Ardi Roelofs

The Discovery of Mind: From Wundt to Neuroimaging

RADBOUD UNIVERSITY PRESS

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Published by RADBOUD UNIVERSITY PRESS
Postbus 9100, 6500 HA Nijmegen, The Netherlands
www.radbouduniversitypress.nl | www.ru.nl/radbouduniversitypress
radbouduniversitypress@ru.nl

Design: Textcetera
Print and distribution: Pumbo.nl

ISBN: 9789493296794
DOI: 10.54195/RAWG9704

Free download at: www.radbouduniversitypress.nl

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To Herman and Pim,
my teachers regarding history

Preface

This short monograph is a brainchild of 16 years of teaching the Theoretical Psychology course at Radboud University in Nijmegen, taken by approximately 6,500 students. The course focused on the empirical research and psychological theorizing that has been done in scientific societies and universities over the past 200 years, since the philosophical armchair was replaced by the laboratory. The course gave me an alibi to delve into the history of psychology and related fields and to read many original books, articles, manuscripts, letters, and handwritten notes from pioneers. I discovered that, surprisingly, the work of one of the founders of scientific psychology, Wilhelm Wundt, has been largely forgotten, despite its relevance to contemporary psychology. This book is intended to tell the story of the scientific discovery of the mind, recognizing Wundt's groundbreaking work. I synthesize crucial evidence from past behavioral and patient studies to recent neuroimaging to support an integrated account of key aspects of the human mind.

The year 2024 marks the 200th publication anniversary of Pierre Flourens' *Recherches Expérimentales sur les Propriétés et les Fonctions du Système Nerveux, dans les Animaux Vertébrés* and the 150th of Carl Wernicke's *Der aphasische Symptomencomplex: Eine psychologische Studie auf anatomischer Basis* and Wundt's *Grundzüge der physiologischen Psychologie*, which historian Edwin Boring (1950) called "the most important book in the history of modern psychology" (p. 322). Wundt's book is the vantage point for my story about the scientific discovery of the mind. My book's cover shows part of Wundt's diagram of the mind on a pixel array used to create neuroimages.

The book is gratefully dedicated to Pim Levelt and Herman Kolk, who wrote their own history books (Kolk, 1994; Levelt, 2013) and were mentors throughout my career. In 2008 I took over the History of Psychology course from Herman, in which I had once been a student, and which I transformed into Theoretical Psychology. Pim made me aware of the three handshakes between Wundt, Michotte, himself, and me, and much more.

Over the years I have received feedback from students and colleagues about my account of the history of psychology and theoretical view of the mind. The book was written in the inspiring environment of the Centre for Cognition of the Donders Institute for Brain, Cognition and Behaviour in Nijmegen. Irina Chupina, Pim Levelt, Herman Kolk, and two anonymous reviewers read the entire draft manuscript and

provided comments. All this has improved my exposition in the book, for which I am very grateful to everyone. I thank my wife Jantine for her encouragement and continued support, and for sitting through all my anecdotes, fun facts, and stories from the book at our breakfast and dinner table.

Ardi Roelofs,
Cuijk,
March 18, 2024

Prologue

This book briefly describes the history of the scientific discovery of the mind. Although people have speculated about the nature and functioning of their minds for thousands of years, it was only about 200 years ago that they began to investigate the mind scientifically. In this book, I describe the most important empirical and theoretical discoveries that have been made and where we are today in understanding the mind.

In their critically acclaimed book *The Organisation of Mind*, published in 2011, Tim Shallice and Richard Cooper stated: "Sixty years ago, virtually nothing scientific was known about the general organisation of the mind" (p. 2). According to them, "It was in the period 1950-70 that the first major developments occurred" (p. 4). But as I make clear in this book, Shallice and Cooper were wrong by 150 years. They mistook a revival for the beginning.

The scientific study of basic abilities of the mind, such as perception, movement, attention, learning, memory, language, thinking, emotion, and motivation, is called *cognitive psychology*, which is the backbone of psychology. Other branches of psychology, like clinical, developmental, and social psychology, and larger disciplines like *cognitive science* and *cognitive neuroscience* draw on methods and insights from cognitive psychology. Ulric Neisser, who coined the term in his book *Cognitive Psychology* in 1967, discussed visual and auditory perception, attention, memory, and thinking with regard to the adult rather than the developing or disordered mind. However, cognitive psychology has not begun in the 1960s. Rather, Neisser's book aimed to present an alternative to behaviorism, which dominated American psychology in the first half of the 20th century and repressed an older cognitive psychology that began with Wilhelm Wundt (1832-1920) in the second half of the 19th century.

Figure P.1. Wundt's house in Großbothen, where he completed his memoirs and passed away.

When 88-year-old Wundt dictated the last words of his memoirs to his daughter Eleonore in his country house in Großbothen near Leipzig, a week before his death in 1920, he could look back on a successful life. Half a century earlier, he had laid the foundation for psychology as a scientific discipline, with its own place in the university curriculum, its own laboratories, and its own journals. Together with his 188 doctoral students in Leipzig, he had made important scientific discoveries and developed a comprehensive theory of the human mind. His students had initiated application areas such as clinical psychology and psychological testing and founded new journals such as *Science*. His work was nominated three times for a Nobel Prize. But after his death, Wundt and his work were quickly forgotten, and he came to be seen as an "icon of a dead and failed past", as noted by Blumenthal (2001, p. 142), who went to great lengths to rehabilitate Wundt (e.g., Blumenthal, 1975, 1976). When many of Wundt's findings were rediscovered after World War II, they were associated with the names of the rediscoverers and not with Wundt. His theory has also been redrafted by others, without knowledge of Wundt's original proposal. What is now called cognitive neuroscience includes the field of science at the intersection of physiology and psychology that Wundt proclaimed the birth of 150 years ago, but in which Wundt's name is rarely mentioned.

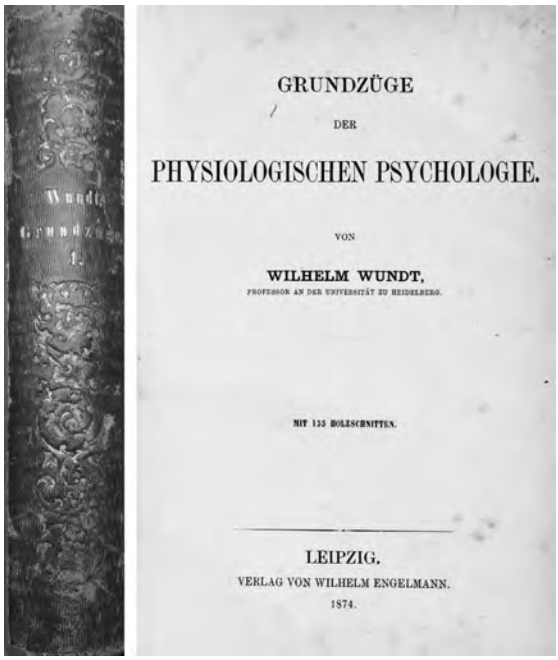

Figure P.2. Spine and title page of (the author's copy of) the first edition (1874) of Wundt's *Grundzüge*.

In the preface to the first edition of his book *Grundzüge der physiologischen Psychologie* (*Principles of Physiological Psychology*), which appeared in 1874, Wundt stated:

> The work that I am hereby making available to the public attempts to define a new area of science. … In some cases, even the anatomical-physiological foundations of the discipline being studied here are not at all certain, and the experimental treatment of psychological questions is still in its early stages. (p. iii)

In my book, I discuss major empirical discoveries that have been made, and theory building that took place, in the few decades before and in the 150 years after the publication of Wundt's 1874 book, with special emphasis on his work. Compared to previous philosophical speculations about the mind, the new scientific theories were better supported by empirical findings and made new predictions that could be empirically tested and possibly refuted. Theoretical issues were resolved in cycles of empirical research, which is the hallmark of the *scientific method*. The scientific method and ways of discovery are described, for example, in Popper's (1959) *The Logic of Scientific Discovery*, Simon's (1977) *Models of Discovery and Other Topics in the Methods of Science*, and Wundt's (1880a, 1883) *Logik: Eine Untersuchung*

der Principien der Erkenntniss und der Methoden wissenschaftlicher Forschung (*Logic: An Examination of the Principles of Knowledge and the Methods of Scientific Research*). In a world of uncertainty, superstition, and pseudoscience, the scientific method is the most reliable "candle in the dark" (Sagan, 1997). Importantly, researchers started doing experiments. As Spearman (1923) stated: "The great modern point of vantage is the experimental procedure, long the chief tool of the physical sciences, and now last brought by Weber, Fechner, and Wundt – in rising order of genius – to the aid of mental science also" (p. 34). Replication and extension of empirical findings and the incremental development of theories led to cumulative advances in understanding the mind. The emphasis in my book is on developments in areas central to contemporary cognitive psychology and which were main interests of Wundt and his students, namely the organization of the mind, attentional control, consciousness, and intelligence. Along the way, fundamental mental functions such as perception, movement, attention, learning, memory, language, thinking, emotion, and motivation are discussed.

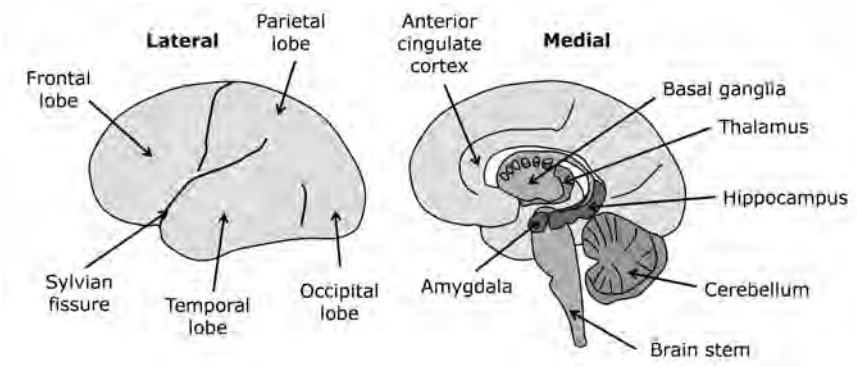

Figure P.3. Lateral and medial views of the human brain, the biological organ of mind, showing the major lobes of the cerebral cortex, the anterior cingulate cortex (part of the frontal lobe), basal ganglia, thalamus, hippocampus, amygdala, cerebellum, and brain stem. A fifth lobe, the insular cortex, is folded deeply into the Sylvian fissure and is not visible from the side. The named parts of the brain are the most relevant ones for this book.

When discussing mental functions, I often make reference to the human brain, the biological organ of mind (Figure P.3). Over the past 200 years, all major theories have been *materialist*, assuming that the mind is what the brain does, in contrast to *dualistic* theories that have dominated the past, such as Descartes' (1664). Dualist theories assume that the mind and brain are fundamentally different substances

(e.g., Berrios, 2018). Materialism does not imply that the mind is explicable purely in physiological terms. Instead, a dominant view today is that the mind should be characterized in functional terms (e.g., Dennett, 1981, 2023). Yet evidence from brain anatomy and physiology can be used to constrain and clarify theories in functional terms, as argued by Wundt.

When Wundt used the term 'physiological' in the title of his *Grundzüge* in 1874, the intention was clear to his contemporaries, namely to designate an empirical, experimental psychology as an independent scientific discipline rather than as a branch of speculative philosophy, as psychology had been for thousands of years. According to Wundt, physiological psychology wants to utilize physiology as an auxiliary discipline to psychology. In the following decades, however, the adjective 'physiological' took on a different meaning, namely reducing psychology to physiology, as, for example, Sigmund Exner (1846-1926) attempted to do in his *Entwurf zu einer physiologischen Erklärung der psychischen Erscheinungen* (*Design for a Physiological Explanation of Psychological Phenomena*) in 1894. Therefore, in the fifth edition of the *Grundzüge* published in 1902, Wundt clarified his use of the term 'physiological'. He stated that physiological psychology is "primarily psychology ... It is neither a branch of physiology nor, as has been misleadingly claimed, does it seek to derive or explain the psychological phenomena from the physical phenomena of life" (p. 2). Instead, the name 'physiological psychology' indicates two objectives:

> Insofar as physiological psychology is based on physiology in the development of experimental methods, it is *experimental psychology* ... Of the two missions thus indicated in the name of physiological psychology, the *methodological* one, which points to the *use of experiments*, and the *complementary* one, which points to the *physical foundations of mental life*, the first is the more essential for psychology itself. (pp. 3-4)

In line with the Wundtian neurocognitive goal of linking cognitive functioning to structures and processes of the brain, Marr (1982) argued that a complete understanding of cognitive processes requires that they be characterized at three levels. A theory should describe what the mental processes aim to achieve, how the processes are functionally organized, and how the functions are implemented in the brain.

While behavioral measurements in healthy participants and lesion-deficit analyses in patients with brain damage have informed theorizing about the mind since the early days of scientific psychology, the range of techniques has expanded considerably since World War II (e.g., Raichle, 1998). From then on, researchers not only conducted behavioral and patient studies but also began to make use of neurophysiological methods. These methods were designed to measure brain *function*

(which was considered a reflection of the mind) rather than structure (i.e., neuroanatomy). Electroencephalography (EEG) was already used in the 1940s and 1950s (Schirmann, 2014) and became an important research tool in the study of mental processes from the 1960s (e.g., Coles, 1989; Meyer et al., 1988). Furthermore, the arsenal of physiological techniques has been expanded even more since the 1980s to include magnetoencephalography (MEG) and hemodynamic methods. EEG measures the brain's electrical activity from outside the skull and MEG records magnetic activity, which has been used since the 1990s. Hemodynamic methods include positron emission tomography (PET), used since the 1980s, and functional magnetic resonance imaging (fMRI), since the 1990s. PET uses radioactive tracer to measure local blood flow, energy metabolism, or specific neurotransmitters. The fMRI method measures the blood oxygen-level-dependent (BOLD) response which reflects local ratios of oxyhemoglobin versus deoxyhemoglobin, indexing neuronal activity.

The spatial resolution of the hemodynamic methods is good (typically a few millimeters in fMRI), but the temporal resolution is limited (a few seconds in fMRI and about 40 seconds in PET). Conversely, the temporal resolution of electrophysiological methods is good (a few milliseconds), but the spatial resolution is limited (several centimeters in MEG and more in EEG). In addition to the functional methods, *structural* methods create images of brain anatomy. For this purpose, computed tomography (CT) uses X-rays (Röntgen) and MRI uses strong magnetic field gradients and radio waves. While for a long time, the 3D course of fiber tracts could only be determined by postmortem microdissection, nowadays, diffusion tensor imaging (DTI) in combination with tractography software can be used in the living brain. DTI measures the movement of water molecules along axons. These functional and structural techniques are collectively called *neuroimaging* (e.g., Banich & Compton, 2023; Gazzaniga et al., 2018; Op de Beeck & Nakatani, 2019). Modern neuroimaging can be seen as an extension of the methods of 19th-century physiological psychology, which aimed to investigate the causal mechanisms of mind and brain.

However, some people have argued that functional neuroimaging results do not show causal involvement but only correlation. For example, R. Sternberg (2005) stated, "Biological approaches seem to have a certain attraction for suggesting a causal mechanism … But they really are not attractive, because the existing data are all correlational" (p. 243). However, the idea that functional neuroimaging studies do not demonstrate causal involvement is incorrect (e.g., Weber & Thompson-Schill, 2010). This is because these studies typically use experimental manipulation, which is the gold standard for testing causal involvement. As Woodworth (1938) put it, "The experimentalist's independent variable is antecedent to his dependent variable; one is cause (or part of the cause) and the other effect" (p. 3). What neuroimaging

methods such as fMRI, PET, and MEG cannot show is whether an area or process is necessary, which can only be demonstrated in patient studies (with patients in the acute phase) or by using brain stimulation methods. These methods include direct electrical stimulation (DES) during awake brain surgery in patients and transcranial magnetic stimulation (TMS) applied noninvasively through the skull to the brains of healthy participants.

Empirical research forms the basis for theory development. Today, theory building uses not only diagrams or mathematical formulas, as theorists did in Wundt's time, but also computational modeling. A computer model represents a concrete implementation of a proposed theory that can be rigorously tested to assess whether its assumptions are necessary and sufficient to explain the observed data. For example, while Wundt (1903) *qualitatively* examined frequency distributions of reaction times to evaluate his theory of attention, such distributions can be derived mathematically or approximated stochastically in computer simulations, and it can be statistically determined whether they correspond *quantitatively* to the empirically observed distributions (e.g., San José et al., 2021). While Wernicke (1874) explained aphasia syndromes resulting from brain damage by showing that they can be informally "computed according to the laws of combination" (p. 69) using a diagram, both the symptoms and the amount of damage in different brain areas can be inferred quantitatively for large numbers of individual patients in modern computer models (e.g., Roelofs, 2023a). It should be noted that to be useful, models must simplify reality. Illustrating the necessity of simplification, Borges (1964) described cartographers who constructed a map as large and detailed as the land itself, capturing most of reality but being completely useless. In his seminal *Beiträge zur Theorie der Sinneswahrnehmung* (*Contributions to the Theory of Sense Perception*), Wundt (1862a) emphasized the importance of mathematical tools for psychology. He stated: "Where in a science a large number of facts can be derived from a few axioms through a series of more or less complicated inferences, without the simple procedures of formal logic being sufficient for this derivation, then science is forced to use mathematical symbol language" (p. xix). Such symbol language is at the heart of modern computational modeling.

The goal of my book is threefold. First, I want to describe some of the most important discoveries about the mind over the past 200 years, showing that the first major developments took place in the first half of the 19th century and making it clear that much was known about the general organization of the mind well before the mid-20th century, contrary to what Shallice and Cooper (2011) claimed. Shallice and Cooper are not alone in suggesting that the scientific discovery of the mind began after World War II. In his book *Attention in a Social World* (2012), Michael Posner stated:

> The idea of neural networks as the basic units underlying thought goes back to the work of the Canadian neuropsychologist D. O. Hebb and his 1949 book *The Organization of Behavior*. … In Hebb's time, the idea of a network (cell assembly or phase sequence) was a rather vague verbal abstraction that did not allow for models that could produce specific predictions. (pp. 2-3)

However, several of Hebb's ideas about cell assemblies can already be found in Exner's *Entwurf* from 1894 and his other publications (e.g., Verstraten et al., 2015). Furthermore, in 1874, Wernicke published his epoch-making network model of word production and comprehension, and their breakdown in aphasia, which provided testable predictions. Wernicke's view foreshadowed modern ideas about multiregional cell assemblies (Gage & Hickok, 2005). Similarly, Wundt had put forward a network model of attentional control in the various editions of the *Grundzüge*, also a precursor of modern ideas (Roelofs, 2021). Neither Hebb nor Posner referred to the work of Exner, Wernicke, and Wundt.

Second, I want to show that the physiological approach proposed by Wundt in his *Grundzüge* of 1874 has been and continues to be fruitful (e.g., Dehaene, 2023; Peelen & Downing, 2023). That is, physiological methods can be used to illuminate the mind, contrary to the claims of skeptical voices in contemporary psychology who have argued against neuroimaging as a means of studying the mind in principle or in practice (e.g., Coltheart, 2006, 2013; Page, 2006; Pereira, 2017; Uttal, 2001; Van Orden & Paap, 1997). Knowing the mind's functional neuroanatomy is considered useful, contrary to what Fodor (1999) wrote: "If the mind happens in space at all, it happens somewhere north of the neck. What exactly turns on knowing how far north?" (p. 3). I make clear that knowing the spatial coordinates of mental processes can contribute to their understanding.

Third, I want to demonstrate the feasibility of an integrative theoretical account. Recently, Beller and Bender (2017) argued that theory is "the final frontier" in psychology. Their analyses of all 2,046 articles in *Frontiers of Psychology* in 2015 showed "references to a specific (named) theory in less than 10% of the sample and references to any of even the most frequently mentioned theories in less than 0.5% of the sample" (p. 1). From these and other analyses, it becomes clear that psychology considers empirical findings more important than theory. In contrast to this practice, I argue for a strong role of theory development and testing of alternative theories. Data cannot live without theory. As Gigerenzer (1998) wrote:

> Several years ago, I spent a day and a night in a library reading through issues of the *Journal of Experimental Psychology* from the 1920s and 1930s. This was professionally

> a most depressing experience. ...What depressed me was that almost all of this work is forgotten; it does not seem to have left a trace in the collective memory of our profession. It struck me that most of it involved collecting data without substantive theory. Data without theory are like a baby without a parent: their life expectancy is low. (p. 202)

In *The Modularity of Mind*, Fodor (1983) suggested that only perceptual and motor systems can be scientifically understood, while central systems are beyond reach. Against this claim, I show that central abilities of the mind, such as attentional control, consciousness, and intelligence, can be understood theoretically and that an integrative explanation is possible.

In the introduction to his book on attention, Posner (2012) stated: "The present volume is largely a personal statement. It does not seek to review all studies or controversies in the field, but rather to lay out ... one [i.e., his] approach to understanding the attention system of the human brain" (p. *xix*). Similarly, John Duncan's *How Intelligence Happens* (2010) is a personal account of what intelligence is and how it is underpinned by the brain. Likewise, in this monograph, I do not intend to provide a comprehensive overview of the history of psychology, but only a selection of crucial discoveries and insights, and a demonstration that an integrated account is possible. I also regularly refer to research done by myself or with colleagues because it is relevant as well as to demonstrate my credentials to write about these topics. In *A History of Modern Experimental Psychology* (2007), George Mandler wrote, "I avoid anything as recent as the last two decades – and it will be some time before a history of this period can be written from a more objective point of view" (pp. 225-226). Mandler's book, therefore, does not describe the modern advances in neuroimaging that illuminated the mind. Now, 20 years later, my book addresses these modern developments.

There are different approaches to historical description (e.g., Donnelly & Norton, 2021). For example, Benjamin (2007, 2024) described how academic psychology emerged and became professionally organized, especially in the US, and how areas of application became established. Mandler (2007) focused more on psychological ideas and the social and political conditions under which they were developed, and Danziger (1990) described the development of psychological methods in their historical context. In my book, I describe the history of the empirical and theoretical discoveries that led to what we know today about the mind, the debates that arose from them, and the different approaches. Decisions about which facts and events to include in the book were based on their relevance to the history of discoveries that led to our current understanding of the mind.

In my historical research, I have used primary sources (i.e., original books, articles, manuscripts, letters, and handwritten notes of pioneers) as much as possible. All translations from German and French were done by myself unless otherwise stated. The original texts can be found in the Open Science Foundation folder for my book at https://osf.io/57za4/.

With a fresh look at historical sources, I explain what has been discovered about how the mind is organized, how it controls itself, what consciousness is, how intelligence arises, and how the mind can deteriorate due to harm, such as stroke and neurodegeneration. In these areas, I also explain what the main modern neuroimaging techniques have taught us about the mind so far. Along the way, I wake up a number of "sleeping beauties", as Levelt (2015) called forgotten discoveries. My story also includes some key characters missing from other books on the history of psychology (e.g., Benjamin, 2007, 2024; Brysbaert & Rastle, 2009; Goodwin, 2011; Leahey, 2017; Mandler, 2007), such as Charles Spearman and Carl Wernicke, or whose work is not substantively discussed, such as Wundt. Boring (1950) described the work of Wundt and Spearman, but not Wernicke. I have economized on names, by often repeating names where other names could have been mentioned. Despite that, there are still a lot of names in the book. There is no index of names and subjects because, in the electronic version of the book, any desired word can be searched for using the standard search function.

Before the 19th century, investigators had explored and described the boundaries of the mind. They moved inland about 200 years ago from different starting points, and their reports on what they discovered were largely in agreement, I argue. In this book, four expeditions and their discoveries are described in each of four chapters, followed by a fifth chapter with an integrated account of key aspects of the human mind.