pattern *a / b c / d e*. . . . Having the second version (*a / b c / d e . . .*) simultaneously over the whole set of dots is completely impossible for most people" (p. 130). Additional didactic patterns of dots or lines are spread over many parts of the paper. Some of these dot tasks refer to parametric experimental variations; for example, near the end of the paper (§48), he writes,

> "One can replace the dots in the series of §1, and similarly in other series, with:
> A. Several dots closely one above the other (series of vertical rows of dots);
> B. Vertical lines;
> C. Additional horizontal rows of dots going through the top and bottom of configuration A, closing it off; and corresponding continuous horizontal lines at the top and bottom of configuration B. Here too the factors [principles] discussed above are effective in principle: the factor of similarity, and likewise the factor of proximity, as can easily be tested" (p. 175f.).

This quotation also shows Wertheimer's struggle to come up with a systematic quantification of the Gestalt principles (for still other dot task examples in the paper, see §43, p. 167, and also §46, p. 173).

Methodological Relevance of Wertheimer's Dot Tasks

Working through these dot patterns helps the reader gain the following methodological insights: (1) The Gestalt principles are based on empirical, not merely theoretical, grounds. (2) Readers should become actively involved and work on such tasks by themselves, at best for all Gestalt principles, not only for one or two of them. (3) These tasks are important for event perception too, and they should be studied experimentally. (4) The dot task method may be even more relevant when used in the systematic study of absolute versus relative distance (cf. the Epilogue, this volume).

Regular Motion and Musical Gestalten (Melodies)

As already mentioned, the Gestalt principles are proposed by Wertheimer also for the study of motion and tonal Gestalten (melodies). For example, the factor of proximity is relevant for apparent motion too, namely, "A principle of proximity is also known to apply in stroboscopic motion: Movement normally results chiefly in the smaller (spatial) separation [figure 18a]. Successive exposure of all the *b* dots after the simultaneous exposure of all *a* as a rule produces movement from *a* to *b*, from left to right, in the pattern of the smaller separation and not—simultaneously across the whole pattern—the movement . . . from right to left" (p. 142). And furthermore, "A principle of similarity applies here too. Other things being equal, motion results chiefly among similar items [figure 18b]. Here the spatial distances of the stimuli are the same; but the quality is different. There [now] results chiefly a motion from left to right, not from right to left" (p. 142f.).

In this context Wertheimer refers briefly to the publication of A. Korte (1915), Kurt Koffka's (1886–1941) doctoral student, concerning the quantitative establishment of the Korte–Koffka laws of apparent motion, all based on psychophysical experimentation. Furthermore, the mentioning of melody Gestalten is another example of the application of Gestalt principles to event perception—the relevance of which can hardly be overstated. Wertheimer here treats the factor of set ("*Einstellung*") in the context of motion Gestalten, mostly on an experimental–phenomenological basis as well as in another of his dot tasks in stroboscopic perception and in musical recognition (cf. §18, p. 142 and §38, p. 161).

Note that the demonstration of regular motion Gestalten provides a crucial link between Wertheimer's two articles of 1912 and 1923. This link illustrates the critical relevance of spatiotemporal complexities in all of perception. In his own words (§17), "If one operates with systematic variations of the spatial and temporal distance relationships in opposition to [for instance] the factor of similarity, then the results soon show a clear disparity which indicates one of the differences in the laws of simultaneous as against successive Gestalten. In simultaneous Gestalten the factor of similarity appears to work differently than in successive Gestalten, in general much more 'strongly'" (p. 141).

Two or More Gestalt Principles Combined

Wertheimer also treats the interaction between the Gestalt principles or factors—specifically, of two factors in simultaneous and successive object perception. One of his main ideas is represented in the following passage (§12): "What happens when two or more such factors exist together throughout a configuration? One can let the two factors work with each other or against each other. For instance, if the one is set to favor the tendency toward *ab* / *cd* / . . . , then one can set the other to favor the same one or the opposite (. . . / *bc* / *de* / . . .). This is similar to the way in which, through change in the distance relationships using the law of proximity (cf. §45), one can weaken or strengthen an existing tendency" (p. 139). This assertion is remarkable as it suggests a two- or even multifactorial design paradigm by means of a systematic Gestalt psychophysical approach. Furthermore, two of Wertheimer's major concepts mentioned above may be relevant here, namely the Prägnanz tendency and the principle of good Gestalt: Both concepts resulted mostly from Wertheimer's extensive phenomenological inquiry.

In Search of the Biological Roots of Gestalt Perception

Toward the end of the paper, in §42 (cf. footnote 3, p. 129), Wertheimer emphasizes the need for a systematic search for the neurobiological basis of all kinds of Gestalt perception. Although the claim is made here only on theoretical grounds and, remarkably, without a reference to Wolfgang Köhler's (1887–1967) monograph on "Physical Gestalten" (1920), he clearly articulates the need for such research, still largely lacking today: "As a rule, in natural life, the pattern [of Gestalt perception] corresponds with reality. . . . [C]ould not this be due to biological regularities at work in receiving [perceptual] information, regularities typically quite adequate in our world . . . ? Biologically, is it not very generally true that there are regular, general kinds of organizations, modes of operation quite adequate under their biological regular conditions . . . ? The nervous system has developed under the conditions of the biological environment. [Therefore,] it is no wonder that the Gestalt tendencies developed thereby correspond with the regular conditions of the environment . . ." (p. 166f.). This evolutionary account of the biological roots of Gestalt perception is significant even though it does not contain any reference to published work of his time. In other places, the article cites Goldstein and Gelb's (1920) seminal publication on brain injury and alexia; this may help the reader to appreciate Wertheimer's continuing interest in a neuroscientific approach (cf. p. 129, footnote 3; p. 158, footnote 15).

In the final section of the article, §50, a few issues in recent Ganzfeld work carried out by Wertheimer and some of his students in Berlin receive attention, although only in a cursory manner (pp. 178ff.). The problem of "subwholes" (*Teilganze*) in Gestalt research is also strongly emphasized, once again with the help of a tonal illustration (top-down approach) using a melody. Altogether, the 1923 paper started an impressive research program that has had a profound and lasting effect on perceptual psychology.

Acknowledgment

Earlier versions of this text have been published elsewhere (Sarris, 1987/1995). I am indebted to Michael Wertheimer for reading and valuable comments on a draft of this synopsis.

The Current Status of Gestalt Rules in Perceptual Research: Psychophysics and Neurophysiology

Lothar Spillmann

Abstract

A common notion holds that the visual system produces a facsimile representation of the visual world. However, what we perceive phenomenally can often not be explained on the basis of known physical properties of the stimuli around us. Visual illusions are one example; ambiguous stimulus patterns another. Such phenomena demonstrate the potential ambiguity of stimuli in our daily environment, but—as a rule—there is only one percept. The Gestaltists were masters in deriving organizational principles from the lawful way in which we see, thereby assigning an active role to the visual brain and defeating naive realism. This movement started with Max Wertheimer (Ash, 1998).

Stimulus patterns are perceptually structured according to a number of *Gestalt factors* that enable (i) figure–ground segregation and (ii) grouping. Max Wertheimer described some of these factors in his 1923 article: symmetry, parallelism, good continuation, and closure for figure–ground organization and proximity, similarity, and common fate for grouping. In addition to these factors, common region, element connectedness, synchrony, and edge region grouping have more recently been proposed.

Much progress has been made in identifying the neuronal mechanisms underlying these segregation and grouping factors. For example, neurons in area V2 of the macaque have been found to respond as though they mediate border ownership (Rubin's *law of the inside*). The facilitation of a response in area V1 to a line in the presence of collinear flankers has been interpreted as a correlate of the Gestalt factor of *good continuation*. Response synchronization of MT neurons has been discussed as a correlate of *common fate*. Yet other response properties have been described for cortical cells that may be interpreted as neural correlates of perceptual *completion* (in area V2) and *filling-in* (in area V3).

This essay aims at bringing figure–ground research (Rubin, 1915/1921; Wertheimer, 1923) into the twenty-first century by reviewing psychophysical and neurophysiological studies from four perspectives: emergence of figures, grouping of elements, filling-in of surfaces, and shape-from-motion. It concludes with unresolved issues pertaining to isomorphism, infant vision, and innate versus acquired visual perception. The variety of phenomena discussed under each of these headings covers—in brief capsules—much of the correlational research on figure–ground and grouping that has emerged in the field of visual perception during the last 25 years. It is hoped that this review contributes to the renewed discussion of Gestalt vision and its neuronal underpinnings for a better understanding of why we see the way we do.

Introduction

Why do things look as they do?
—Kurt Koffka (1935, p. 76)

How the brain sees is one of the most important problems facing neuroscience today. The problem of how we group elements (Wertheimer, 1923) and parse stimulus patterns into figure and ground (Rubin 1915/1921) is critical for how we perceive objects and acquire a representation of the world around us. A hare in the field is only visible if it differs in brightness, color, or texture from the ground; without a difference, it is perfectly hidden from our eyes. Only when it casts a shadow or moves does it stand out. This and other examples from nature are important for a better understanding of visual perception.

This essay reports on studies of perceptual organization inspired, in part, by Max Wertheimer's (1923) seminal article on grouping and figural organization. Subsequent research in this field can often be traced to his pioneering study, even if his name is not explicitly mentioned and no reference is made to his work. For example, Wertheimer discussed the effects of fixation, eye movements, focus of attention, past experience, and set (*Einstellung*) on visual perception, topics that subsequently developed into research areas of their own (Chun & Wolfe, 2001; Kimchi, Behrmann, & Olson, 2003).

The questions asked in the studies presented here focus on the factors and processes responsible for transforming the retinal image into a *structured percept*. How do stimuli impinging on the photoreceptor mosaic become figural representations of objects in the brain? What is the time course of the transformation from stimulus to percept, and what are the inner dynamics that favor one perceptual outcome over another? Finally, how does it all happen: by inborn mechanisms, learning, or features inherent in the outer world?

Little was known early in the twentieth century about the neuronal mechanisms underlying these perceptual processes. Meanwhile, psychophysical and neurophysiological studies have shed light on the mechanisms that are responsible for figure–ground organization, grouping, and surface perception. Among these, studies of the spread of brightness and color information from the edge of a uniform region to the interior by long-distance interaction suggest how representations of contours may evolve into representations of surfaces.

The following survey aims at presenting the current status of knowledge as it pertains to Gestalt principles in a number of fields hardly anticipated by Max Wertheimer. Phenomenology, developmental and comparative psychology, psychophysics, single-cell neurophysiology, cognitive neuroscience, computational modeling—all have contributed to the renaissance of Gestalt psychology that is taking place right now. This is an unprecedented development in an area that has progressed as fast as any in the brain sciences and is worthy of the prophetic fighting spirit (*Aufbruchsstimmung*) that prevailed in the 1920s and 1930s, making Gestalt psychology one of the most influential—and challenging—intellectual enterprises of its time (Metzger, 1954).

Consider these developments: Early feature analysis and parallel processing of visual information (Hubel & Wiesel, 1965; Livingstone & Hubel, 1987, 1988) have found their way into neuronal network analysis and computational modeling (Marr, 1982; Grossberg & Mingolla, 1985; Ullman, 1990). Bottom-up (in the physiological sense) mechanisms (Koffka, 1935; Metzger, 1936/2006) have been complemented by cognitive or top-down strategies (Gregory, 1972, 1998). Backward propagation by reentrant signals (Singer, 1989; Tononi, Sporns, & Edelman, 1992; Lamme, 1995) and horizontal interaction (Gilbert, 1992; Gilbert & Wiesel, 1992) have been recognized as important principles of neural processing (for review, see Lamme & Roelfsema, 2000). Furthermore, *perceptive fields* (Jung & Spillmann, 1970) have been introduced as perceptual correlates of neurophysiological receptive fields, and the term *beyond the classical receptive field* (Nelson & Frost, 1978) is now commonly used to capture neuronal responses originating from the larger surround. Finally, early, intermediate, and late vision have become frequently used labels in perception research, although there are only few attempts to correlate them with the neurophysiological and neuroanatomical substrates in the visual pathway.

Figures on a ground are the most salient percepts mediated by our highly developed visual brain. Vision without figures would be like trying to see with an opaque cornea or a turbid lens. Such vision could provide brightness, color, motion, and flicker, but it would lack borders, edges, and delineated surfaces. As such, it would have no *structure* or *figure–ground* organization (i.e., no forms and shapes).

According to Rubin (1915/1921), figures are characterized as follows: They have object character (represent a thing), adhere or cling together (are compact), appear closer to the observer (even on a two-dimensional surface), are surrounded by a contour (that is unilateral), possess a form (often convex and symmetrical), and are superimposed onto a background, which they partially occlude.

In comparison, the ground or background has a “loose” structure (Rubin’s “substance”); it appears further away than the figure, is partially occluded by the figure and continues behind it; it is shapeless (e.g., the sky between the clouds) and larger than the figure. The figure is perceptually richer than the ground, has a bounded surface, and evokes connotations, whereas the ground is space-filling, poorly presented in awareness, and often not remembered. Figures represent objects with which we interact while the ground is “stuff.” The distinction between figure and ground is not given in the physical stimulus; it is an achievement of the brain.

In order for us to perceive figures, stimuli need to differ in brightness, color, texture, depth, or motion from their surround. Classical psychophysics dealt with these issues under the heading of differential threshold (Ehrenstein & Ehrenstein, 1999). Unless a stimulus on the retina exceeds a certain threshold relative to the ground, it will not be seen, and edge assignment will not be possible. Strangely, among all the Gestaltists this basic truth of sensory physiology seems to have been recognized only by Liebmann (1927) in her systematic study of isoluminant colors (see the translation by West et al., 1996).

The Primacy of Objects

In a bold stance, Max Wertheimer starts his famous paper in 1923 (p. 127) as follows:

> I stand at the window and see a house, trees, sky. For theoretical purposes, I could now try to count and say: There are . . . 327 brightnesses (and color tones). Do I “have” 327? No, I have sky, house, trees. Having the 327 as such is something no one can actually do. If, in this droll reckoning, there happen to be 120 shades of

brightness in the house and 90 in the trees and 117 in the sky, then at any rate I have that grouping, that segregation, and not, say, 127 and 100 and 100; nor 150 and 177.

Stumpf (1906), who taught Wertheimer, Koffka and Köhler, had already contested this elementistic view of sensation even before the Gestalt theorists did. What counts in our visual world are *structured percepts* that lie before us when we open our eyes—percepts that are far from the point-like image on the photoreceptor mosaic (Metzger, 1961). But instead of a punctiform image, we perceive coherent shapes and surfaces in spatial relationships to one another as well as their meaning to us. To perceive an object requires seeing lines and edges of given lengths and orientations, junctions, branch points, and endpoints, as well as surfaces of given brightnesses, colors, textures, and depths. These attributes taken together combine into objects of given shape that can be seen, perceived, and recognized. Marr's (1982) proposal of a primal sketch (contours only), 2½-D sketch (surfaces), and three-dimensional sketch (depth) captures these ideas in a modern, computational language. Not all three stages are necessary for perception. Contours without surfaces (i.e., outlines) suffice in many instances to represent and recognize an object; just think of the drawings of children.

Gestalt Factors

Using simple experiments with dot and line patterns, Wertheimer (1923) proposed and identified a host of so-called *Gestalt factors* responsible for figural segregation and grouping. These are symmetry, parallelism (Morinaga's, 1942, *Ebenbreite*), good continuation, convexity, and closure for the purpose of figure segregation (i.e., shape formation); and proximity, similarity, and common fate for the purpose of grouping (i.e., clustering of elements). However, more factors continue to be found: common region (Palmer, 1992), element connectedness (Palmer & Rock, 1994), synchrony (Lee & Blake, 1999; Palmer, 2003), and edge region grouping (Palmer & Brooks, 2008). These latter factors describe a tendency towards perceptual grouping when elements are tied together within the same bounded area, are connected (e.g., by a bar), change at the same time (e.g., time-correlated changes in orientation or simultaneous contrast reversal), and exhibit different edge groupings (e.g., textures). Palmer (1999) proposes that all of the above factors can be subsumed under the criterion of similarity and calls them *ceteris paribus* rules, implying that everything else being equal, grouping is favored by a given factor, for example, proximity.

These so-called *laws of seeing* (Metzger 1936/2006) are thought to *disambiguate* individually, or in combination, the infinite ambiguity present in the visual stimulus and enable segregation and segmentation of a stimulus pattern. Using a Kantian phrase, one could call them *a priori* conditions for the possibility of experience (*a priori Bedingungen der Möglichkeit für Erfahrung*). Thus, although Gestalt psychology may be classified as experimental phenomenology because its proponents were primarily concerned with empirical phenomena, Gestalt theory importantly was conceived of as a brain theory of perception (Köhler, 1920).

So far this goal has not been reached for two reasons: First, Gestalt factors are not easily defined and even less easily quantified, despite the fact that they are intuitively correct (self-evident). Second, no physiological mechanisms were known until recently to support the rules derived from phenomenology. Therefore, Palmer (2003) labels the Gestalt factors the best known and least understood terms in visual perception research.

Attneave (1954) attempted a quantification of the strategies used in visual perception by proposing a computational approach. He demonstrated that while contours represent high information content (high uncertainty), the information gained from uniform surfaces is largely redundant (i.e., strives towards entropy). In addition to surfaces, straight contours are likewise considered redundant, whereas corners imply variance and are robust shape descriptors (see figure 1). Indeed, when segments of high curvature are deleted (e.g., in an outline square), the shape is degraded much more severely than with deletion of low curvature segments (Ghosh & Petkov, 2006). In this sense the Gestalt grouping and figure–ground criteria may be considered perceptual strategies that minimize information (complexity), while maximizing redundancy in the

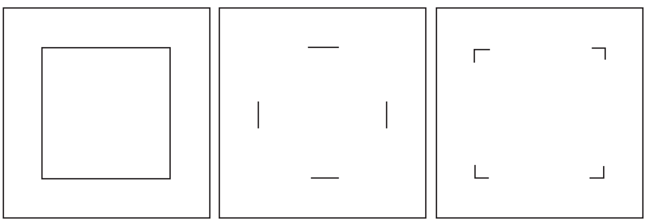


Figure 1
Perceptual salience of low versus high curvature sections in an outline square. Left: Complete representation; middle: side segments only; right: corners only. The image on the right mediates the percept of a square much better than the image in the middle although the total contour length is the same. (Modified from Ghosh & Petkov, 2006. Reprinted with permission.)

interest of greatest balance and order. Curiously, the same cannot be said for outline pictures of many everyday objects. Here, identification is often better with straight fragments than with curved segments of the contour (Panis et al., 2008).

Excellent treatments of the historical, phenomenological, and computational aspects of grouping and figure–ground organization are available, testifying to the continued interest of vision scientists in Gestalt perception (e.g., Rock, 1975; Kanizsa, 1979; Kubovy & Pomerantz, 1981; Beck, 1982; Hochberg, 1998; Palmer, 1999; Shipley & Kellman, 2001; Kimchi, Behrmann, & Olson, 2003; Peterson, 2003). An example is the work of Pinna (2010), who has designed new and fascinating examples of global–local and local–global intrafigural interactions (see figures 2A–C). In addition, he created intriguing phenomena of apparent rotation, long-range assimilation, apparent causality, perceptual meaning, and even visual language and sentence structure.

In this essay, I am confining myself to a review of select research on perceptual organization as it has emerged largely from psychophysical and neurophysiological studies during the last 25 years. In each subsection, I describe one or two phenomena and thereafter briefly discuss the presumed neuronal mechanism(s) by which they are produced (Spillmann,

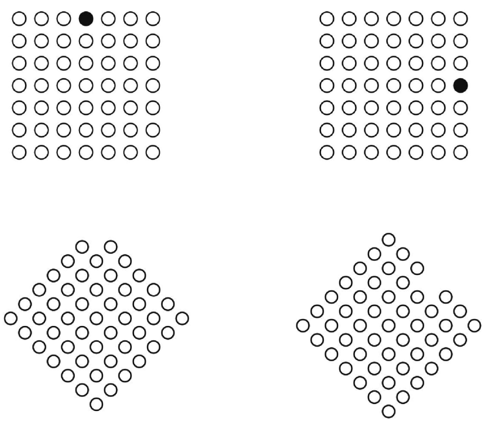


Figure 2A
Local–global interaction in a pattern composed of circles.
A local change affects the global appearance of the overall percept. Top: Two squares, one dot makes a difference in the apparent orientation of the square; left: vertical, right: horizontal. Bottom: Two diamonds, one missing circle makes a difference of how one sees the pattern; left: a diamond on its tip, right: a square on its side. (From Pinna, 2010; and Pinna & Sirigu, 2011. Reprinted with permission.)

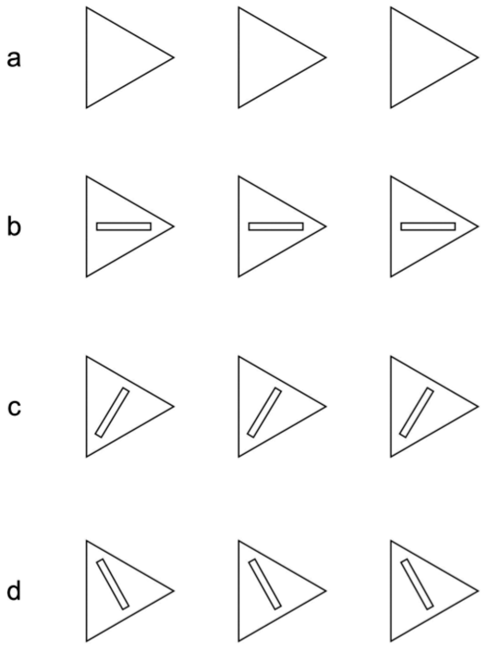


Figure 2B
Local–global interaction. Identical triangles.
A local change in the pointing illusion affects the global appearance of the overall pattern. a–d: The triangles seem oriented in the direction of the corner toward which the bars are pointing. (From Pinna, 2010. Reprinted with permission.)

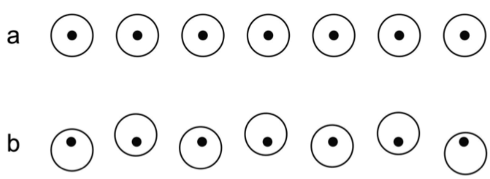


Figure 2C
Global–local interaction in a chain of dots.
A global change (circle) affects the appearance of the local feature (dot).
(a) Control. All the dots are centered and aligned along the horizontal. (b) The same aligned dots appear to dance up and down depending on their position within the large circle. This suggests a dynamic tendency towards centering (symmetry, inner balance). (From Pinna, 2010. Reprinted with permission.)

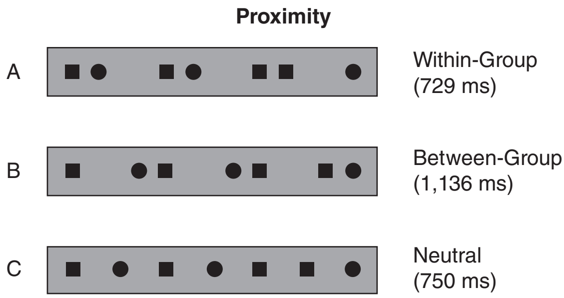


Figure 3A
Gestalt factor of proximity.
Two identical elements are detected much faster when grouped together (A) than when separated by a space (B), thereby seemingly belonging to different groups. Detection time in parentheses. The equispaced elements serve as a control (C). (From Palmer, 2003. Reprinted with permission.)

2009). It is my conviction, if one wants to understand the Gestalt principles governing grouping and figure–ground organization, that one must study the brain mechanisms underlying them.

The bulk of individual topics treated in this essay may be roughly categorized in four sections: emergence of figures, grouping of elements, filling-in of surfaces, and shape-from-motion. I conclude with a section dealing with some still to be answered questions pertaining to isomorphism, infant vision, and innate versus learned origin of vision.

1 Emergence of Figures

1.1 Detection versus Grouping Thresholds

Attempts to quantify the effect of Gestalt segregation and grouping factors were limited to a relatively small number of laboratories. Here, I will give some examples.

Using a repetition discrimination test, Palmer (2003) describes how two identical elements (e.g., squares) in a series of squares and circles were detected much faster when they were grouped, rather than not grouped, in a pair. This is a straightforward way of quantifying the Gestalt factor of *proximity* (see figure 3A).

The same method was applied to two identical elements grouped within the same bounded area as compared to the same elements grouped in different bounded areas. Again, the former group was detected much faster than the latter, confirming the strength of the Gestalt factor of

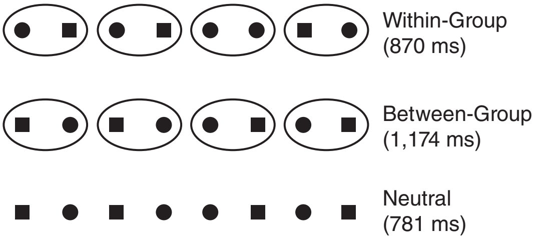


Figure 3B
Gestalt factor of common region.
Two identical elements are detected much faster when bound together within a common region (top) than when contained within different regions (middle). The unbound elements serve as a control (bottom). (From Palmer, 2003. Reprinted with permission.)

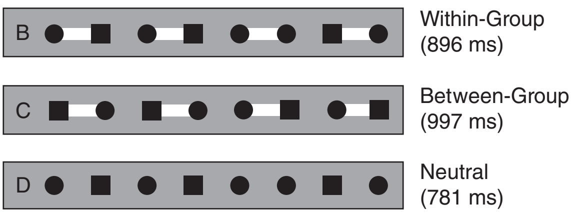


Figure 3C
Gestalt factor of element connectedness.
Two identical elements are detected more easily when tied together (top) than when separated by a gap (middle). However, the difference is not nearly as large as for the Gestalt factors of proximity and common region (figures 3A and 3B). (From Palmer, 2003. Reprinted with permission.)

common region. Analogous results were obtained for *element* connectedness (see figures 3B–C; Palmer, 2003).

In a recent study of Gestalt psychophysics Gori and Spillmann (2010) presented dot patterns similar to those used by Wertheimer (1923) and varied the relative distance between them. Specifically, they measured the threshold at which neighboring dots appeared to be merely irregularly spaced as compared to perceptually grouped, that is, the Gestalt factor of *proximity*. They found that the two kinds of thresholds differed by a factor of 5. Thus, grouping required much wider gaps than detection (see figure 4). An even larger difference between the two kinds of thresholds obtained for size and brightness, that is, the Gestalt factor of *similarity*. Clearly, in order to achieve grouping, the visual system must organize the stimulus from a mere aggregate of dots to a structured whole or assembly.

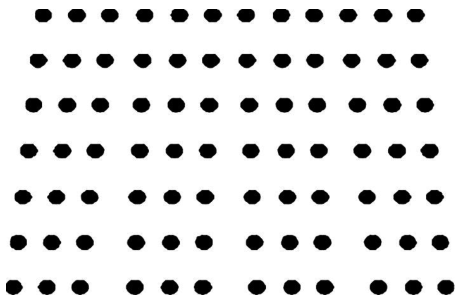


Figure 4
Spacing versus grouping of dots.
Pattern used for measuring the threshold for perceived irregularity versus grouping of dots according to the Gestalt factor of proximity. Irregularity is seen earlier than grouping. (From Gori & Spillmann, 2010. Reprinted with permission from Elsevier.)

This suggests the need for a *psychophysics of Gestalten* as opposed to mere *detection* for future work.

Using a different approach, Kubovy and Wagemans (1995) proposed a quantitative theory that predicts the probability of grouping by the Gestalt factor of proximity for different kinds of multistable dot lattices (periodic dot patterns). Lattices consist of dots separated by variable interdot distances and are organized in a regular grid. The lattices are arranged in five different ways: hexagonal, rectangular, rhombic, oblique, or square shaped. Dot lattices were shown tachistoscopically with four different orientations and observers were asked to report which of these orientations of dot grouping they had perceived. It was found that the strength of perceptual grouping between the dots decayed exponentially with increasing interdot distance. This relationship held independently of the geometry of the lattice. Kubovy, Holcombe, and Wagemans (1998) extended this analysis by showing that the grouping function was scale invariant in space and time. They considered the exponential fall-off as a major descriptor for Gestalt-like grouping interactions.

1.2 Emergence

The next line of research to be reported here takes up, in a way, the important but little-known study by Wohlfahrt (1925/1932) on the emergence of percepts under unfavorable viewing conditions (microgenesis). Such conditions include the presentation of small, low-contrast, and peripheral (blurred) stimuli. The percepts perceived under degraded

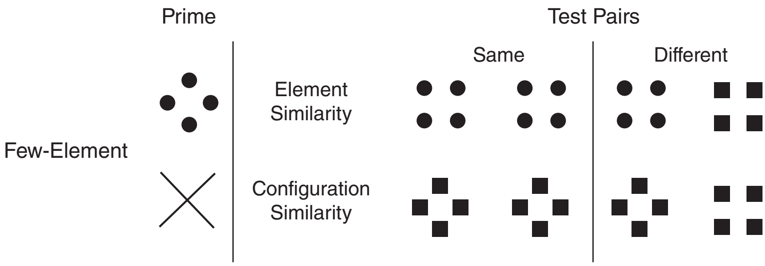


Figure 5A
Elements versus configuration.
Example of a stimulus pattern used to match a test pair to a prime. The prime is shown on the left, same and different test pairs are on the right. The X was used as a neutral prime (baseline). When the prime was configured as a diamond made of four solid circles, observers responded to test pairs consisting of the same circles but arranged in a square (element similarity) faster than to diamonds made of squares (configuration similarity). This difference in response was observed under brief prime durations but decreased with increasing prime duration. In contrast, when the prime was made of 16 relatively small elements, the preference reversed and responses to configuration-similarity test pairs were now faster than to element-similarity test pairs. (From Kimchi, 1998. Reprinted with permission.)

viewing conditions were generally more regular and perceptually better balanced than the stimuli by which they were elicited, suggesting primacy of the whole (*Primat des Ganzen*). They were interpreted as an undifferentiated early stage of figural organization (*Vorgestalten*) under the overarching principle of *Prägnanz* (i.e., structural simplicity or goodness).

In order better to understand the early processes involved in the *emergence* of figure and ground, Kimchi (1998) and colleagues made use of a primed-matching paradigm, whereby a prime is followed by two test patterns that are either the same as each other or different from one another. The task was to respond as quickly as possible to the pair that was similar to the prime. Response time was generally shorter when the patterns in the pairs were similar to the prime than when they were dissimilar. Using this procedure, Kimchi presented a prime—e.g., a pattern composed of black circles arranged as a diamond—for various durations and studied its effect on two types of test pairs: The *element-similarity* test pairs were composed of the same elements as the prime but had a different configuration (e.g., black circles arranged in the shape of a square), whereas the *configuration-similarity* test pairs had the same configuration but were composed of different elements (e.g., black squares arranged in the shape of a diamond; see figure 5A).

The question was this: When confronted with this kind of stimulus pattern, do we first see elements and only then group them into a configuration? Or, vice versa, do we first extract the global structure and then decompose it into elements, as advocated by the Gestalt psychologists? Kimchi (1998) predicted that if the elements emerged prior to configurations, observers should respond to *element-similarity* test pairs faster than to *configuration-similarity* test pairs; the opposite result was predicted for an earlier emergence of configurations. A shorter response time for *element-similarity* test pairs was indeed found when prime duration was short (40 ms), implying that grouping into global configuration takes time. However, this relationship obtained only with stimulus patterns consisting of a few, relatively large elements and actually reversed when stimulus patterns consisting of many small elements were used. Clearly, number and relative size of elements play a critical role in the perceptual organization of such patterns. Thus, the question of whether elements or configuration are afforded primacy by the perceptual system could not be unequivocally answered.

1.3 Time Course

Another experiment by Kimchi (2000) aimed at investigating the *time course* of perceptual organization of line segments into contours and configurations, using the primed matching procedure described above. A diamond composed of four open-ended oblique lines served as a prime to study the effect of *closure*, whereas an Ehrenstein figure composed of four collinear radii with a gap in the center was used to study the effect of *collinearity* (see figure 5B). Gap size was varied in both figures. Two diamonds or two crosses, respectively, were presented to test for configuration similarity, and two Xs or two squares, to test for component similarity. The question was whether priming would facilitate recognition of the configuration versus components.

Kimchi (2000) found that configuration similarity was detected faster than component similarity, regardless of the type of prime, but only when gap size was small. No such difference was found for large gap sizes. When both collinearity and closure were combined in the same stimulus pattern, responses to the configuration-similarity test pairs were shorter than for responses to the component-similarity test pairs, regardless of gap size. These results suggest that open-ended line segments are organized into configurations by either closure or collinearity, provided prime duration is short and gap size small. Both features need to be combined if fast configural organization is to occur with large gap sizes. Again, the

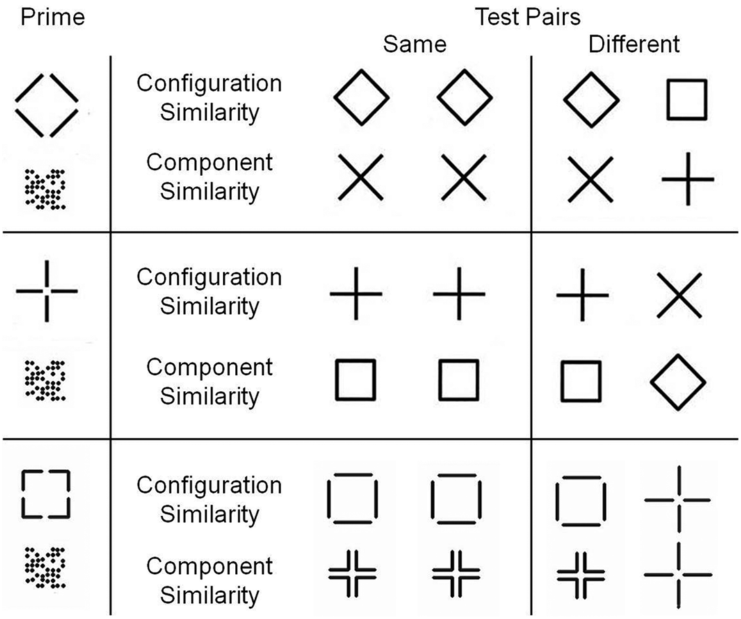


Figure 5B
Configuration versus components.
Example of stimulus patterns used to match a test pair to a prime. The primes are shown on the left, same- and different test pairs on the right. The test pairs are similar to the prime either in configuration or in components. Gap size was varied. The random array of dots was used for a baseline. Top: When the prime was composed of four open-ended oblique lines configured into a diamond by the Gestalt factor of closure, observers responded to a test pair of two outline diamonds faster than to two Xs regardless of prime duration. Middle: When the prime was composed of four lines configured into a cross by the factor of good continuation (i.e., an Ehrenstein figure with a central gap), responses to a test pair of two crosses were faster than to two squares. In both cases, configuration similarity was detected faster than component similarity. These results were obtained when gap size was small, but not when it was large. Bottom: Responses to the configuration-similarity test pairs were faster, regardless of gap size, when collinearity and closure were combined in the same stimulus pattern. (From Kimchi, 2000. Reprinted with permission.)

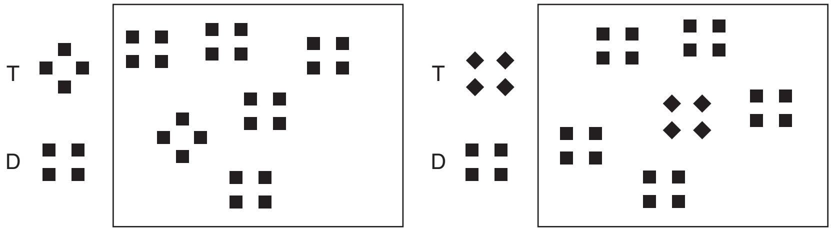


Figure 5C
Rapid visual search.
Example of stimulus displays used for visual search. Left: The target (T) differs from the distractors (D) in regard to the global shape, while the local elements are identical. Right: The target differs from the distractors in regard to the local elements, while the global shape is the same. The number of distractor items was varied. In the above patterns the local target (right) popped out faster than the global target (left), suggesting the need for focused attention in the latter task. Response time for element similarity was short whereas response time for configuration similarity (global target) was long and increased with the number of distractors. However, this relationship was found only for patterns with a few large elements and actually reversed when patterns with many small elements were presented. (From Kimchi, 1998. Reprinted with permission.)

question of whether elements or configuration afforded primacy could not be unequivocally answered although there was an advantage for the latter.

1.4 Visual Search

Kimchi (1998) also found shorter response times for configuration as opposed to elements in a *visual search* paradigm for patterns composed of many relatively small elements. Here, observers were instructed to find a target among a variable number of distractors. The target was presented either at the global level (a diamond composed of four small squares among a number of distractors composed of the same elements, but arranged as squares) or at the local level (a square composed of four small diamonds among a number of similarly arranged distractors composed of four small squares; see figure 5C). The first task tested for similarity of configuration (left), the second for similarity of elements (right). The number of distractor items was varied.

Response time for the local target was found to be short and unaffected by the number of distractors, suggesting fast, *preattentive*, and *parallel* search (i.e., *pop out*). In comparison, response time for the global target was found to be long and increased with the number of distractors, suggesting *serial* search and focal attention. However, this difference between the two search modes was only found with stimulus patterns composed of a few large elements. The relationship reversed when patterns composed of many small elements were used: Here, the global target popped out, whereas the local target required search. These findings reinforce the earlier results, indicating that number and relative size of the elements are important variables in the perceptual organization of these stimuli. Again, the question of elements versus configuration could not be clearly answered.

1.5 Past Experience

One might think that configurations rather than elements that have frequently been seen in the past affect perceptual organization, when similar stimulus patterns come up again. In his 1923 paper, Wertheimer discusses the role of *past experience* for grouping and figure–ground organization when he talks about the tendency for three dots "to result in the familiar, frequently experienced, learned, trained pattern" (p. 160); and he continues: "In principle, which pattern will result depends only on objectively arbitrary habit or drill." Clearly, the "empirical" factor is one of the factors of perceptual organization.

A more recent finding that has been taken as evidence that past experience affects our perception of form is the celebrated Dalmatian dog (photographed by Ron C. James) on a patchy field (Gregory, 1998). At first view, the dog is nearly invisible, because its texture is similar to that of the background. However, once our brain succeeds in organizing the fragments into a coherent percept, we can see and recognize the dog almost instantaneously on repeated exposures. On the other hand, we never see the original "meaningless" picture in the same way.

The conclusion that knowledge of specific object shapes may facilitate perceptual organization of line segments into configurations, is in accord with earlier claims by Peterson (1994; and Peterson & Gibson, 1994) that familiarity with the stimulus can affect figure–ground assignment. The opposite view that bottom-up processes (in the physiological sense) govern our perception and that figure–ground organization precedes object recognition is advocated by Marr (1982). Examples supporting this latter view are given in the following.

1.6 Camouflage

Not everything that we are familiar with will readily reveal itself when we encounter it in unusual surroundings. This is known as camouflage and demonstrates that the same Gestalt principles used to see are also effective in hiding. For example, the hidden figures by Gottschaldt (1926) show that simple geometrical targets that we have seen many times before can be rendered invisible by perceptual integration within a larger context. Inconspicuity is achieved primarily by the use of the Gestalt factor of *good continuation*. In this way junctions, branch points, and endpoints are obscured, so that the targets become embedded within a larger surround. Even if one succeeds in visually isolating a given target through serial search, one cannot hold on to it; it tends to slip away. This agrees with Wertheimer (1923, p. 127) who wrote: "what nature of togetherness and segregation I see is not simply a matter of my whim. I can by no means just get any other pattern of coherency I like at will."

Camouflage in the animal kingdom uses some of the same Gestalt principles as in the Gottschaldt figures. The Gestalt factors of good continuation, similarity, and common fate are prominent among the "tricks" nature uses to conceal animals (Metzger, 1936/2006). For example, bird eggs are harder to detect among pebbles, swaying with the reed hides a heron, and playing dead helps to make an animal invisible to its predators. Similarly, the military uses camouflage by breaking up and distorting the shape of airplanes, ships, and tanks through disruptive coloration and obliterative shading, thereby producing inappropriate segmentations (Behrens, 1981). The battle dress (fatigues) of soldiers serves the same purpose. Camouflage leads to a nonveridical partitioning of a stimulus by changing the inherent structure of the pattern so that it blends with the texture of the background.

However, the effectiveness of those factors is relative; there is no intrinsically inconspicuous color or texture. In an inappropriate context, camouflage can turn into the opposite: Instead of concealing, it now *reveals*. A snow hare is inconspicuous only on a snowy background and when seen from above. From the side it stands out starkly against the sky, a perfect sight for a marauding fox. Also, a zebra behind the trees gives itself away the moment it moves. The fact that prey, predator, and human observers are equally deceived by camouflage testifies to common mechanisms of perceptual organization (Metzger, 1936/2006, chapters 5 and 10). It also lends support to the claim that Gestalt principles are innate laws and that they are universal. Chameleons, flounders, octopuses, and many insects are masters of camouflage by changing their color, patterning, and posture in response to a changing environment, sometimes within seconds (Ramachandran et al., 1996). Apparently nature invented Gestalt laws and we are reinventing them.

Another way devised by nature to obscure a figure is *countershading*. The back of a bird, a mammal, and a fish often is dark, whereas the underbelly is bright. Light coming from above will tend to cancel this coloration as it has the opposite gradient (Thayer's law). Therefore the body will appear uniformly gray, and consequently its volumetric appearance will be lost. These findings suggest that the neuronal mechanisms which enable camouflage are hardwired and part of the genetic inventory.

1.7 Meaning

From camouflage it is a short step to perceptual meaning. Pinna (2010) traces the perceptual meaning of a visual shape back to the same organizational principles that underlie perceptual grouping, thus following the phenomenological and epistemological leads laid out by the early Gestaltists. He thereby enters the realm of dynamic cognitive perception as known from certain cartoons and representations of animated events. This is reminiscent of Wolfgang Köhler's (1933) paradigm "Maluma–Takete," the first suggesting round and soft, the second sharp and hard. Pinna's extension of these early beginnings represents a large step beyond the classical Gestalt principles (Wertheimer, 1923). By showing 24 variations of a square, he demonstrates that as many different perceptual meanings can be derived when one of its corners is transformed in various ways (see figure 6).

Studies using functional magnetic resonance imaging (fMRI) may some day be able to show differences that are correlated to the felt appeal (*Anmutungsqualität*) of such percepts. In this way they may tell us where visual perception meets language.

2 Grouping and Completion

2.1 Collinearity: Illusory Contours

Modern neurophysiology has elucidated some of the neuronal mechanisms that mediate perceptual attributes, starting from the *center-surround organization* of retinal receptive fields to the hierarchical arrangement of *specialized neurons*. These are subpopulations of cells responsive to one or more stimulus parameters such as luminance, wavelength, orientation, lateral disparity, and motion. However, to be able to account for structured percepts, more complex neuronal mechanisms are needed.

Baumgartner, von der Heydt, and Peterhans (1984), in the macaque (see also Redies, Crook, & Creutzfeldt, 1986, in the cat), took a first step

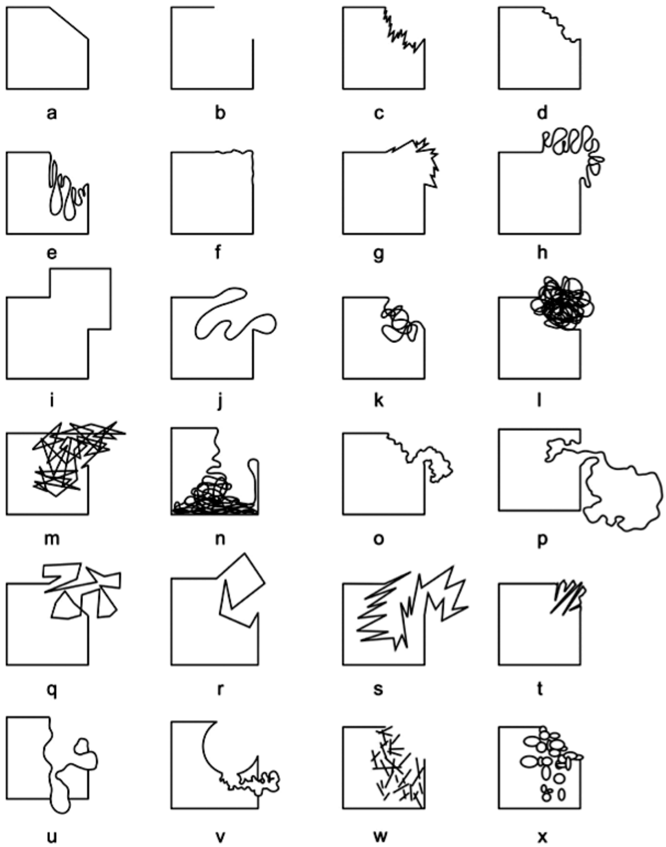


Figure 6
Illusion of meaning–something different happens to each square.
a–x: A local change at the corner affects the global appearance of the overall pattern. For example, from a beveled square (a), the figure changes to a square with its top right corner cut off (b), to a glass square broken at the corner (c), a gnawed or nibbled square (d), a square made up of dripping plastic (e), a square deformed by a scorch (f), etc. None of these meanings can be fully accounted for by the shape of the deformation, although the visual percept intuitively suggests the meaning. (From Pinna, 2010. Reprinted with permission.)

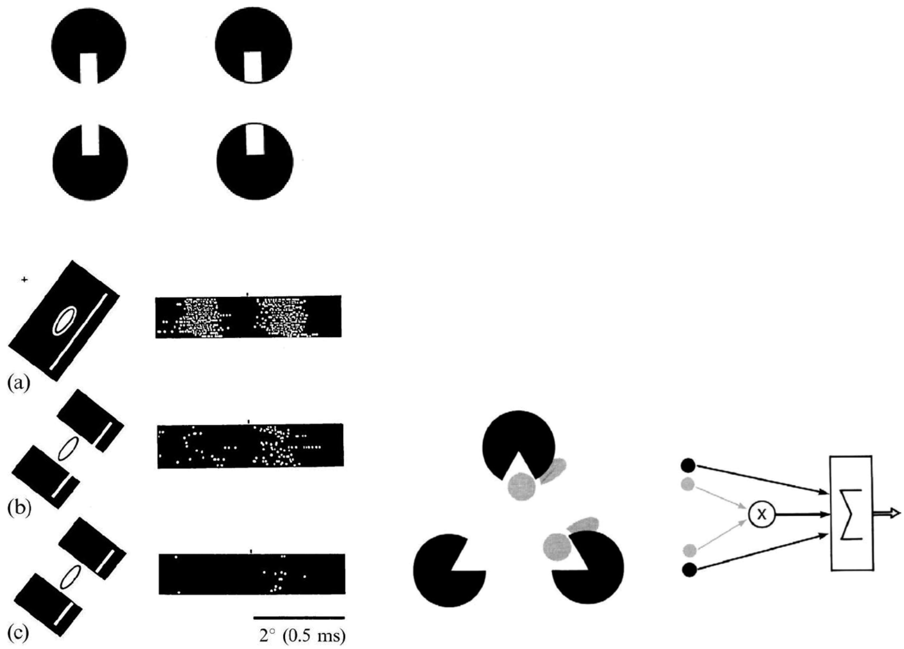


Figure 7
Illusory contours in the Schumann and Kanizsa figures.
Top, left: Schumann figure. An illusory bar is seen on the left, but not on the right. Bottom, left: Response of a V2 neuron in the monkey to (a) a complete bar, (b) a bar with a gap in the middle, and (c) a bar with top and bottom segments closed. The oval illustrates the receptive field of the neuron. While the response to the continuous bar is strong, the response to the incomplete bar is reduced, although clearly present. There is no response when the two segments are sealed with a thin line. The fact that the neuron in (b) responds although there is no luminance change in the center when the incomplete stimulus is swept across the receptive field suggests input from beyond the classical receptive field. This response has been interpreted as the neurophysiological correlate of illusory contours as seen in the Schumann figure above and the Kanizsa triangle to the right. Shaded areas in the Kanizsa triangle represent receptive fields of end-stopped cells (gray oval: orientation-selective excitatory region; gray disc: inhibitory end zone). The hypothetical mechanism for contour generation (on the far right) combines edge signals with occlusion signals. The occlusion signals are multiplied (×) and at a higher level added to the edge signals (∑). (Modified from von der Heydt & Peterhans, 1989. Reprinted with permission.)

in this direction when they studied incomplete patterns, such as the Schumann figure (see figure 7, top left). Here, one observes a slightly brighter, delineated strip bridging the gap between the upper and lower section although physically it is not supported. The authors found that neurons in area V2 responded to this incomplete stimulus although the two segments on the top and bottom lay outside their receptive fields (figure 7, bottom left). Clearly, the information must have come from *beyond the classical receptive field*. When the two segments were closed by a thin contour, the response fell to zero; so did the Schumann illusion. This response therefore was taken as the neural correlate of perceptual completion and was an immediate breakthrough in the search for *perceptive* neurons (Baumgartner, 1990).

Another illusion illustrating this kind of completion is the well-known Kanizsa triangle (1955, 1979), as shown in figure 7 (right). It is composed of three black disks with cut-out sectors ("pacmen") aligned to form the corners of a fictional triangle. Analogous to the Schumann figure (1904), observers spontaneously report seeing a brighter triangle delineated by illusory contours. Peterhans and von der Heydt (1989, 1991) suggested that the corners of the pacmen constitute occlusion features that are detected by *end-stopped* cells (orientation-selective cells that respond to terminations of edges or lines in the receptive field; Hubel & Wiesel, 1965). Higher-level neurons would then integrate the end-stopped cell responses to fill in the gaps with illusory contours (see figure 7, far right).

Disrupted contours are often seen in natural images on structured backgrounds, when contour contrast reverses or vanishes, a well-known problem in computer vision. End-stopped cells respond to such line terminations. Thus, the use of end-stopped cells as sketched in figure 7 (right) may illustrate a general principle for the detection of occluded contours (von der Heydt & Peterhans, 1989; Heitger et al., 1992, 1998).

Recent reports that certain fish and insects behave as though they can "see" illusory contours in Kanizsa-type figures (Horridge, Zhang, & O'Carroll, 1992; Nieder, 2002; Wyzisk & Neumeyer, 2007) are consistent with a bottom-up (in the physiological sense) explanation. At the same time they cast doubt on a cognitive theory of these phenomena as advanced by Gregory (1972), who proposed that visual perception uses hypotheses to "make sense" of unlikely stimulus patterns. On the other hand, there are examples where a neurophysiological mechanism is not yet readily available, such as an explanation of the brightness enhancement in the Kanizsa triangle.

An explanation may come from computational vision. Kogo et al. (2010) have recently proposed a model to account for illusory contours based on surface filling-in, rather than contour filling-in, in conjunction with depth segregation from local occlusion cues.

2.2 Collinearity: Blind-Spot Filling-In

Neurons bridging a gap are plausible candidates not only for explaining the emergence of illusory contours, but they likely also mediate the perceptual completion across a scotoma such as the physiological blind spot. This is an area on the retina, 6 × 8 deg of visual angle in size, from where the optic nerve exits from the eye. No signals reach the brain from this area since there are no photoreceptors in it, and yet one does not see a hole in the visual field. Similarly, a line traversing the blind spot would be expected to have a gap in it similar to the gap in the Schumann figure. However, we are not aware of any such break.

Why do we fail to see what is missing? A plausible explanation is that the retinal image is filled in from the surround. For example, the neuronal response to a (discontinuous) bar presented at opposing edges of the physiological blind spot is similar to the response to a continuous bar presented outside the blind spot area (Fiorani et al., 1992; for review, see Komatsu, 2011). The same presumably holds for lesion scotomata, which are typically not noticed. Diabetic patients whose eyes were laser-coagulated many times report when looking at a white wall that they do not see any dark spots despite numerous scars on their retinae. The boundary conditions and hypothetical neuronal mechanisms responsible for blind spot completion have been studied extensively (for review, see Durgin, Tripathy, & Levi, 1995; Spillmann et al., 2006).

Yet, not all stimuli can be filled in. Line segments that differ substantially in orientation are *not relatable* and cannot be restored (Kellman & Shipley, 1991; Shipley & Kellman, 1992). This is consistent with the assumption that they are not parts of the same object.

2.3 Collinearity: Lines and Flankers

Why would a mechanism piecing together disrupted contours have evolved in nature? The answer is that many objects in our visual world are partially occluded and therefore given only incompletely in the retinal image. The visual system needs to group and connect these contours (as in the Kanizsa triangle) to restore the object. Collinearity is a prerequisite for this achievement.

Psychophysical studies have demonstrated that a subliminal target line is detected more easily when placed directly on the seen location of an

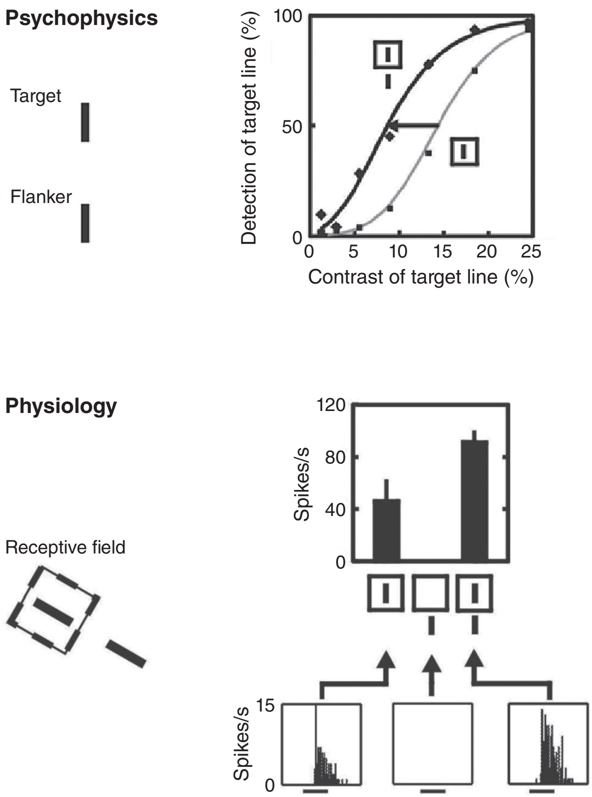


Figure 8
Lateral facilitation by a collinear line.
Top: Psychophysics. Left: Vertical line stimulus (target) used for measuring the detection threshold with and without a collinear line (flanker below). Right: Detection threshold plotted as a function of contrast of the target line with the flanker present (thick curve) or absent (thin curve) as indicated by the boxes next to the curves. The flanker clearly facilitates detection (curve shift to the left). Bottom: Neurophysiology. Left: The target line is pictured inside the receptive field, with the flanker outside. Right: The neuronal response of a V1-neuron to the target alone (left column), flanker alone (middle), target and flanker together (right column). The combined response to both lines is greatly enhanced relative to the response to the target alone and is consistent with the facilitation of the psychophysical threshold obtained under comparable conditions as shown above. (Modified from Kapadia et al., 1995. Reprinted with permission from Elsevier.)

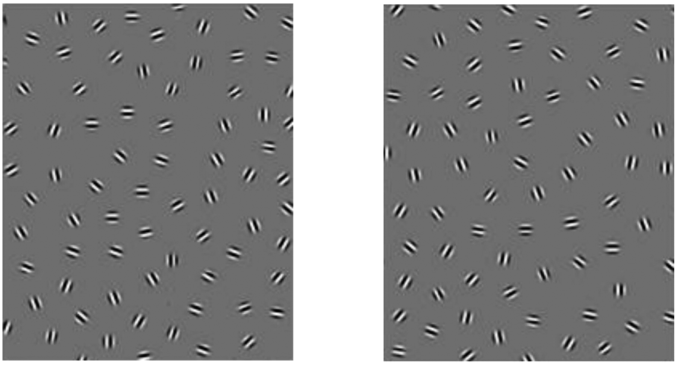
illusory contour or when one or two collinear flankers are presented a short distance away (e.g., Dresp & Bonnet, 1991; 1995). Figure 8, top, from Kapadia et al. (1995) illustrates the effect. This kind of subthreshold summation depends critically on gap size as well as orientation, stimulus alignment, and contrast polarity (Dresp & Langley, 2005). A slight offset between the target line and the flanker weakens and ultimately abolishes the effect (see also §2.1). These findings have been interpreted as a neural correlate of the Gestalt factor of *good continuation* (Polat & Sagi, 1994).

There are parallels in neurophysiology. Neurons responding to collinear contour stimuli have been found in area V1 of the monkey (Kapadia et al., 1995). Such neurons respond more strongly when a collinear flanker is presented in the larger surround than without it (figure 8, bottom). These neurons are preferably linked together by long-range horizontal axons connecting cells of similar orientation specificity (Gilbert & Wiesel, 1989; Schmidt et al., 1997; Stettler et al., 2002). In this way they enable an integration of collinear stimuli over much larger parts of the visual field than covered by their individual receptive fields (Lund, Yoshioka, & Levitt, 1993). The circuitry for contour integration required for the Gestalt grouping criterion of *collinearity* (Kapadia, Westheimer, & Gilbert, 2000) is thus already present at the level of V1 (Löwel & Singer, 1992; Schmidt et al., 1997).

There is more evidence suggestive of low-level integration. It has been estimated that three fourths of the excitatory inputs to a given receptive field come from outside its hypercolumn (Stepanyants et al., 2009). Therefore, by accessing information from the larger surround, a cell can transform a local stimulus to a global stimulus and a local receptive field to a global perceptive field (Spillmann, 1999; Spillmann & Werner, 1996). Observations by Pan et al. (2012) on real and illusory contour processing using optical imaging and single cell recording in macaque area V4 are consistent with this interpretation. Westheimer (1999, p. 12), writing on Max Wertheimer's anticipation of recent developments in visual neuroscience, remarked that these findings support the idea of "context-driven brain states [inviting] the consideration of global structure that . . . conditions the properties of its parts rather than the reverse" (i.e., *Ganzbestimmtheit der Teile*).

2.4 Collinearity: Gabor Patterns

In addition to collinear lines, some researchers have used Gabor patches to study grouping and figural organization by orientation (Field, Hayes,



a b

Figure 9
Emergence of a figure from elements.
(a) A few aligned patches embedded within a field of randomly oriented Gabor patches elicit the percept of a curved contour. (b) The circular contour is more readily seen when the curve formed by the aligned Gabor elements is closed. (From Kovács & Julesz, 1993. Copyright 1993 National Academy of Sciences, U.S.A. Reprinted with permission.)

& Hess, 1993; Kovács & Julesz, 1993). These patches mimic the excitation–inhibition profile of cortical receptive fields. As a test stimulus, a string of aligned Gabor patches of similar orientation (serving as figure) was presented amid a large number of randomly oriented Gabors (serving as ground). After some search, observers reported seeing, for example, a snake or part of a ring (see figure 9a). When the ring was complete, it could be seen more easily than the open-ended contour, presumably because a closed—and symmetrical—figure represents a better Gestalt (figure 9b). So impressed were Field and Hayes (2004) by the pop-out effect in strings of aligned Gabor elements, that they compared it to the view of the Great Wall of China from outer space.

These observations are remarkable, as the gaps between collinear Gabor patches can be greater than the axial length of the individual stimulus elements (Li & Gilbert, 2002), suggesting that information from outside the classical receptive field is integrated within an *association field* (Field, Hayes, & Hess, 1993). The perceived contour integration is consistent with the Gestalt factors of *good continuation* and *closure* (Hess & Field, 1999).

Meanwhile, psychophysical and simulation studies have defined the boundary conditions for this kind of grouping (e.g., Pettet, McKee, & Grzywacz, 1998; Field, Hayes, & Hess, 2000; Claessens & Wagemans, 2005; Kirchner & Thorpe, 2006). Results show that grouping strength depends on the distance and (interpolated) curvature between pairs of Gabor elements and that a sudden change in orientation or removal of a single Gabor patch in a closed-path contour severely reduces detectability (Kovács & Julesz, 1993).

Subsequent work has examined the interactions between contour grouping and surface segregation, using Gabor lattices in which contours were defined by good continuation (curvilinearly arranged elements) and surfaces by homogeneity (isolinear surface elements) of local orientations (Machilsen & Wagemans, 2011). Target shapes were detected significantly better when both cues, contours and surface, were combined. The improvement was higher than predicted by probability summation, suggesting a facilitatory interaction between the two kinds of processes involved.

"Gaborized" outline patterns embedded within Gabor elements of different orientations are accessible not just to human observers (Sassi et al., 2010); rhesus monkeys trained to detect Gabor figures performed just as well (Mandon & Kreiter, 2005). Their thresholds for spatial distance and alignment between elements were similar to those of human observers, enabling them to detect and identify an embedded Gabor figure when stimulus duration was as short as 30–60 ms. Horizontal interactions in area V1 may underlie this kind of contour integration (Bauer & Heinze, 2002), although feedback from extrastriate areas (Zipser, Lamme, & Schiller, 1996; Angelucci et al., 2002) may also qualify for an explanation since the response latencies and conduction velocities are about the same (Lamme & Roelfsema, 2000; Girard, Hupé, & Bullier, 2001).

2.5 Collinearity: Bregman's Partially Occluded Figures

A most interesting pattern illustrating the power of grouping and completion is from Bregman (1981; see figure 10). In this pattern, the individual fragments shown on the left are self-contained, and thus there is no need for perceptual completion across the gaps. However, with the black occluder overlaid (middle), the pieces immediately connect up, and five Bs pop out from behind. The reason for this reorganization is a switch of border ownership (see §2.6) for lines that are perceived as closing contours for the individual pieces.

With the black occluder in front, these same lines now belong to the occluder rather than the individual pieces. Thereby, the individual fragments can link up perceptually behind the superimposed figure and become integrated into Bs. This is called *amodal completion*. When the contour segments under consideration are removed (right), the five Bs are

Figure 10
Completion from occlusion.
Left: A jumble of unconnected pieces. Middle: Five Bs pop out from behind an amorphous occlusion figure. The pieces are the same as on the left. Right: Five Bs readily emerge from the jumble when the "inappropriate" closing lines on the left are deleted. (Figure on the right courtesy of JingTing Huang.) (From Bregman, 1981. Reprinted with permission.)

easily recognized even without the occluder, although they are now supported by short collinear dashes only with large gaps in between. Here, the Gestalt factor of *good continuation* enables figure–ground segregation of fragmented contours analogous to the strings of Gabor patches discussed above (§2.4).

2.6 Border Ownership

Up to here, I have mostly discussed dot figures, line figures, or outline figures. The figures described in this section emerge because of a difference in *surface* properties such as brightness, color, texture, depth, or motion (Nothdurft, 1992, 1993). Such differences between adjacent regions constitute a perceptual step akin to an edge or boundary. Is there a neuronal mechanism that segregates such figures from the ground?

Candidate neurons that may underlie figure–ground segregation and surface formation have been found in area V2, less frequently in V1, of the monkey (Baumann, van der Zwan, & Peterhans, 1997; Heider, Meskenaite, & Peterhans, 2000; Zhou, Friedman, & von der Heydt, 2000). Such neurons respond strongly when the stimulus traverses a receptive field in one direction, but less in the other. Figure 11 shows the response of a V2 neuron to an edge. The response is strong on the leading edge, but weak on the trailing edge. One quarter of the neurons in V2 exhibit this asymmetry, recalling Rubin's (1921) *law of the inside* that the border is owned by the figure, not the ground (Nakayama, Shimojo, & Ramachandran, 1990). The coding for edge assignment and border-

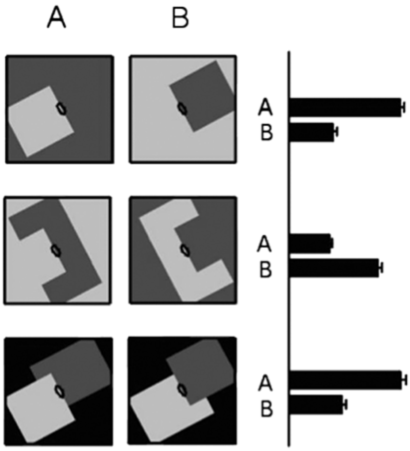


Figure 11
Border ownership in a neuron of the macaque
Left: In all six panels, a purple-to-gray (light-to-dark) edge stimulates the receptive field (small ellipse) of a V2-neuron. Top: In A, the edge is owned by the purple square on the lower left; in B, it is owned by the gray square on the upper right. Middle: Here, the direction of border ownership is reversed. In A, the gray bracket owns the edge, in B the purple bracket. Bottom: Stimulation by the border between two overlapping figures. In A, the border is owned by the purple square, in B by the gray square. Right: The black columns labeled A and B show the neuronal responses for each of the stimuli on the left. The response is consistently stronger when the edge is owned by the figure. This asymmetry is taken as evidence for a neuronal correlate of border ownership. (Modified from Zhou, Friedman, & von der Heydt, 2000. Reprinted with permission.)

ownership (Zhou et al., 2000) suggests that figure–ground organization originates early in the visual system.

A mechanism emphasizing a unilateral border is optimally suited to define objects in our environment. Most borders of natural objects are one-sided; shared borders are rare (e.g., cells in a honeycomb). As a result, while we superbly perceive figures, we often are "blind" for the ground (Metzger, 1936/2006). This observation finds its neural correlate in the above asymmetry and is reflected in the proposal that figure–ground perception is based on a winner-take-all competition (Peterson & Gibson 1994). The winning shape (figure) is enhanced, whereas the losing shape (ground) is suppressed.

Are there any other features associated with a unilateral border? The same neurons that in the monkey respond differentially to figure and ground are also selective for a difference in depth (Bakin, Nakayama, &

Gilbert, 2000; Qiu & von der Heydt, 2005). Thereby, they can assign contours to the foreground and signal partial occlusion. Furthermore, these neurons are also modulated by *attention*, possibly by feedback from higher cortical areas, and show evidence of persistence, suggesting *object continuity* or *permanence* (Qiu, Sugihara, & von der Heydt, 2007; O'Herron & von der Heydt, 2011). These findings have played an important role in the neural underpinning of the computational model for the perception of Kanizsa-type figures described above (§2.1; Kogo et al., 2010).

Evidence that area V2 is critical for border ownership selectivity has also been found in human observers, using fMRI (Fang, Boyaci, & Kersten, 2009). Furthermore, different brain sites for processing figure and ground are suggested by studies using EEG recordings. When figure and ground were modulated at slightly different flicker rates, separate neuronal networks engaged in the processing of each of the two regions (Appelbaum et al., 2006). While the figure region was routed preferentially to the lateral occipital cortex, the background region was routed to more dorsal areas. Using a similar procedure, steady-state visual-evoked potentials also were stronger and peaked earlier for the figural region than the ground region (Brooks & Palmer, 2011).

When the stimulus pattern does not give rise to a stable figure–ground organization, the resulting percept is ambiguous. An example is Rubin's (1915/1921) well-known vase–faces illusion. A vase or goblet is seen because the white surround has no shape of its own and thus becomes part of the background. However, when a square-shaped frame surrounds the pattern, the white region attains figure status, and two profiles facing each other are now seen, alternating with the vase. With each reversal, border ownership changes from one to the other. This bistability is a puzzling phenomenon as the two percepts emerge spontaneously in response to the same stimulus pattern. Gregory (1998) therefore interpreted "flipping" as a reflection of the dynamics of the brain when it cannot decide which of the two patterns to choose. Different subpopulations of neurons are likely responsible for this effect.

Another task for future research, seemingly forgotten by the Gestaltists, is the "shaped aperture" or hole (Peterson, 2003; Bertamini & Hulleman, 2006; Tanca & Pinna, 2008). Holes are ubiquitous in our world; they have a shape (e.g., a keyhole), but the boundary of the hole belongs to the surface from which the hole has been cut, and that surface appears in the foreground. A hole therefore is not a figure in Rubin's (1915/1921) sense since the foreground figure typically owns the border.

3 Filling-in of Surfaces

3.1 Stratification and Transparency

With border ownership assigned to neurons in area V2, the question arises, where in the brain are surfaces added to contours? In other words, where does the primal sketch in the sense of Marr (1982) become a 2½-D sketch? In a series of papers on the role of perceived stratification for surface perception, Nakayama et al. (1989, 1990, 2009) hypothesized that visual surfaces are represented at an intermediate level, different from low-level vision and independent from top-down cognitive inferences. The key observation was that the neon color disk in the Ehrenstein figure (Redies & Spillmann, 1981), when presented with crossed disparity, was seen to hover over the figure, but, when presented with uncrossed disparity, appeared as part of the background behind it. In the first case the disk was transparent, in the second opaque; thus, a small change in depth caused a large change in appearance.

Similar observations were made using a barber pole placed behind a grid of horizontal bars. Here, the barber pole could only be amodally completed if the slabs in the interspaces were perceived as lying behind the grid bars. When seen in front, they could not be integrated into a whole. This suggests that the farther surface is essentially "unbound," free to link up with other unbounded areas nearby. To perceive a surface in a display therefore requires that its depth order be determined relative to others by taking into account border ownership (Nakayama, Shimojo, & Silverman, 1989; Nakayama, Shimojo & Ramachandran, 1990).

The authors' call for an orderly layout of surfaces, color, and depth to represent the visual world was an important concept that proved enormously fruitful (Nakayama & Shimojo, 2009). It is reminiscent of the Gestalt credo that the simplest, most regular and balanced order prevails (Metzger's, 1936/2006, "love for order"). The conclusion that surface processing must occur early in the visual cortex is consistent with single-cell responses in areas V2 and V3, as described in §3.4. It is unclear, however, whether the responses in those areas are primarily stimulus-driven or whether they arise by feedback from higher visual areas (Hupé et al., 1998; Angelucci et al., 2002).

3.2 Filling-in of Brightness

The question arises how surfaces resulting from such processing are maintained in our perception. It is known that neurons stimulated uniformly in space and time respond poorly and adapt quickly (for a review, see Spillmann, 2011). Therefore, the interior of a figure would be expected rapidly to fade from view (i.e., Troxler's effect). However, as can readily be confirmed, this does not happen. Why then is it that we continue to perceive such figures largely unchanged over time? The answer is because of involuntary eye movements and filling-in.

Our eyes execute small involuntary eye movements all the time (Martinez-Conde, Macknik, & Hubel, 2004), even if we try to keep them perfectly still. On a large uniform surface, these eye movements have no effect, as they do not generate any onsets to counteract local adaptation. It is at the edge that they constantly refresh the signals traveling to the brain and thereby keep our perception of the border "alive."

Recent psychophysical and neurophysiological research suggests that it is not just the border that benefits from the spatiotemporal modulation; the enclosed surface area may benefit as well. There is evidence that neurons stimulated by the edge actively propagate their information to neurons representing the interior of the stimulus via long-range interaction. In this way filling-in from the border may sustain the brightness of the enclosed surface area over time (Paradiso & Nakayama, 1991; Huang & Paradiso, 2008; for a review, see Spillmann, 2011).

3.3 Filling-in of Color

A striking example, showing that filling-in not only occurs in the domain of brightness but also in the domain of color is the watercolor effect (Pinna, Brelstaff, & Spillmann, 2001; Werner, Pinna, & Spillmann, 2007). Here, two differently colored contours (e.g., a dark purple and a light orange line) flanking each other will induce a tinge of orange that spreads uniformly across the enclosed surface area. Note that this kind of spreading occurs orthogonal to the inducing contours, not collinear as in the Kanizsa triangle. Achromatic contours with an appropriate luminance profile (see figure 12) also elicit the watercolor effect (Pinna, Brelstaff, & Spillmann, 2001; Noguchi, Kitaoka, & Takashima, 2008), suggesting a luminance-dependent mechanism (DeVinck et al., 2005).

The watercolor effect not only imparts color onto the enclosed surface area, but also strongly promotes figure–ground segregation and, in doing so, overrules several of the classical Gestalt factors, such as the factors of proximity, good continuation, and parallelism (Pinna, Werner, & Spillmann, 2003). For instance, in the watercolor version of the Maltese cross, the *wide* sectors are seen as figure, outweighing the factor of proximity. Real color does not have the same strong effect (von der Heydt & Pierson, 2006).

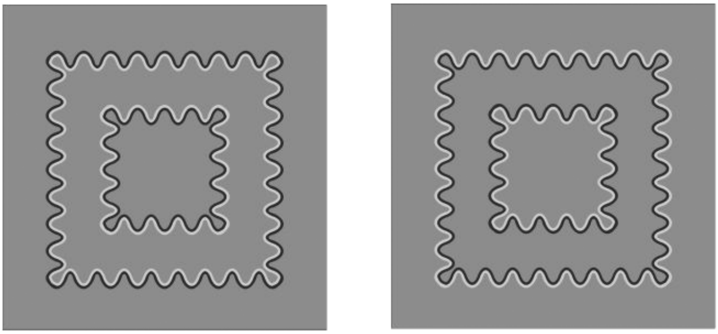


Figure 12
Achromatic version of Pinna's watercolor effect.
⟨http://www.scholarpedia.org/article/Watercolor_illusion⟩
Brightness spreading (left) and darkness spreading (right) elicited by sparse stimulation. Note the reversal of the contour profile. (From Noguchi, Kitaoka, & Takashima, 2008. Reprinted with permission.)

Assimilative color spreading from the contour to the interior may be accounted for in two steps: first, by weakening of the low-contrast contour through lateral inhibition from the high-contrast contour, that is, local diffusion, and second, by an unbarriered flow of color onto the enclosed surface area, that is, global diffusion. This requires a neural mechanism sensitive to an asymmetrical edge profile (von der Heydt & Pierson, 2006). The large-scale spreading from sparse stimulation is compatible with the neon color effect (Bressan et al., 1997). Both effects have been discussed in terms of the Form-And-Color-And-Depth (FACADE) model proposed by Grossberg and Mingolla (1985): a boundary contour system (BCS) generating boundaries and a feature contour system (FCS) filling-in the boundaries with surface features (i.e., color). (For detail, see Pinna & Grossberg, 2005.)

3.4 Filling-in of Texture

Apart from brightness and color, surfaces are characterized by textures. Early examples of so-called textons were blobs, terminators, and crossings (Julesz, 1981). However, no neurons have been found selectively to respond to such texture elements. Furthermore, Nothdurft (1991) demonstrated that figure–ground segregation does not rely on the salience of features as such but rather depends on the texture contrast at the edge. This explains why no demarcation is perceived in a textural gradient.

A simple but effective texture is hatching by orientation. Studies have shown that the response of a V1-neuron to an optimally oriented bar is reduced when bars of the same orientation are presented in the receptive field surround but is enhanced when the surround bars are oriented at right angles (Allman, Miezin, & McGuinness, 1985; Knierim & van Essen, 1992; Kastner, Nothdurft, & Pigarev, 1999). This is called *orientation contrast* or cross-orientation facilitation (Sillito et al., 1995) and marked the advent of *contextual neurons* in visual neurophysiology (for review see Albright & Stoner, 2002).

In a remarkable experiment, Lamme (1995) found that contextual neurons in area V1 of the monkey respond to texture contrast in a way consistent with figure–ground segregation. In this study, an obliquely hatched square on a background of opposite orientation elicited a stronger response than the same square embedded in a background of identically oriented hatching (see figure 13). This is surprising, as the receptive field of the neuron was located fully inside the square and therefore had no direct information from the edges. Long-range lateral interaction must be invoked to explain this finding.

A follow-up study by Lamme, Rodriguez-Rodriguez, and Spekreijse (1999) in area V1 of the monkey focused on the temporal dynamics of edge–surface interaction (see also Lamme & Roelfsema, 2000). Figure 14 (left) demonstrates that the neuronal signal elicited by a texture boundary first emerges 70–80 ms after onset of the stimulus, then increases up to 90–100 ms, and reaches a peak between 115 and 125 ms. At that time the representation of the surface in the neuronal response is still evolving. Thus, there is a clear latency difference between boundary and surface signals, with the delay for the surface signal becoming longer with increasing distance from the edge (see figure 14, right). These results provide strong evidence that neuronal processing of orientation contrast (and thus figure–ground assignment) proceeds from the texture boundary to the interior, consistent with the idea of surface filling-in (see §3.2). Feedback from higher-level areas to V2 and V1 may explain the large spatial range of context integration (Lamme, 1995; Angelucci et al., 2002; Huang & Paradiso, 2008).

De Weerd et al. (1995) using an artificial scotoma such as a 4 deg white square on a jittering background of vertical slashes (see figure 15, left) also found sequential filling-in from the boundary, but in area V3 of the alert monkey. Here, the square disappears from view after a few seconds of fixation and becomes uniformly filled in with the texture. The neuronal

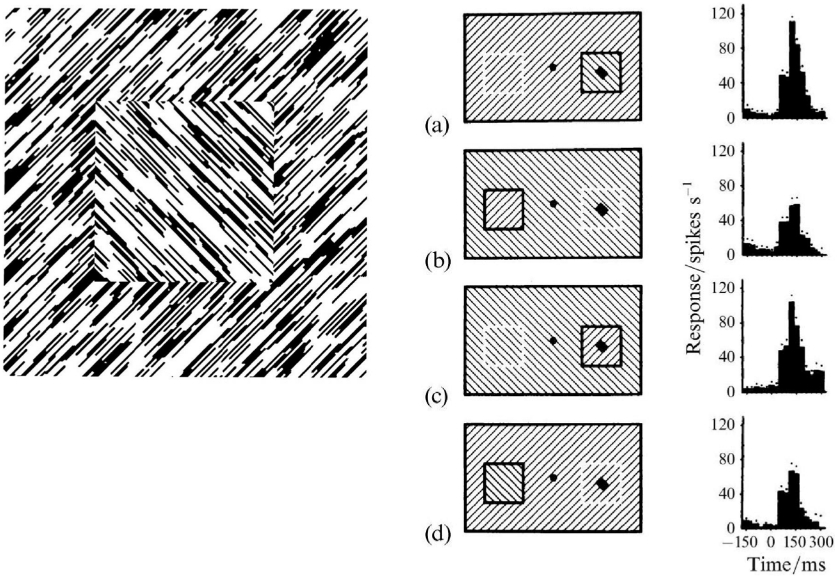


Figure 13
Texture contrast by orientation.
Left: Example of stimulus pattern in which figure and ground have oppositely oriented hatchings. Middle: Different kinds of experimental stimulus patterns used (schematic). The small solid rectangle in each stimulus pattern represents the receptive field of a V1 neuron in the monkey, from which recordings were made. In panels a and c, the area surrounded by a square-shaped frame is oriented orthogonally to the background. This is analogous to the texture contrast of the stimulus pattern on the left. In panels b and d, the orientation of the hatching inside and outside is the same and there is no figure–ground segregation contrast. The black and white frames only serve to delineate the figure but were not shown in the experiment. Right: The histograms on the far right refer to the four texture stimuli used. Note that the receptive field received no information from the surround. Yet, the neuronal response is stronger in conditions a and c than for the corresponding pair members b and d, although the hatching in each case was identical. This suggests a neuronal correlate of figure–ground segregation by texture contrast. (Redrawn from Lamme, 1995. Reprinted with permission.)

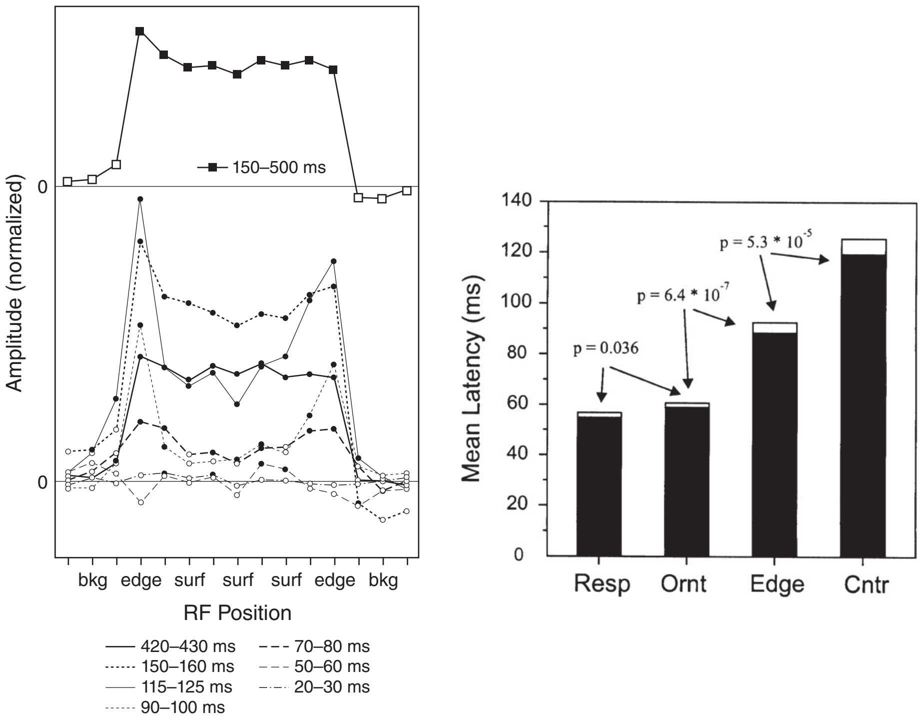


Figure 14
Texture filling-in of a surface.
Left: Response of a V1 neuron in the monkey (on the ordinate) to the square-shaped textural stimulus depicted in figure 13 (left). The abscissa gives several receptive field positions relative to the target: background, edge of target, surface of target, edge of target, and background. Different response curves refer to different time bins after onset of the stimulus (in milliseconds). Curves change progressively from flat to U-shaped. Evidently, edge enhancement is present long before surface representation. Right: Mean latency for the response to the stimulus (Resp), orientation tuning (Ornt), edge enhancement (Edge), and center of the surface (Cntr), reflecting the time sequence of the neuronal response to the corresponding positions shown on the left. (From Lamme, Rodriguez-Rodriguez, & Spekreijse, 1999. Reprinted with permission from Oxford University Press.)

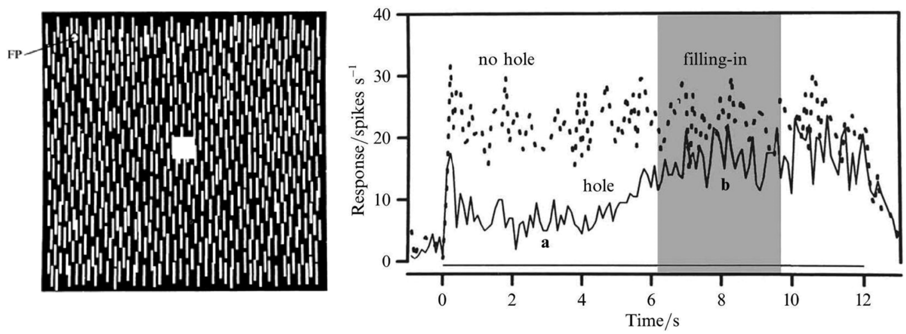


Figure 15
Filling-in of texture.
Left: A pattern with a white square in the middle surrounded by a jittering background of vertical slashes was used for a stimulus. The receptive field of the neuron (not shown) was located entirely inside the white square and thus had no direct information from the background. A trained alert monkey fixated on the dot in the upper left corner (FP). Right: the response of a V3-neuron (ordinate) is plotted as a function of time (abscissa) after the beginning of fixation. The continuous curve labeled "hole" refers to the condition when the artificial scotoma (white square) was present in the stimulus whereas the dotted curve labeled "no hole" refers to the background without the white square (control). Note that the experimental curve first drops, then slowly recovers until it approaches the control curve at which point the neuron can no longer differentiate between the two stimulus conditions. The shaded area represents the average time required for perceptual filling-in of the same stimulus pattern when viewed by human observers. It coincides with the time when the lower curve approaches the upper one, suggesting that the time course for perceptual filling-in and neural filling-in is the same. (From De Weerd et al., 1995. Reprinted with permission from Macmillan Publishers Ltd: *Nature*, 1995.)

response parallels the phenomenal observation. A neuron whose receptive field is entirely enclosed within the square ("hole"), will quickly adapt, but recover its initial firing rate within some 5–10 seconds, although it has no direct access to the textural information in the surround (see figure 15, right). This is analogous to the finding by Lamme (1995) just described. The neuron first responds with a burst, followed by a brief period of low-level activity and a gradual increase of the firing rate. This increase ("climbing activity") continues until the response to the test stimulus (hole) approaches the response to a control stimulus (no hole). At this point, a neuron can no longer differentiate between the two kinds of stimuli. The authors took this as evidence for long-range interaction and filling-in.

No behavioral data are available from the monkey in this study. However, when human observers were asked to report when the artificial scotoma had disappeared from view, the time for perceptual filling-in matched that for neuronal filling-in (shaded area). This suggests that the time course of response recovery in the monkey represents the *neural correlate* of perceptual filling-in. De Weerd et al. (1995) therefore propose two stages for fading and filling-in: (1) Slow local adaptation corresponding to the fading of the contour, followed by (2) fast filling-in of information from the surround. In everyday vision, involuntary eye movements and filling-in by long-range interactions from the border ensure that a surface is sustained over time and does not disappear under normal viewing conditions (Spillmann & De Weerd, 2003).

3.5 Stereo-Depth Planes

The last example in this section deals with stereo vision. The traditional view of why we see stereo-depth is that it depends on binocular fusion of slightly displaced retinal images of the same object, that is, by lateral disparity. Such stimuli invariably have contours and bounded surfaces. However, in random-dot stereograms, Julesz (1971) demonstrated that a 3D figure can arise in binocular vision although no edge is contained in the monocular stimulus. This demonstration requires a point-to-point correlation between the two monocular stimuli in the brain and is not easily reconciled with the Gestalt view.

Neurons responding to fused Julesz-type stereograms have been found in areas V1 and V2 of the behaving monkey (Poggio et al., 1985), with neurons detecting stereoscopic edges in area V2 (von der Heydt, Zhou, & Friedman, 2000). Such neurons signal the location, orientation, and depth polarity (near vs. far) of the stereoscopic edges as though they were straight contrast edges. How a crisp, straight edge is extrapolated from individual dots lying along a jagged path remains unclear (Spillmann & Werner, 1996). Another puzzle is why the perception of depth in random dot patterns initially takes a long time to emerge but is seen much more rapidly on subsequent exposures, analogously to the Dalmatian dog mentioned earlier (§1.5).

4 Shape from Motion

4.1 Coherent Motion

The preceding three sections have discussed emergence, segregation, and filling-in in relation to various Gestalt factors. The most powerful Gestalt

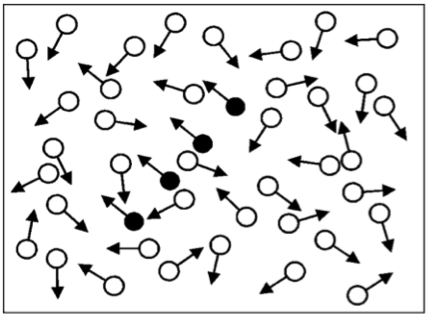


Figure 16
Coherent motion within a random field.
Four dots moving coherently on a dynamic dot background, where each dot has its own motion vector. Trained observers can specify the direction of the group of four coherently moving dots within 450 ms. This time depends on the speed and spacing of the dots. All dots were shown as white blobs on a dark background. (From Uttal et al., 2000. Reprinted with permission from Elsevier.)

factor of all is the factor of *common fate*. For example, stimuli moving coherently in the visual field are grouped together and are seen as a figure on the ground. Research on highly trained observers has shown that as few as four dots (4%), moving at the same speed and in the same direction, will stand out as a group among a random field of 100 dots, each of which has a different motion vector (Uttal et al., 2000; Stürzel & Spillmann, 2004). This is illustrated in figure 16.

More surprisingly, perceptual grouping occurs within less than half a second, demonstrating the enormous power of the Gestalt factor of common fate. For comparison, Britten et al. (1992) in the macaque obtained a similar signal-to-noise ratio of 6.7%. These are remarkable achievements of the brain that call for a rapid grouping mechanism extracting and integrating figural information across distance (Spillmann & Werner, 1996).

A simple demonstration may serve to illustrate the effect. Imagine a small number of widely spaced dots drawn, for instance, in the shape of a circle on a transparent foil; and superimpose it on a random dot background. The circle will remain invisible as long as both, the figure and the background, are stationary but will immediately pop out when either the foreground or background is moved. This kind of figure–ground discrimination by relative motion has also been shown to be effective in insect vision (Reichardt & Poggio, 1979).

Neurons responding to coherent motion have been found in area MT. Such neurons were shown to synchronize their response patterns when stimulated coherently and in this way may enable perceptual grouping and figure–ground segregation (Gray et al., 1989; Eckhorn, 1991). The resulting temporal coupling of neuronal responses has been interpreted in terms of Gestalt-like *feature binding* (Singer, 1989; Castelo-Branco et al., 2000). This so-called binding-by-synchrony hypothesis has been enormously productive, fostering numerous studies in neurophysiology and psychophysics. Yet, despite its attractiveness, the hypothesis has recently been challenged (Thiele & Stoner, 2003; Palanca & DeAngelis, 2005; Dong et al., 2008). In particular, neurophysiological recordings from more than two neurons do not appear to have been made. Thus, the question of how a number of neurons, whose receptive fields in the visual field are far apart, communicate with each other to enable perceptual grouping of distant stimuli remains to be resolved.

Common features such as brightness, color, orientation, or texture of the stimulus frequently accompany coherent motion. An example from daily life is a group of schoolchildren walking in pairs together and wearing the same uniform within a large crowd. The correlated movement of the children combined with their common appearance makes them even more conspicuous as a figure on the ground. To study this problem, Croner and Albright (1999) added color to a number of target stimuli moving coherently among a large number of randomly moving dots. As predicted, thresholds for directional discrimination in human observers and monkey MT cells improved several fold, although more so for human observers. The authors conclude that MT neurons are not only selective to motion direction (Britten et al., 1992), but also account for threshold facilitation when coherent motion is combined with color as an additional grouping factor.

4.2 Shape-from-Motion

All the stimulus patterns used in the preceding experiments were artificial laboratory stimuli and unfamiliar to the observer. One may ask how much information is required to perceive coherent motion when a *biological* stimulus is used. In a breakthrough experiment, Johansson (1973) demonstrated that surprisingly few cues are needed to recognize a human being moving in the dark. He showed that a number of small and dim lights attached to the principal joints of the body suffice instantaneously to reveal two people dancing in the dark.

This is evidence for *shape-from-motion* from sparse stimulation and prompted the name *biological motion*. Note that the coherent motion of a point walker is defined differently from §4.1, as each stimulus on the circumference of the body has its own motion vector. In the Johansson experiment, the individual lights moved in different local directions and at different velocities, and yet they were integrated into a coherent motion (and shape) percept. Taiwan has adopted this technique in its traffic lights, thereby enhancing safety for crossing pedestrians.

Behavioral studies suggest that monkeys and humans perceive motion-defined shapes in a similar manner and presumably also possess common neural mechanisms mediating them (Unno et al., 2003). Oram and Perrett (1994) found neurons that respond to figures defined by biological motion in the anterior superior temporal polysensory area of the monkey while Servos at al. (2002), using fMRI, reported activity corresponding to higher-order motion processing in the lingual gyrus.

4.3 Shape by Accretion–Deletion

Another intriguing example of shape-from-motion is dynamic occlusion and emergence. Shipley and Kellman (1994, 1997) have demonstrated figural segregation based on spatiotemporal boundary formation by progressively uncovering the leading and covering the trailing edge of a moving region. As a result, a global surface is perceived that is based on sequential changes of local motions (including color and orientation) across space. Such a situation happens quite often under natural conditions as one walks past occluding obstacles.

For example, the thicket of a dense hedge would be considered severely disruptive to shape perception, as only snippets of objects are admitted to the eye. However, when we walk along a hedge, we clearly can see objects on the other side, especially when they are moving. A soccer game can easily be watched this way. Both the position of the players and the ball are constantly updated, thereby enabling perception of a continuous scene of the game. The spatiotemporal scene thus obeys the Gestalt factor of exhaustiveness (*Gestalt Faktor des Aufgehens ohne Rest*), stating that the components of previous glimpses are included in the following ones in the interest of preserving a coherent percept.

One would therefore expect a neuronal mechanism to have evolved that can explain this kind of perception from a discontinuous stimulus sequence. Indeed, Sary et al. (1995) described cells in the inferotemporal cortex that responded to kinetic boundaries, whereas a later study (Stoner, Duncan, & Albright, 1998) described neurons that can account for dynamic shape perception in area MT.

5 Unresolved Issues

5.1 Isomorphism

Throughout this essay one may have assumed that a stimulus imaged on the retina must be isomorphic (*gestaltgleich*) with its representation in the cortex and the visual percept that derives from it. This problem of shape correspondence goes back to the Gestalt psychologist Wolfgang Köhler (1920, 1938), who asked how brain images compare to the retinal stimulus on one hand (isomorphism of the first kind) and to the phenomenal percept on the other (isomorphism of the second kind). Köhler claimed that the phenomenal state is linked to a structurally identical process at the so-called *psychophysical level*. Is there evidence for isomorphism from neurophysiological studies?

Accurate predictions of the retinal projection (mapping) onto the visual brain have been available for some time. Radioactive tracing studies (Tootell et al., 1982) suggest that there is a complex logarithmic transformation between retinal and cortical images (see also Wood & Schwartz, 1999). Figure 17 illustrates the topographic representation of a circle, square, and triangle in area V1 of the human cortex. It is obvious from these figures that continuous lines in the retinal image remain continuous in the cortex, at least in the early stages of the visual pathway, where *retinotopy* prevails.

On the other hand there is little resemblance between the three geometric outline patterns used and their computed cerebral projections. The geometric shape is not preserved in these brain images, and therefore one might say that they are not isomorphic with the visual stimulus. Surely, none of the stimuli on the left could be identified from their functional substrate on the right. This same argument also holds for the alleged isomorphism between the brain image and its correlated percept.

An answer to the so-called *inverse optics* problem of how to identify a stimulus from the corresponding neuronal activity thus remains for future research (see Boynton, 2005; Haynes & Rees, 2005; Kamitani & Tong, 2005; Kay & Gallant, 2009).

5.2 Infant Vision

Up to this point, the essay has dealt with adult vision but has paid little attention to visual development during childhood. The question arises at

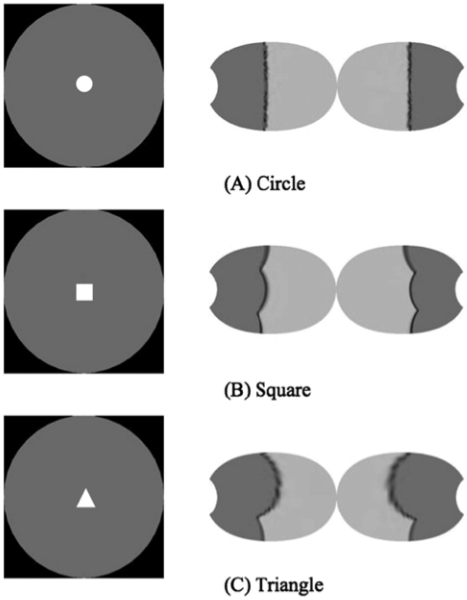


Figure 17
Computed representation of simple geometric patterns in area V1 of the human brain. Left: Retinal projections of a circle (A), a square (B) and a triangle (C), all of size 12°. Stimulus size has been increased by approximately a factor of 2 in the interest of better visibility. (See original figure in Spillmann, 2009, p. 1514.) Right: Both cortical hemispheres are shown: left hemisphere (right visual hemifield) is on the left and right hemisphere (left visual hemifield) is on the right. The light gray areas represent the figure while the dark gray areas represent the ground. The black lines depict the edges of the figure. (Courtesy of Prof. Eric Schwartz. Reprinted with permission from Elsevier.)

what age the mechanisms governing figure–ground organization and grouping are present in infancy. From limited evidence in outline drawings, Metzger (1936/2006) concluded that child vision obeys the same Gestalt principles as adult vision, although the weights are distributed differently. In child vision, the Gestalt factor of closure dominates, not unlike in touch (Gallace & Spence, 2011).

Although it may seem impossible in human babies to prove that a given perceptual function is present at birth, there is increasing evidence for an early onset of Gestalt functions from developmental studies. For example, Kellman and Spelke (1983) demonstrated that infants at 4 months of age respond to *common fate* motion and are sensitive to *good continuation* and *similarity* at 7 months. In a review article, Quinn, Bhatt, and Hayden (2008b) report on studies from their laboratory that push the point in time still further back. In a preferential looking test, 3-month-old infants were found to behave consistent with *lightness similarity* (see figure 18A). Results further suggest that *good continuation* as an organizational principle is present at the same age. The factor of *proximity* is similarly found to be operational in 3–4 month-old infants. Further experiments testing for the presence of *good continuation* in complex patterns agree with an early onset of figural organization (see figures 18B–D).

However, in contrast to these grouping principles, *form similarity* could not be demonstrated in infants of 3–4 months (see figure 18E), only at 6–7 months. Quinn & Bhatt (2006) and Quinn, Bhatt, and Hayden (2008b) therefore suggest that different Gestalt factors may become operational at different times during development. They further suggest that the earlier factors may unfold "automatically" as assumed by the Gestaltists while the later factors may require learning from experience.

Even earlier evidence from developmental studies of visual perception comes from the work of Johnson and colleagues, who studied a variety of perceptual functions in infants as young as 2 months of age (e.g., Johnson & Aslin, 1995; Johnson & Aslin, 2000; Johnson & Mason, 2002). For

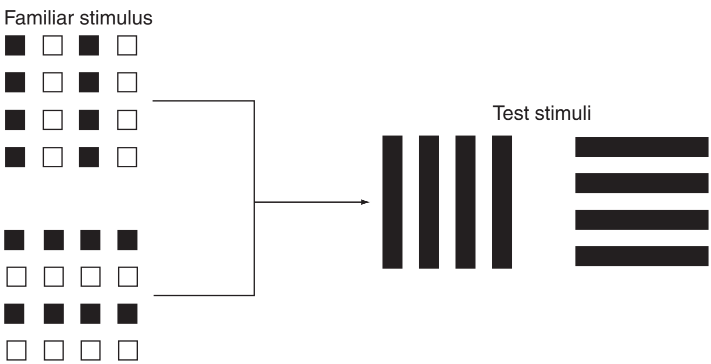


Figure 18A
Test for lightness similarity in infants.
Preferential looking utilizes the tendency of an infant to prefer a novel stimulus pattern to a familiar stimulus pattern. Each of the two patterns on the left was presented for familiarization, followed by the two test patterns on the right. Infants of 3 months of age preferred the novel pattern, suggesting that they can perceptually group the squares on the left according to lightness. (From Quinn, Burke, & Rush, 1993. Reprinted with permission from Elsevier.)

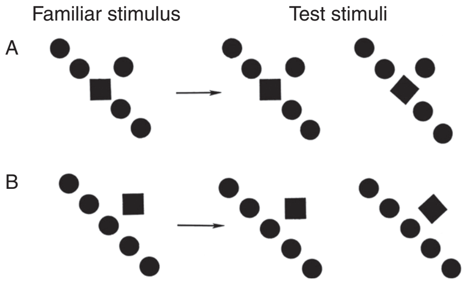


Figure 18B
Test for good continuation in infants.
Top and Bottom: The patterns on the left were shown for familiarization, followed by the two test patterns on the right. (A) Online condition: The target (square) is included in the series of distractors. (B) Offline condition: The target is presented outside the line of distractors. Infants of 3 months of age preferred the diamond in B, but not in A, suggesting that it had been grouped with the distractors in A according to the Gestalt factor of good continuation. (From Quinn & Bhatt, 2005. Reprinted with permission.)

Figure 18C
Test for proximity in infants.
Infants were first shown the pattern on the left and then tested with the two patterns on the right. Infants of 3–4 months of age preferred the three long horizontal bars for novelty, consistent with perceptual grouping of the square-shaped elements along the vertical to which they had become habituated. (From Quinn, Bhatt, & Hayden, 2008a. Reprinted with permission from Elsevier.)

example, perceptual completion was examined by asking if infants show behavioral evidence of bridging a gap in the middle of a moving rod that was partially occluded. Evidence for such unit formation was found in 4-month-olds, suggesting the presence of mechanisms that support the perception of *common motion, alignment,* and *good continuation.* Two-month-olds showed unit formation only when the occluder was relatively narrow or otherwise revealed more of the moving rod.

On the other hand, the same infants responded to kinetic illusory contours created by accretion/deletion on a random dot background texture. This observation suggests that the capacity for spatiotemporal boundary

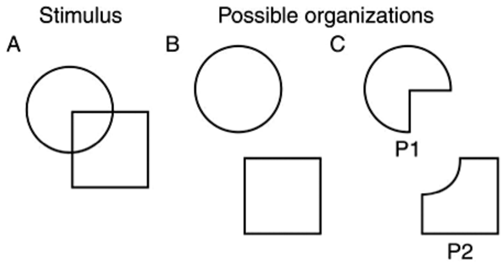


Figure 18D
Test for good continuation in infants.
The intertwined stimulus pattern (A) was shown first, and thereafter the two decomposed test stimuli (B and C) were shown. Infants of 3–4 months of age chose patterns P1 and P2 as the novel stimulus, suggesting that they had parsed stimulus pattern A according to the Gestalt factor of good continuation. (From Quinn, Brown, & Streppa, 1997. Reprinted with permission from Elsevier.)

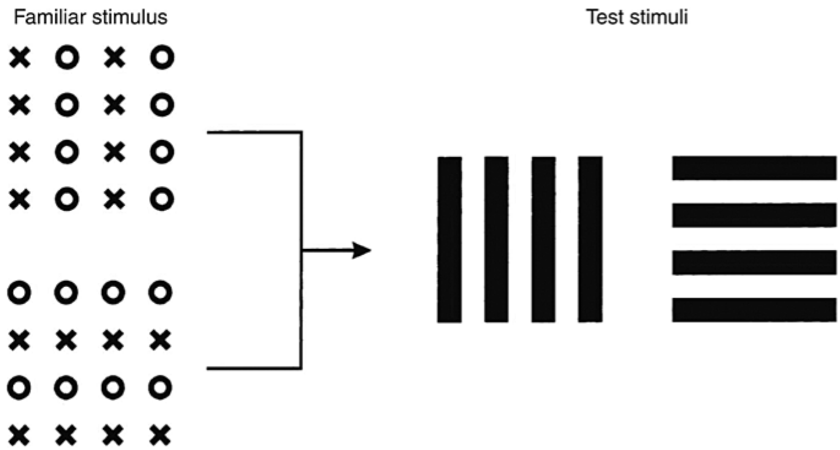


Figure 18E
Generalization task for form similarity in infants.
The patterns on the left were shown for familiarization followed by the two patterns on the right to test for form similarity. Infants of 3–4 months of age failed to show a preference for the novel orientation of the bars (e.g., for horizontal bars after familiarization with columns of X's and O's), but older infants of 6–7 months succeeded. (From Quinn et al., 2002. Reprinted with permission.)

formation (and thus figure–ground segregation) is present shortly after birth (Johnson, 2004). However, motion, texture, and depth cues in the stimulus are essential. Object unity is not perceived even by 4-month-olds when the displays are stationary (Kellman & Spelke, 1983). Slower maturation (Pomerantz, 1981), developmental mechanisms and associative learning have been invoked to account for these results.

5.3 Gestalt Factors Inborn or Learned?

The next question therefore is this: Are Gestalt factors expressions of evolutionary mechanisms, or are they due to early learning?

The fact that the majority of Gestalt factors are operational rather early in life points towards an innate origin and is consistent with observations in the animal kingdom. The behavior of animals that must be able to escape from predators right after birth suggests that essential visual functions are part of their operational inventory. Mechanisms for survival need to be fast, safe, and robust. The observation that camouflage in nature works equally well for both humans and animals (§1.5) also testifies to the Gestalt factors as *natural laws* (Metzger, 1936/2006).

Experiments demonstrating that monkeys, fish, and insects behave as though they perceive illusory contours in Kanizsa figures (§2.1) further suggest that the mechanism for contour completion is hardwired. Accordingly, Palmer (2003) interprets the Gestalt principles as physiological constraints that have evolved during evolution in response to ecologically relevant structures in the environment. For example, the reason why we are sensitive to bilateral symmetry in the visual domain is because symmetry is a salient property of many objects in nature. This factor then became a determinant for figure–ground organization and grouping (for a review, see Wagemans, 1997).

Todorovic (2008) similarly argues in terms of ecological relevance, taking a Gibsonian view (Gibson, 1950, 1979) when he asks whether the Gestalt principles could be heuristics acquired from general features of the external world rather than fundamental properties of the visual system (see also Rock, 1975). He remarks: "Objects in the world are usually located in front of some background (figure–ground articulation), have an overall texture different from the texture of the background (similarity), consist of parts which are near each other (proximity), move as a whole (common fate) and have closed contours (closure) which are continuous (continuity)."

There is growing evidence showing that the statistics of natural scenes support some of the factors involved in grouping and figure–ground organization (Elder & Goldberg, 2002). Starting with Brunswik and Kamiya (1953), who investigated the ecological cue validity of the Gestalt factor of *proximity,* a number of studies have confirmed that the regularities of natural scene statistics are consistent not only with Gestalt factors but also with the neurophysiological response properties of cortical cells (Field, 1987; Coppola et al., 1998; Olshausen & Field, 2000; Sigman et al., 2001; Purves & Lotto, 2011).

At present, we can only speculate which answer will ultimately be given to the question whether dispositions acquired during evolution on one hand (Geisler et al., 2001) or Hebbian probability learning during infancy on the other (Sigman et al., 2001) are responsible for the way we see. Much speaks in favor of the visual system having evolved bottom-up in response to the ecological demands of the environment. This probably is the reason why the principles by which we structure our visual world are present early in life and are the same as those used in the animal kingdom.

However, modifying influences from experience and top-down regulation from higher cortical levels (attention, memory, and set) may well contribute. There is now evidence suggesting massive top-down control of visual function (Perkel, Bullier, & Kennedy, 1986; Bullier, 2001). For example, far more fibers (90 : 10%) descend from the primary visual cortex (V1) to the lateral geniculate nucleus than ascend in the opposite direction (Peters, Payne, & Budd, 1994; Murphy & Sillito, 1996). Other studies suggest similar feedback from higher visual areas (V2–V4) to lower ones (Payne et al., 1996). Yet, the function of these local feedback loops is still unclear.

Unclear is also the relevance of recent results discussed under the label of perceptual learning. Experience-dependent changes in adult vision are typically retinotopic, orientation-specific, and monocular (Karni & Sagi, 1991). Furthermore, they require thousands of stimulus exposures over many weeks, suggesting a slow but long-term modification of cortical circuitry. This leaves open the question of how relevant these changes are for everyday perception.

There is also evidence demonstrating short-term dynamic changes of visual neurons (Allman, Miezin, & McGuinness, 1985; Schwartz, Maquet, & Frith, 2002; Gilbert, Li, & Piëch, 2009) as the basis for perceptual learning in monkeys and adult human observers (Li, Piëch, & Gilbert, 2006, 2008), making one wonder how these startling new findings relate to the large range of visual stimuli encountered in an everyday environment.

Closing Remarks

This essay dealt almost exclusively with visual perception in normal observers, largely ignoring the findings offered by neuropsychological case studies. For example, selective deficits of figure–ground segmentation have been reported in brain-damaged patients suffering from injuries both in the ventral and parietal lobe (Baylis & Baylis, 1997). Furthermore, *integrative agnosia* (Riddoch & Humphreys, 1987) shows failures to group a stimulus by proximity, similarity, or closure and to integrate image features into a coherent object (Treisman, 1998).

Other instances are the inability to group collinear edges and correctly localize depth relationships between foreground and background in occlusion patterns. These and other findings have prompted the conclusion that perceptual organization is a multistage process (Behrmann & Kimchi, 2003; Humphreys, 2003), involving early low-level operations such as grouping by collinearity, as well as later more complex visual operations, for example, configural processes.

The question "What goes with what" in a visual stimulus pattern (Wertheimer, 1923; Quinn, Bhatt, & Hayden, 2008b) is a fundamental one in perceptual grouping and figure–ground organization. Although much progress has been made in understanding the neuronal underpinnings of the factors governing visual perception such as good continuation, closure, and common fate, more work lies ahead of us before we can answer the question "Why do things look as they do?"

It is hoped that the translation into English of both of Max Wertheimer's landmark articles in this book will help in this endeavor and spur further efforts not only in psychophysics and neurophysiology but also in related fields such as visual computation, neuroimaging, comparative physiology, and cognitive neuroscience at large.

Acknowledgment

This essay was written while the author was a visiting professor at China Medical University, Taichung (Taiwan), on leave of absence from Freiburg University (Germany). I am indebted to the *Johann Gottfried Herder Stiftungsinitiative*, Bonn, and China Medical University for jointly supporting my *Gastdozentur* in Taiwan, and the Serena Yang Foundation for funding my stay at The University of Hong Kong. Prof. John S. Werner kindly hosted me at the University of California, Davis. A number of colleagues, among them Geoffrey Blowers, Joseph Brooks, Birgitta Dresp, Sergei Gepshtein, Diederick Niehorster, Paul Quinn, Rüdiger von der Heydt, Johan Wagemans, Michael Wertheimer, and Jeremy Wolfe, kindly read my draft and provided comments and suggestions. I thank them all.

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Epilogue: Max Wertheimer in Frankfurt and Thereafter

Viktor Sarris

A century ago, Max Wertheimer's studies "On Seeing Motion" (1912) and "Principles of Gestalt Perception" (1923) stirred up a rebellion against the then dominant schools in psychology, first against that of Wilhelm Wundt's structuralism in Europe and, somewhat later, against that of Clark Hull's and Kenneth Spence's behaviorism in the United States (cf. the chronology of Wertheimer's life in Appendix A).

These two articles—which belong together (cf. *Synopsis 1* and *Synopsis 2*, this volume)—generated serious debates about the heuristics and validity of the core issues of Gestalt theory, especially about its doctrine of the priority of the whole (Gestalt) as an emergent property and also about its basic top-down ("from-the-whole-to-its-parts") axiom in perception and cognition. In addition, Wertheimer's style of presentation—even if it may be judged as ingenious in character—was also sometimes criticized as idiosyncratic, occasionally even lacking today's stringent "clarity" (see appendix B).

In the following, Wertheimer's life and work in Frankfurt are briefly sketched (Frankfurt I: 1910–1914; Frankfurt II: 1929–1933), his life in Berlin (1914–1929) is touched on, and a short account is provided of his later activities in New York (1933–1943). Extensive treatments of Wertheimer's works during his two stays in Frankfurt are available elsewhere (e.g., Sarris & Mich. Wertheimer, 1987; Ash, 1989; King & Mich. Wertheimer, 2005).

Epistemological Basis of Wertheimer's Work

What are the epistemological origins of Wertheimer's work?

The basis and the development of Gestalt theory, as advanced at the Frankfurt Institute of Psychology and elsewhere, are closely related to the accomplishments of Wertheimer together with those of his teachers

Christian von Ehrenfels, Carl Stumpf, and Friedrich Schumann and of his colleagues and friends Wolfgang Köhler and Kurt Koffka (e.g., Boring, 1942). Wertheimer primarily used experimental phenomenology for his studies (cf. Michotte, 1954; see also Ehrenstein et al., 2003; Sinico, 2003; Forti, 2009; Spillmann, 2009; Gepshtein, 2010). At that time, the phenomenological approach was in common use, although somewhat controversial in all of psychology because of the qualitative nature of its reasoning. The historical roots of phenomenological thinking may be traced back to such eminent figures as Ernst Mach, Franz Brentano, Edmund Husserl, and the physiologists Jan Evangelista Purkinje and Ewald Hering. Indeed, phenomenological thinking was in the air when Wertheimer's Gestalt revolt began. Nowadays the fruitful implications of experimental phenomenology are hardly questioned any more as long as the qualitative approach is accompanied by, or leads to, quantitative experimental work—probably at best by interrelated psychophysical and neurophysiological research (cognitive neuroscience; e.g., Sekuler, 1996; Westheimer, 1999; Cutsuridis et al., 2011; cf. also Sekuler, this volume, and Spillmann, this volume).

Wertheimer in Frankfurt I: 1910–1914

Since Wertheimer's 1912 article, psychologists and neuroscientists distinguish between real motion (RM) and apparent motion (AM). In the case of AM smooth motion is observed—as if it were RM—under specified experimental conditions, although its physical basis consists merely of a sequence of discrete (stationary) stimulus changes (e.g., Burr & Thompson, 2011; see appendix C).

From the Whole to Its Parts

Today, we are surrounded by much AM technology, the perception of which is taken for granted by our eyes and brains. Indeed, cinema, television, and computer animation provide a plethora of compelling examples of apparent ("illusory") motion perception, taken as real motions by everyone and also by other animal species. Wertheimer conducted his motion studies on a firm experimental basis given the research methodology of his time. In fact, he suggested a completely different line of thinking in psychology, his revolutionary rationale "from-the-whole-to-its-parts," now better known as the "top-down" approach in perceptual psychology. This was contrary to what most of his contemporary colleagues in Germany and the United States favored. Indeed, Wertheimer's studies in Frankfurt drew the line between "old" and "new" psychology (as any modern student of psychology knows). Consider the implications of his neurophysiological reasoning, especially in his epoch-making article on seen motion (1912): His unique strategy in both theorizing and experimentation is nowadays called a system-theoretical approach in both psychology and neurobiology. For example, see today's "set theory" in music (e.g., Lerdahl, 2001; Kostka & Payne, 2004). System theory is strongly related to the conceptual distinction between higher-level versus lower-level perceptual and cognitive processing in modern research (e.g., Ehrenstein et al., 2003; Cutsuridis et al., 2011).

Further Roots of Wertheimer's Work

What about the biographical roots of Wertheimer's way of creating his compelling demonstrations, which also stem from music and psychoacoustics in his 1912 and 1923 articles? Anna Wertheimer-Hornbostel's, Wertheimer's former wife's, account—many years later of Max's lifelong passion in music and his philosophical values on human freedom—may help to answer this question:

> Max Wertheimer took violin lessons starting at quite an early age—he also wrote poetry and composed chamber music. [He was engaged in] fine arts and [concerned about] social freedom in his teens. (His mother was an accomplished amateur pianist.) The writers Max Brod and Franz Werfel were among his early friends in Prague. Later he also was involved with them in initial plans and projects . . . with the first President T.[omás] G. Masaryk [(1850–1937)] when the Republic of Czechoslovakia was founded at the end of the First World War. (1965, unpublished manuscript; cf. Sarris, 1997)

This quotation of Anna Wertheimer-Hornbostel may help us today to understand some of the background of Wertheimer's published work.

The Quest for Objectivity

Wertheimer is also known for his enduring struggle for objective, natural-science, support for the Gestalt approach (e.g., Ash, 1995; King & Mich. Wertheimer, 2005; Sarris, 1995). This effort is exemplified, for instance, in some of the early work of his collaborator Kurt Koffka: Only three years after Wertheimer's 1912 paper, Koffka's doctoral student Adolf Korte published quantitative experimental work on apparent motion (AM) which contained a careful description of the so-called "Korte laws," nowadays also called the "Koffka–Korte laws" of apparent motion (e.g., Sarris, 1989). Koffka (1919) himself summarized these quantitative laws, formulating three mathematical equations for perception of optimal motion (cf. Sarris, 1989):

The establishment of these three laws illustrates the rigor and vigor of the early Gestaltists' struggle for objectivity. S. Smith Stevens (1951, pp. 20f.), in his influential handbook chapter on "Mathematics, Measurement, and Psychophysics," praised the early quantitative work by Korte as a model of scientific advance in experimental psychology.

Analogous Studies of Auditory Apparent Motion

Wertheimer's passion for objectivity also led him to scientific cooperation with Erich von Hornbostel, a chemist who was an expert in psychoacoustics (von Hornbostel & Wertheimer, 1920). As Anna Wertheimer-Hornbostel remembers: "During the early part of the First World War Max together with his friend, Erich von Hornbostel[,] developed the [acoustical] direction finder [the "*Wertbostel*,"] a device to localize the source of sounds with great accuracy." Today's scholars of the history of psychoacoustics are well aware of the revolutionary Hornbostel–Wertheimer auditory work (cf. also the musical set theory in modern work, cited above).

Brain Research

From the beginning, there was much neurophysiological theorizing relating the experimentally irreducible motion phenomena to cortical processes in the human brain. In fact, Wertheimer was convinced that the phi phenomenon could not be explained by peripheral sensory mechanisms, but only by taking into account higher-order brain processes. His basic hypothesis (the "short-circuit theory") is well-known nowadays, and partly—but only partly—substantiated by the discovery of potentially relevant brain processes in both animals and humans (e.g., see the essay by Sekuler, this volume).

In this context, one must also emphasize the relevance of Wertheimer's clinical observations, as described in his 1912 article. His study of a brain-damaged patient, carried out together with the neuropsychiatrist Otto Pötzl at the Psychiatric University Clinic in Vienna (under the directorship of the later Nobel laureate Julius Wagner von Jauregg), helped corroborate Wertheimer's hypothetical brain theory of motion perception. (See also the supportive studies by Kurt Goldstein and Adhémar Gelb of brain-injured patients at the Psychiatric University Clinic in Frankfurt during World War I; cf. Sarris & Mich. Wertheimer, 2001.)

The experimental clinical Gestalt work by Gelb during the first two decades of the twentieth century in Frankfurt produced results consistent with Wertheimer's theorizing and became a milestone in the history of cognitive neuroscience (e.g., Zihl, von Cramon, & Mai, 1983; Zihl, 2010).

Wertheimer in Frankfurt II: 1929–1933

In Berlin (1916–1929) and later in Frankfurt (1929–1933), Wertheimer further pursued his interests in basic science. He continued his work on motion perception and other Gestalt-oriented work in several ways. Because this research was published mostly under the names of his students, the findings ascribed to Wertheimer during the years of his professorships in Berlin and Frankfurt are relatively few. He is reported to have said: If a result is correct, others will find it sooner or later; if it is wrong, it is not worth publishing (see also appendix D).

Relational Perception

A note on Wertheimer's insistence on the "relational" nature of perception seems to be in order here. The relational-perception issue concerns mainly his concepts of frame of reference (1912) and of relative distance (1923). Wertheimer himself did not describe his empirical results or theoretical insights at length. Readers must consult his students' papers, with Wertheimer's name typically mentioned only in an acknowledgment (e.g., Ternus, 1926; Duncker, 1929; Metzger, 1934, Krolik, 1935; Oppenheimer, 1935: all cited in Sarris, 1989; King & Mich. Wertheimer, 2005). Yet another relational-perception issue, namely "*transposition*," which is a special kind of perceptual transfer, was treated by Wertheimer (1959) in New York, as cited below. (For example, chickens that were trained to peck at grain on the lighter of two surfaces will continue to peck at grain on the lighter surface, even when the level of illumination is raised so that the formerly darker surface now has the same luminance as the formerly lighter one.)

Wertheimer's interest not only in psychological relativity but also in Einstein's theory of relativity in physics deserves special mention. Anna Wertheimer-Hornbostel recalls:

> Max Wertheimer was immensely fascinated by the theory of relativity and the way of thinking which led Albert Einstein to his famous results. A deep relationship existed between the two men since about 1910. (See chapter X of *Productive Thinking*): Einstein was delighted and intrigued by Wertheimer's philosophical

and psychological approach to his way of thinking and the two scientists worked on its logical representations during many extended personal meetings. Both men were at that time teaching and doing research at the University of Berlin; there as well as later during his years (1929–33) in Frankfurt, Max Wertheimer concerned himself at least as much with philosophical as with psychological problems. (Anna Wertheimer-Hornbostel, unpublished manuscript, 1965; see Sarris 1997)

Unfortunately, it is not clear whether, and if so to what extent, Einstein's theory of relativity in physics influenced Wertheimer's own experimental work in perception.

Many years later, Wertheimer's (1959) publication on the basic concept of perceptual relativity—transposition in human and animal perception—reflects the relevance of relational thinking once again. This paper was a strong theoretical attack against the behavioristic tradition of "absolute" stimulus–response learning theory in favor of a *relational* Gestalt approach. This posthumous article treats the issue of transposition from a theoretical point of view but without the empirical perspective of some of Wertheimer's own experimental data. Perhaps partly because of this it did not have the desired impact on his opponents' thinking in the United States and elsewhere (e.g., Sarris, 2006, 2010; Bhatt & Quinn, 2011a,b).

From Frankfurt to New York

Wertheimer's professorship at the University of Frankfurt was abruptly terminated as a result of the Nazi ban on employment of Jews. The dramatic circumstances of the Wertheimer family's flight from Frankfurt have been described at length elsewhere (e.g., Sarris, 1997; King & Mich. Wertheimer, 2005). Anna Wertheimer-Hornbostel writes:

In March 1933, two days before Hitler became Chancellor, [Max] and his wife went to a neighbor's house to listen for the first time to one of Hitler's speeches over the radio (no radio existed in Mr. Wertheimer's house [in Frankfurt]). He was deeply disturbed—during the few minutes on the way home, he decided to leave the country the following morning without telling a soul about it: he was so horrified that even then he already thought that such a regime was liable to do any deed, such as stopping him at the border. And so he, his wife and their three young children [Valentin, Michael, and Lise] left the following morning with a few small suitcases, leaving everything behind, never to return. (Unpublished manuscript, 1965; quoted from Sarris, 1997)

Before Wertheimer left Frankfurt permanently in March 1933, he had checked all the equipment belonging to the Institute of Psychology, as he was, after all, the institute director (1929–1933) and therefore in charge of its collection of apparatus (see the List of Apparatus with Wertheimer's signature in Appendix E).

Wertheimer in New York (1933–1943)

In autumn of 1933, Wertheimer became a professor at the New School for Social Research in New York, informally called the University in Exile (cf. the chronology in Appendix A). The New School was dedicated to social research and had no laboratory equipment to speak of. Therefore, although it provided a much-needed home for his work, it was not an ideal setting. In fact, Wertheimer did not himself carry out or publish any experimental studies after he left Frankfurt. Nevertheless, even without any laboratory apparatus at hand, he kept a lively interest in perceptual phenomena, as testified by his lectures at the New School and elsewhere, and by his consultations on students' experimental work.

Wertheimer's Book on "Productive Thinking"

The best-known work from Wertheimer's period in the United States undoubtedly is his book *Productive Thinking*, published posthumously (Wertheimer, 1945). Much of the material contained in this seminal work is based on his previous work at the universities in Berlin and Frankfurt (cf. Ash, 1995; King & Mich. Wertheimer, 2005). The book, still in use, is a valuable introduction to the central theoretical claims and practical applications of the Gestalt approach in the psychology of thought processes. For instance, one out of many: Wertheimer points to the school exercises in arithmetic with children in New York City as instructed by his assistant Catherine Stern, the mother of the historian Fritz Stern (2006, chap. 5), and to her obvious success with the inspiring Gestalt-oriented application in contrast to the typical "drill" of standard teaching—a thought-provoking method as praised also by Albert Einstein (Wertheimer, 1945, pp. 127, 133; cf. C. Stern, 1949; in today's use see *Stern Math*, http://sternmath.com/who-we-are.html).

Wertheimer on Philanthropic and Ethical Values

Wertheimer's whole life and work teaches us about what an individual of high personal integrity and creativity can accomplish even under adverse circumstances (1933–1943). In addition to the aforementioned achievements, Wertheimer contributed to yet other issues in psychology: ethnology and legal psychology, thinking and problem solving, aesthetics and the psychology of music written before he left Germany, as well as later articles on such philosophical issues as truth, ethics, democracy, and freedom while he taught at the New School in New York. As testimony to his important contributions to the psychology of human values, one may take Albert Einstein's enthusiastic appraisal of these philosophical papers by Wertheimer (cf. Einstein's text cited in King & Mich. Wertheimer, 2005). Hardly known today are Wertheimer's peace efforts during the various phases of World War I as well as his humanitarian support of many endangered European scholars during the thirties and early forties of the last century. He was a member of the American Psychological Association's Committee on Displaced Foreign Psychologists, 1938–1943 (see Sarris, 1997; King & Mich. Wertheimer, 2005).

Some Modern Accounts of Gestalt Theory

The continuing impact of Gestalt thought well into the twenty-first century is evident in many ways: Wertheimer's work is still profoundly influencing current research internationally in cognitive neuroscience, cognitive psychology, social psychology, aesthetics, and other areas.

International Journals

The former German journal *Psychologische Forschung*, founded by Wertheimer, Köhler, Koffka, and others in 1921, became an English language international outlet by the name of *Psychological Research*. It covers mostly empirical research, with frequent emphasis on Gestalt issues. By contrast, the journal *Gestalt Theory*, founded after World War II, contains mostly theoretical contributions, but recently also some articles with original experimental data.

Collective Books

Two collective volumes, edited by Michael Kubovy and James R. Pomerantz (1981) on the one hand and Marlene Behrman, Ruth Kimchi, and Carl Olson (2003) on the other, were originally based on Gestalt psychology symposia and contain many papers about high-level experimental research in psychophysics, neurophysiology, and computer science (e.g., see Kubovy & Gepshtein, 2003). The two books collectively helped continue to promote Gestalt-oriented work despite, if not because of, the disappearance of the formal "schools" of psychology in recent decades (cf. also Sporns et al., 1991; Oyama & Miyano, 2008; Kimchi, 2009; Sarris, 2010).

The Max Wertheimer Lectures

The international Max Wertheimer Lectures organized by the author at the Johann-Wolfgang-Goethe University in Frankfurt am Main during the period 1994–2003 were devoted to the discussion of present-day advances based on Wertheimer's multifaceted work on perception, cognition, and thinking. Leading experts from four countries were invited, most of them from the United States or Germany, but also one each from Israel and England: Stuart Anstis, Detlev von Cramon, Patricia Goldman-Rakic, Klaus-Peter Hoffmann, Ruth Kimchi, Christof Koch, Michael Kubovy, Mortimer Mishkin, Ken Nakayama, Karl Pribram, Robert Sekuler, Wolf Singer, Lothar Spillmann, Anne Treisman, Michael Wertheimer, Gerald Westheimer, Semir Zeki, and Josef Zihl.

The Max Wertheimer Lectures were governed by a caveat adopted from Wolfgang Köhler, who had warned that human cognition—and even scientific judgment—may easily fall into such simplistic dichotomies as nature–nurture, mind–body, holistic–atomistic, experimental–theoretical, and other tempting polarities in psychology. Whereas the Lectures tended to avoid such extreme dichotomies, they provided thought-provoking exchanges towards a better understanding of the psychological and neurophysiological issues involved in modern Gestalt theorizing (e.g., Sekuler, 1996; Westheimer, 1999; Gepshtein, Elder, & Maloney, 2008; Kimchi, 2009; Bhatt & Quinn, 2011a,b).

Final Remarks

Wertheimer's (1912, 1923) two seminal articles on seen motion and perceptual organization paved the way not only for the development of one of the most highly visible "schools" in psychology, but also for much current research in twenty-first century cognition, neuroscience, psychophysics, and other areas. Present and future generations of psychologists and cognitive neuroscientists may judge Wertheimer's work as fruitful but unfinished or merely programmatic. While his experimental research did not result in a finished, definite theory, it continues to highlight the serious deficiencies of an "atomistic" theory or "mechanistic" model of human and animal perception and cognition.

Modern researchers are now aware of the relational nature of all perceptual processes and their higher-order organization into cognitive systems (the "top-down" approach). Higher-order motion perception in humans and animals, including apparent motion, is now recognized as a configurational ("patterned") phenomenon; and all spatiotemporal grouping phenomena, including the figure–ground issue, are appropriately treated as emergent properties (e.g., Sekuler, this volume; Spillmann, this volume). The Gestalt character of perceptual and cognitive processes in nearly all creatures is studied in interactive neurophysiological, psychophysical, and computational research, although there also still is some important interest in a "bottom-up" approach to the basic sensory processes (e.g., Sporns et al., 1991; Papathomas, 1995; Cutsuridis et al., 2011).

How Did Gestalt Psychology Get Started, about 100 Years Ago?

Kurt Koffka, one of Wertheimer's collaborators in Frankfurt (1910–1914), recalled the following:

> It began with Wertheimer and Köhler in Frankfurt (1910), with me as a third. . . . We did not start a "movement," we hoped to get rid of a number of problems that had been debated for a long time without any apparent progress. . . . We had the same kind of enthusiasm, the same [intellectual] background, we saw each other daily discussing almost everything under the sun. (Koffka, from a letter to Edwin G. Boring, Harvard University, 22 April, 1932; quoted in Harrower, 1983)

Finally, Wertheimer in most of his work, not only in his 1912 and 1923 papers, emphasized the relativity of all human perception and cognition; but, being an engaged person and professor, he also shared an anti-relativistic perspective. He took a firm stand concerning the validity and relevance of basic human values. Among his courses at the University of Frankfurt (1929–1933) there was also his celebrated seminar on "Truth" ("*Wahrheitseminar*"). A brief summary of its main theme was later published by him in English (cf. Sarris, 1997; King & Mich. Wertheimer, 2005):

> Science is rooted in the will to truth. With the will to truth it stands or falls. Lower the standard even slightly and science becomes diseased at the core. Not only science, but man. The will to truth, pure and unadulterated, is among the essential conditions of his existence. (Max Wertheimer, 1934)

Acknowledgments

Parts of this article are based on an earlier paper by Sarris (1989). A more representative sample of the excerpts from Anna Wertheimer-Hornbostel's typewritten manuscript on Max Wertheimer's life and work has been published elsewhere (Sarris, 1997); her original text is housed in the Archives of the Leo Baeck Institute in New York. The gracious funding of the Max Wertheimer Lecture Series by the President's Office at the Johann-Wolfgang-Goethe University in Frankfurt am Main (1994–2003) is kindly acknowledged. Furthermore, I am grateful to Jürgen Bredenkamp, Allen Parducci, and Michael Wertheimer for reading and correcting some earlier versions of this Epilogue. Above all, I appreciate Michael Wertheimer's help concerning my Max Wertheimer studies over so many years (1987–2012).

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Appendices

Appendix A

Chronology: Max Wertheimer (1880–1943)

1880	Born in Prague on April 15.
1898–1903	University studies in Prague with C. von Ehrenfels and in Berlin with C. Stumpf and F. Schumann.
1904	Doctoral dissertation on forensic psychodiagnostics with O. Külpe at Würzburg.
1910	Research at the Institute of Psychology at Frankfurt am Main (director F. Schumann); early experiments on stroboscopic motion ("phi phenomenon"). Schumann's assistants W. Köhler and K. Koffka serve as Wertheimer's main subjects (beginning of a lifelong cooperation, also in the United States).
1912	Publication on the phi phenomenon: "Experimentelle Studien über das Sehen von Bewegung" (Experimental Studies on Seeing Motion). Habilitation thesis (1912); lecturer (Privatdozent) at Frankfurt am Main; collaboration during World War I with E. von Hornbostel, Berlin.
1918–1929	Lecturer (1918), then associate professor (1922) at the University of Berlin.
1921	Founding of the journal *Psychologische Forschung* (*Psychological Research*) together with W. Köhler, K. Koffka, and others (most important journal of Gestalt psychology until 1938).
1923	Publication on perceptual organization: "Untersuchungen zur Lehre von der Gestalt. II." (Investigations on Gestalt Principles. II).
1929–1933	Full professor of philosophy and psychology ("Philosophie, insbesondere Psychologie") at the Institute of Psychology at J.W. Goethe University in Frankfurt am Main (predecessors K. Marbe 1904–1909, F. Schumann 1910–1929).

1933	Employment ban by the Nazi government; professor at the New School for Social Research in New York and founder of its Department of Psychology.
1934	Founding of the journal *Social Research*, with Wertheimer as one of the cofounders and coeditors.
1934–1943	Active in rescue efforts for endangered scholars in Germany and, from 1938 on, member of the Committee on Displaced Foreign Psychologists of the American Psychological Association.
1943	Died in New Rochelle, New York, on October 12.
1945–1959	Posthumous works: *Productive Thinking* (1945); "On Discrimination Experiments: I. Two Logical Structures" (1959).

Acknowledgment

Slightly modified from Sarris (1989).

Appendix B

Max Wertheimer's Publications

1. Psychologische Tatbestandsdiagnostik (with J. Klein). *Archiv für Kriminalanthropologie und Kriminalistik*, 1904, *15*, 72–113.
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Acknowledgment

Slightly revised and supplemented, after Michael Wertheimer (1959, 1982).

Appendix C

Max Wertheimer's Courses at the Frankfurt Institute of Psychology: 1912–1916

Summer 1912	Exercises in the psychology of mental abilities
Winter 1912/13	*Völkerpsychologie* (Psychology of higher mental, cultural, and social processes)
	Selected topics in psychology for medical students
Summer 1913	Epistemological problems
	Psychology of memory
Winter 1913/14	Origins of philosophy
	Recent work in psychology with special attention to medicine
Summer 1914	Introduction to psychology
Winter 1914/15	*Völkerpsychologie*
	Psychological analysis of brain-pathological cases
Summer 1915* until	History of recent philosophy
Summer 1917*	Readings in philosophy
Winter 1917/18*	Logic
	Readings in philosophy
Summer 1918*	History of recent philosophy
	Readings in philosophy

Acknowledgment

Slightly modified from Sarris (1995).

* Suspended due to World War I.

Appendix D

Max Wertheimer's Courses at the Frankfurt Institute of Psychology: 1929–1933

Winter 1929/30	Psychology of productive thinking
	Philosophical seminar (on Gestalt theory)
	Consultation on scientific projects
Summer 1930	Epistemology
	Völkerpsychologie (Sociocultural psychology), with demonstrations
	Philosophical seminar (with P. Tillich, K. Riezler, and A. Gelb)
Winter 1930/31	Psychology (with demonstrations and experiments)
	Psychological seminar (for advanced students)
Summer 1931	Psychology (with demonstrations)
	Psychological seminar (for advanced students)
	Consultation on scientific projects
	Philosophical colloquium (with P. Tillich, K. Riezler, and A. Gelb)
Winter 1931/32	Psychology (with demonstrations)
	Psychological seminar (for advanced students)
	Consultation on scientific projects
Summer 1932	Logic
	Seminar on problems in logic
	Exercises in experimental psychology (sensory perception)
	Consultation on scientific projects
Winter 1932/33	Logic (with consultation)
	Exercises in psychology (with W. Metzger)
	Consultation on scientific projects

Summer 1933*	Psychology of perception Exercises on problems in logic Consultation on scientific projects

Acknowledgment

Slightly modified from Sarris (1995).

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* Suspended due to the Nazi ban 1933.

Appendix E

Max Wertheimer's 1933 Apparatus at the Frankfurt Institute of Psychology

Viktor Sarris

While preparing the exhibition "Max Wertheimer in Frankfurt," which opened in October 1987 at the Institute of Psychology, University of Frankfurt, I searched for any remnants of Wertheimer's equipment (e.g., his Schumann tachistoscope, kymograph, epidiascope, acoustic direction finder, and others)—all apparatus that Wertheimer had used in his earlier experimental investigations (1910–1914; 1929–1933). Colleagues at other German universities helped occasionally in this endeavor. Thanks to these efforts, the exhibition succeeded in displaying, for instance, some of Wertheimer's original "sliders," devices he had used in his experiments and for demonstrating the phi phenomenon to students. A passage in a letter, dated 16 February 1987, by Professor Otto Heller, University of Würzburg, may illustrate the difficult nature of the search for these and other lost devices: "A small hint might help: There were 5–7 sliders. I wrapped them in white tissue paper, when I was still at the University of Tübingen (c. 1970), and put them into a brown (?) cardboard box."

During one of these searches, I came across Wertheimer's 1933 List of Apparatus, hidden away in a dusty corner of a side cabinet located next to a secretary's office. Wertheimer and his two assistants, E. Levy and W. Metzger, had signed the document at the end. This list of equipment, possibly typewritten by Wertheimer himself, doubtless was an updated and enlarged version of an earlier list of apparatus started by his predecessors K. Marbe (1904–1910) and F. Schumann (1910–1929) that was also displayed at the 1987 exhibition. It may well be that preparing and signing this list of apparatus was one of Wertheimer's last official acts early in 1933 before he permanently left Germany (cf. the Epilogue, this volume). Most of this archival apparatus is now kept at the Adolf-Würth-Zentrum für Geschichte der Psychologie/Adolf Würth Center for the History of Psychology at the University of Würzburg, which houses the archives of the Deutsche Gesellschaft für Psychologie (German Society of Psychology).

As I also observed in 1987, the exibit's natural limitations were due to the fact that during this unfortunate period in history (1933–1945) many important sources had disappeared for ever or had been destroyed (e.g., Sarris, 1997).

Bei der Uebergabe des Instituts waren im Inventar eine Anzahl von Positionen gestrichen (teils mit, teil ohne Anmerkungen), oder mit Fragezeichen versehen; das war, nach Mitteilungen d. Vorgängers zum grossen Teil auch schon der Fall bei der Uebernahme des Instituts seitens Prof. S c h u m a n n von Prof. M a r b e .

1. Im Rechnungsjahr 1921/2, vgl. Kassenbuch S.60, wurden an das psychologische Universitätsinstitut M a r b u r g , Dir. Prof. J a e n s c h , verkauft:

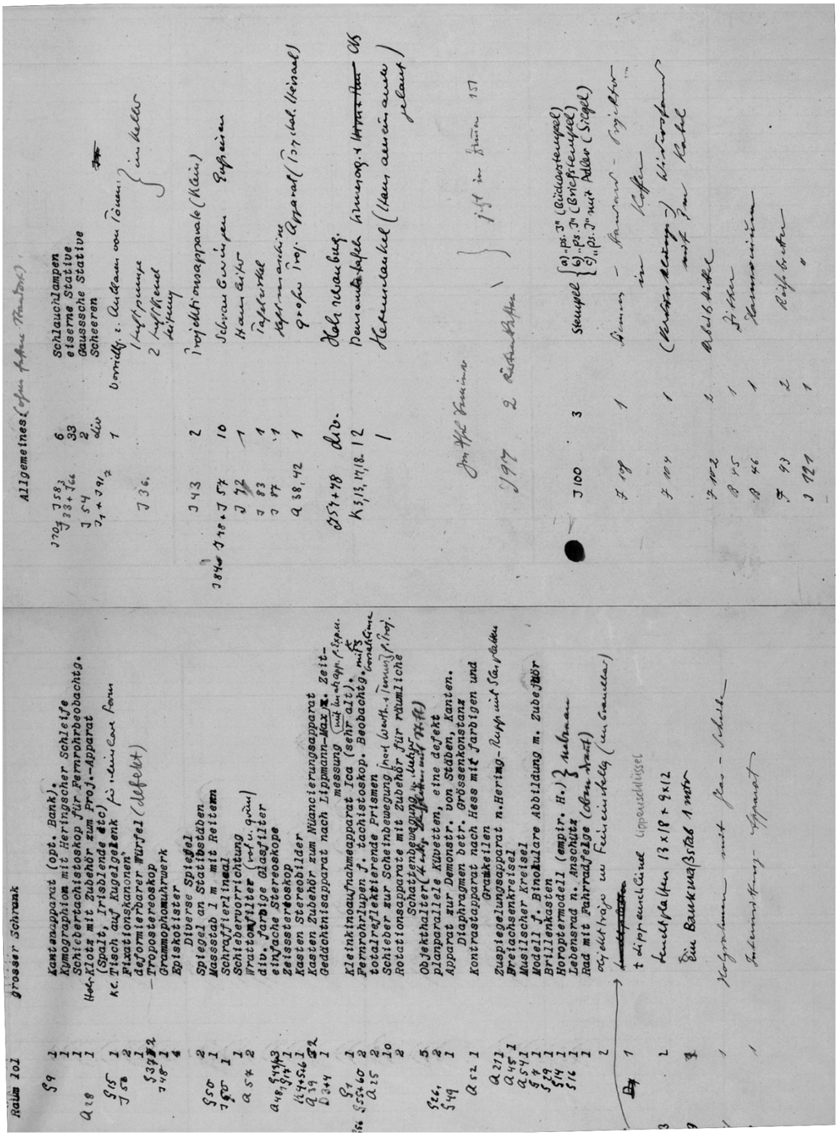
Lfd. Nr.	Gegenstand	Bemerkungen
B3	Sirene (Marbe) mit 4 Scheiben	
B 17	Obertonapparat(König)	
G 11	Kante (Hillebrand)	
G 27	Tachistoskop nach Schumann. mit totalreflektierendem Prisma und zwei gegeneinander verschiebbaren Spalten. dazu gehören: a) 1 kleines astronom. Fernrohr b) eine binokulare Fernrohrlupe.	
G 41	grosser Kantenapparat	
H 1	Universalkontaktapparat mit 13 Schleif- u.2 Drehcontakten.	
J 7	Brenner f. empfindl. Flammen (König); 6 Brenner u.1 Beinahle	gehört zu B 17.

An das Hirnverletzten institut Frankfurt/M. wurde verkauft:

C 1 Pantograph (Jaquet)

2. Seinerzeit vorgenommene Uebertragungen aus bzw. nach anderen Nummern oder Gruppen des Inventars:

Lfd. Nr.	Stückzahl	Gegenstand	Bemerkungen
A29	1	rotierender Spiegel	In A gestrichen und in B 28 dafür aufgeführt.
B 11	1	elektr.Stimmgabel 50S	
B 12	1	" " 100S	übertragen nach C 23,24,25.
B 13	1	" " 1000S	
B 20	3	Sätze Interferenzröhren	waren gestrichen, weil "doppelt inventarisiert", s.B 30/1.Dort irrtümlich gestrichen, sind vorhanden



Raum 101 grosser Schrank

S9 1 Kantenapparat (opt. Bank).
1 Kymographion mit Heringscher Schleife
1 Schiebertachistoskop für Fernrohrbeobachtg.
A28 1 Holz-Klotz mit Zubehör zum Proj.-Apparat (Spalt, Irisblende etc)
S15 1 Kl. Tisch auf Kugelgelenk für binoculare Form
J58 2 Fixationskanonen
1 deformierbarer Würfel (defekt)
S37 2 Tropostereoskop
J48 1 Grammophonuhrwerk
4 Episkotister
Diverse Spiegel
2 Spiegel an Stativstäben
S50 1 Masstab 1 m mit Reitern
J50 1 Schraffierlineal
1 Schiebervorrichtung
A57 2 Wrattonfilter (rot u. grün)
div. farbige Glasfilter
A48, S43 3 einfache Stereoskope
S17 1 Zeissstereoskop
1 Kasten Stereobilder
A39 2 Kasten Zubehör zum Nüancierungsapparat
D34 1 Gedächtnisapparat nach Lippmann-Max. Zeitmessung
S1 1 Kleinkinoaufnahmeapparat Ica (sehr alt).
S55+60 2 Fernrohrlupen f. tachistoskop. Beobachtg.
A25 2 totalreflektierende Prismen
10 Schieber zur Scheinbewegung
2 Rotationsapparate mit Zubehör für räumliche Schattenbewegung
5 Objekthalter
S26 2 planparallele Küvetten, eine defekt
S49 1 Apparat zur Demonstr. von Stäben, Kanten. Diaphragmen betr. Grössenkonstanz
A52 1 Kontrastapparat nach Hess mit farbigen und Graukeilen
A21 1 Zuspiegelungsapparat n. Hering
A45 1 Dreiachsenkreisel
A54 1 Musilscher Kreisel
S7 1 Modell f. Binokulare Abbildung m. Zubehör
S29 1 Brillenkasten
S14 1 Horoptermodell (empir. H.)
S16 1 Lebensrad n. Anschütz
1 Rad mit Fahrradfelge
2 Objektträger m. Feineinstellg.
1 Lippenschlüssel
2 ... 13x18 + 9x12
1 Ein Bankmaßstab 1 mtr
1 Holzrahmen mit Glas-Scheibe
1 ... Apparat

Allgemeines:

J70, J58, J33+J66 6 Schlauchlampen
33 eiserne Stative
J54 2 Gaussche Stative
J1+J91 div Scheeren
1 Vorrichtg. z. ... von Tönen
J36 1 Luftpumpe; 2 ... } im Keller
J43 2 Projektionsapparate (klein)
J84 J48 + J57 10 Schraubzwingen
J72 1
J83 1
J87 1 Heftmaschine
A38, 42 1 grosser Proj. Apparat
J54+48 div.
K3, 13, 17, 18 12 Demonstrationstafeln
1
J97 2 ...
J100 3 Stempel a) „ps. J" (Bücherstempel) b) „ps. J" (Briefstempel) c) „ps. J" mit Adler (Siegel)
F109 1 ... Projektor in Koffer
F104 1 ... mit Kabel
F102 2
B45 1 Zither
B46 1 Harmonium
F93 2 Reißbretter
J121 1 "

Raum 152.

H2 1 Zeitsinnapparat mit Spezialtisch
J35 2 Kopfhalter

Schrank
E5 1 Chronograph n. Chaquet
G28 1 Brille zur Messung der Augenbeweggen.
E7 1 Mikrostetoskop
E2 1 Kardiograph
E3+4+ 3 Sphygmographen
E6! 1 Schlauchstetoskop
B29 1 Kehltonschreiber
1 Exnercylinder (schwarz.weiss)
1 Inversionwürfel
3 Flügelräder(Raumfarbe)
1 Verant (Zeiss)
G66 6 Lampengehäuse mit Fassung für Glimmlampen
6 " " " " 3,5V Lampen
K4 1 Augenmuskelmodell
G57 3 Konkavbrillen
G48 2 totalreflektierende Prismen
1 Doppelprisma
G19 1 Stroboskopapparat z, Projektion
1 Farbenmischapparat z. Projektion
~~1 binokulares Fernrohr~~
A61 1 Farbsinntest nach Stilling -Ishihara
G30 1 Satz Kristallmodelle aus Holz
G2 1 photograph. App. 13 mal 18
G33 1 Hohlspiegel
1 App. z. Dem. d. Scheinbewegg.
2 Rahmen mit je 7 Fäden zum Haploskop.
Unten K21 1 Nachbildapparat
K28 1 Heringscher Farbenkreis
diverse Thermometer
G45 " Kristallpräparate
1 Farbsinntest nach Podestà
K10+11 2 Kontrasttafeln nach Hering
K8 1 Farbsinnprüftafel n. Hering.
G18 2 Linsen (+ u. –)
G64 1 verstellbares Prisma auf Halter
G13 1 Irisblende (defekt)
K12 6 Brillen z. Tiefenwahrnehmung.
J1

Raum 103

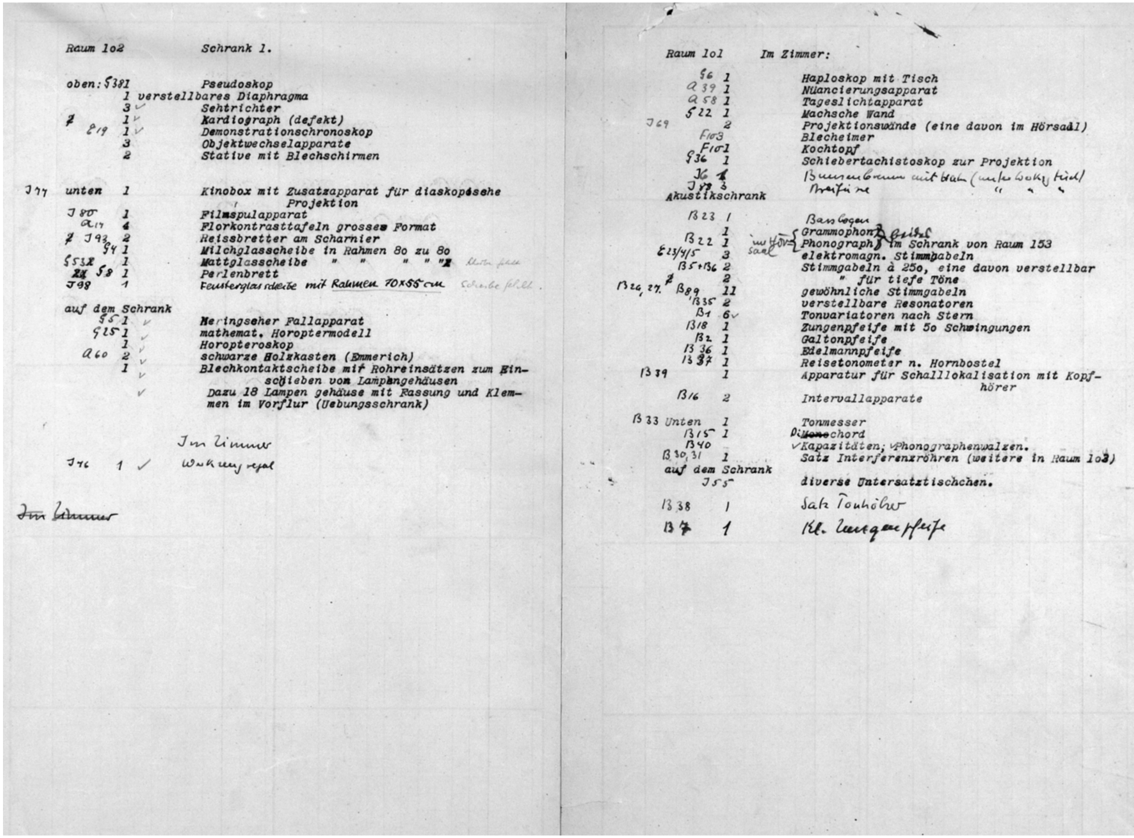
A4 Schrank 3 kleine Motoren (defekt)
A27 1 Flüssigkeitsprisma (leer)
1 A25 Dunkeltonne
1 Dunkelröhre

A55 drauf 1 mit Samt ausgeschlagener Karton mit 3 Fächern
1 Widerstand zu 16 Ohm
B10 unten 8 Resonatoren

im Zimmer
B30/31 2 Kasten Interferenzröhren
B32 1 Gebläsetisch
B34 1 Windlade
G46 1 Fadenperimeter nach Gelb
A44 1 Kontrastapparat
J65 1 Matratze

Raum 104

J73+182 3 Akkumulatoren 2 Volt (die übrigen verbraucht.)
2 " 2 "
J30 3 Aufzeichnungen



Raum 1o2 Schrank 1.

oben:	1	Pseudoskop
	1	verstellbares Diaphragma
	3	Sehtrichter
	1	Kardiograph (defekt)
	1	Demonstrationschronoskop
	3	Objektwechselapparate
	2	Stative mit Blechschirmen
unten	1	Kinobox mit Zusatzapparat für diaskopische Projektion
	1	Filmspulapparat
	4	Florkontrasttafeln grosses Format
	2	Reissbretter am Scharnier
	1	Milchglasscheibe in Rahmen 8o zu 8o
	1	Mattglasscheibe " " " "
	1	Perlenbrett
	1	Fensterglasscheibe mit Rahmen 70x55 cm
auf dem Schrank		
	1	Meringscher Fallapparat
	1	mathemat. Horoptermodell
	1	Horopteroskop
	2	schwarze Holzkasten (Emmerich)
	1	Blechkontaktscheibe mit Rohreinsätzen zum Einschieben vom Lampengehäusen
		Dazu 18 Lampen gehäuse mit Fassung und Klemmen im Vorflur (Uebungsschrank)
		Im Zimmer
	1	Wandregal

Raum 1o1 Im Zimmer:

	1	Haploskop mit Tisch
	1	Nüancierungsapparat
	1	Tageslichtapparat
	1	Machsche Wand
	2	Projektionswände (eine davon im Hörsaal)
		Blecheimer
		Kochtopf
	1	Schiebertachistoskop zur Projektion
Akustikschrank		
	1	Grammophon
	1	Phonograph } im Schrank von Raum 153
	3	elektromagn. Stimmgabeln
	2	Stimmgabeln à 25o, eine davon verstellbar
	2	" für tiefe Töne
	11	gewöhnliche Stimmgabeln
	2	verstellbare Resonatoren
	6	Tonvariatoren nach Stern
	1	Zungenpfeife mit 5o Schwingungen
	1	Galtonpfeife
	1	Edelmannpfeife
	1	Reisetonometer n. Hornbostel
	1	Apparatur für Schalllokalisation mit Kopfhörer
	2	Intervallapparate
Unten	1	Tonmesser
	1	Dichord
		Kapazitäten; Phonographenwalzen.
	1	Satz Interferenzröhren (weitere in Raum 1o3)
auf dem Schrank		diverse Untersatztischchen.
	1	Satz Tonhölzer
	1	Kl. Zungenpfeife

5.

Lfd. Nr.	Stückzahl	Gegenstand	Bemerkungen
			leicht verschmutzbarem Karton, war wohl rasch verbrauch
C 15	1	Druckregler (Schultze)	war seinerzeit (Vor Schumann) mit Fragezeichen versehen und durchgestrichen worden; ist wohl seinerzeit als unbrauchbar geworden gestrichen worden.
C 26	2	Stoppuhren	war laut Notiz Gelb als defekt und ersetzt vermerkt.
F 4	2	Aesthesiometer n. Ebbinghaus	war seinerzeit mit Fragezei chen versehen worden, statt zwei eins; 1 war notiert als verkauft ans Hirnverletzten-institut, ist aber wieder zurückgegeben, Vermerk gestrichen; beide vorhanden.

G 23a	1	Ruhehaploskop dazu	im Inventar stenographiert; vorhanden.
J 59	1o	Fixordner	wurden als verbraucht bezeichnet und gestrichen, sind im Gebrauch der Biblio thek des psychologischen u. philosophischen Seminars.

Eine Reihe von Apparaten, von Herrn Wingenbach hergestellt, waren nicht ins Inventar besonders aufgenommen worden. Wir haben, um genaue Uebersicht zu haben, nun ein Schrankinventarverzeichni sämtlicher Apparate angelegt, bei dem links die Inventarnummer des Inventars verzeichnet worden ist.

Prof. Dr. M. Wertheimer
Assistent Dr. W. Metzger
" Dr. E. Levy.

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