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Received 27 February 2014
accepted 09 March 2014

THE LANGUAGE OF VISUAL REPRESENTATIONS IN THE NEUROSCIENCES – RELATING PAST AND FUTURE

Abstract

In theoretical accounts of the neurosciences, investigative research programs have often been separated into the morphological and physiological tradition. The *morphological tradition* is seen as describing the structure and form of the external and interior parts of the brain and spinal cord. The *physiological tradition* is interpreted as a compilation of those approaches which investigate cerebral functions particularly in their dynamic interactions. It must be regarded as an open question, though, whether the distinction between the morphological and physiological tradition in modern clinical and basic neuroscience has now become obsolete with the most recent neuroimaging techniques, such as fMRI, PET scans, SPECT, etc. Taken at face value, these new imaging techniques seem to relate, overlap, and even identify the anatomical with the functional substrate, when mapping individual patterns of neural activity across the visually delineated morphological structures. The particular focus of this review article is primarily on the morphological tradition, beginning with German neuroanatomist Samuel Thomas Soemmerring and leading to recent approaches in the neurohistological work of neuroscience centres in the United States and morphophysiological neuroimaging techniques in Canada. Following some landmark research steps in neuroanatomy detailed in the first section, this article analyzes the changing trajectories to an integrative theory of the brain in its second section. An examination of the relationship between form and function within the material culture of neuroscience in the third and final part, will further reveal an astonishingly heterogeneous investigative and conceptual terrain.

Keywords

• Korbinian Brodmann (1868-1918) • Epistemology • Franz Joseph Gall (1758-1928) • History of Neuroscience • Language • Objectivity • Neuroimaging • Neuroscientific Research • Phrenology • Samuel Thomas von Soemmerring (1755-1830)

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Introduction

A central point of contention in the modern neurosciences regards the specific contributions that the most recent neuroimaging techniques have made to the study of the relationship between the neuroanatomical sphere of the *brain* and the psychophysiological sphere of the *mind* [1]. The subject has emerged as a major discursive topic when viewed from philosophical, historical, as well as cultural perspectives [2]. This article is of a theoretical nature and grew out of prolonged discussions with neuroimagers, clinicians, basic scientists, historians, and philosophers of science [3,4], and awareness that corresponding views about the “material culture” of the neurosciences have also been voiced from an angle of the history of neurophysiology. Historians of science, Michael Hagner (Zurich) and Cornelius Borck (Luebeck) for example, have scrutinized the development of the electroencephalogram by German

psychiatrist Hans Berger (1873-1941) at the University of Jena, along with the confluence of research directions in the applied cybernetics fields in neurophysiology during the 1930s and 1940s [5].

From such preceding investigations emerged the idea for this article, which aims at aligning and contrasting certain features of the “material culture” [6] of the neurosciences as these emanate from the structure-function dichotomy that has become so central to the language of modern visual representations in this field [7]. In fact, modern neuroscientific work lacking electron microscopes, high-throughput gene sequencing, or functional magnetic tomography would hardly be possible without the apparatuses and instruments – that also embody the conceptual and research assumptions, which the clinical and laboratory workers apply and put to test [8]. It is by no means clear – and needs to be further clarified in the ongoing neuroscientific discussions –

that what seems to hold for the physiological approaches on the one side also holds for the morphological approaches on the other side and *vice versa* – a reciprocal relationship that shall be explored further in this article [9]. With respect to the theory and methodology of the neurosciences, it appears most suitable to explore some of the historical developments in the first part of the article before critically assessing examples from the status quo in its second part. The third part of the article, in the following, aims at assessing the development of interactions between basic and clinical neuroscience approaches which investigate brain structure, function, and disease. Likewise, an explanation shall be attempted as to how such knowledge is translated into societal applications including new neurological and psychiatric therapies [10]. In this respect, the present article presents itself as an investigation of what happens both in actual neuroscientific research groups, along with the

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discussions in the field of neuroaesthetics [11]. While pursuing these historical explorations of the material culture of neuroscience, also draws on earlier observations made by the MIT philosopher Hilary Putnam [12] and the Harvard historian of science Peter Galison [13]. As will be argued further below, what appears to be obvious in the case of the *physiological tradition* (~“language”) likewise holds for the *morphological tradition* (~“visual representations”) in modern neuroscience [14]. It can be viewed as an open question, however, whether the distinction between the morphological and physiological traditions places the emphasis on either one side of the structural and the functional distinction of the language and representation dichotomy [15]. Recent public and scientific discussions over issues of *neuromythology* and *neophrenology* thereby invite a reconsideration of the landmark methodologies from a history of neuroscience perspective [16].

A major incentive for this study of the visual approaches in the history of neuroscience comes from the observation that, at least since the last decades of the 20th century, earlier developments toward an interdisciplinary understanding of neuroscience, the emergence of specialized neuroscientific imaging centers, and the predominance of international exchanges were becoming central to the modern neuroscientific enterprise, as is described, for example, in the historical accounts of late Los Angeles neuroscientist Horrace Winchell Magoun (1907-1991) [17]. While traditional accounts have often looked at the history of neuroscience from rather regional perspectives, the interest of this article sides with the bigger picture and the astounding developments, which carved out some of the foundations of the emerging field of “neuroscience,” since its inception in the Neuroscience Research Program of Francis O. Schmitt (1903-1995) at MIT in Cambridge, Massachusetts. Moreover, some of these early foundations of neuroscience can also be found in histories of neuroscientific and neuroimaging research [18]. Several such theoretical questions about the formation of interdisciplinary endeavours in the modern neurosciences [19] will make their way into this paper as well,

particularly when the intricate relationships between the language of neuroscience and its visual representations are addressed from a historical vantage point. So, again, this is hence not a neuroscience article in the narrow sense of the term, nor is it an attempt to advance a specific neurophilosophical thesis; rather, it proposes a historically informed perspective on research practice and representational theories in modern neuroscience [20]. I want to side here – for the sake of the argument – with 19th-century historian Leopold von Ranke (1795-1886) and raise the question of “what actually happened” [21], in order to get a sense of what the history of neuroscience might offer for a more adequate understanding of the emergence of the modern “*visual brain*” [22]. I am thus interested in finding out what concepts have remained similar to those of our forefathers and foremothers in the neurosciences, and which may have then unconsciously crept by themselves into modern-day practices and methodologies. These historical antecedents could give them direction and led to the reiteration of previous answers, which are not actually as revolutionary as we would hope neuroscience’s approaches to be [23].

The approach of the current article is, first, to venture into several theoretical fields concerning the interrelation of neuroimaging methodologies and research outcomes [24]. Second, I want to take a comparative look at modern developments in the visual representation of structural-functional relationships.

For the sake of the argument, I will not go further back than the 18th century. As my chosen period, that is extensive enough to get a sufficiently deep appreciation for the historical perspective on the language of visual representations in the neurosciences [25]. The long-term trend, which has continued from the works of German-Austrian phrenologist Franz Joseph Gall (1758-1928) through German neuroanatomist Samuel Thomas von Soemmerring (1755-1830) [26] and up to the appearance of modern neophrenological approaches in North America, will be thematized by providing some case examples from the history of the neurosciences. Relating

the past to the future in the latter part of this article, I hope to also stimulate a discussion about the meaning and the function of neuroscientific interdisciplinarity [27]. It is my view that the journal of “Translational Neuroscience” is a particularly worthwhile venue because of its wide readership among European neuroscientists, psychiatrists, and behavioural scientists.

The material culture of the modern neurosciences

“In 1964, some of the world’s leading experimental physicists gathered in Karlsruhe, West Germany, to discuss the radical changes then underway in their profession. ... Lew Kowarski [1907-1979], an experimental physicist from the major European particle accelerator, CERN [Centre européenne pour la recherche nucléaire], waxed enthusiastic about these changes, extolling the virtues of assembling millions of pictures and tackling them with automatic techniques. The audience was stunned. One physicist ... confessed how ‘frightened’ he was to hear that ‘*in a few years [...] one would not go to start a new experiment, but one would just go into the archives, get a few magnetic tapes ... and start to scan the tapes from a new point of view – that would be the experiment!*’ I will argue that laboratory machines can command our attention if they are understood as dense with meaning, not only laden with their direct functions, but also embodying strategies of demonstration, work relationships in the laboratory, and material and symbolic connections to the outside cultures in which these machines have roots. It is by means of such a broader and deeper exploration of tubes, tapes, and tracks that we can get at a material culture of a discipline” [13].

This quotation about developments in 20th-century atomic physics could also be transferred to the current neuroscientific research endeavour, since the interdependence on technology, machines, along with data- and pattern-mining from large-scale data-banks as “experimental archives” has likewise changed the nature of neuroscientific research activities [28]. Philosophical and historical reflections about the material culture of neuroscience

should allow a brief statement here: research in this field can be conveniently classified into the *morphological tradition*, which identifies and characterizes the shapes and structures of the brain's parts, while the *physiological tradition* is preoccupied with recording and observing this organ's operations over periods of time [29]. With the advent of functional imaging, this opposition seemed to have become obsolete, as the new methods often promise to perfectly synthesize the two. However, the new neuroimaging techniques (such as fMRI, SPECT, PET, etc.) have quickly become disparaged as a "new phrenology" [30] that would prioritize cerebral forms of representation over issues of functional integration. The more recent debates thus offer a most adequate opportunity to review major approaches from the history of the neurosciences, while drawing again a comparison to Peter Galison's well-known differentiation between scientific images and theoretical accounts:

"Instead of constructing a theory-dominant account ... the goal here is to demonstrate the deep continuity of experimental practice through an analysis of the instruments [...]. I will follow two competing traditions of instrument making. One tradition has as its goal in the representation of natural processes in all their fullness and complexity [...]. These images are represented, and defended, as mimetic [...]. Because this ideal of representation relies on the mimetic representation of form, I will call it '*homomorphic*' [...]. Against this mimetic tradition, I want to juxtapose what I have called the 'logic tradition,' which has used electronic counters, coupled in electronic logic circuits. These counting (rather than picturing) machines aggregate masses of data to make statistical arguments for the existence of a particle or effect [...]. Because this statistical mode of registration preserves the logic relation among events, I will call it '*homologous*' representation" [13].

Admittedly, the neurosciences were never as clearly divided into specific experimental and theoretical branches, as is the case for physics with its institutional partitioning.

Over long spans of time, nevertheless, shifting advances in the synthesis of brain theory have become discernible in opposing

research strategies [31]. Even an overarching term such as "integration" that served for more than a century as a hallmark of brain theory [32] reveals a surprisingly heterogeneous conceptual space. I thus want to begin my exploration by formulating three basic historical perspectives on the neurosciences which may then function as signposts for my argument.

Philosophical frameworks for brain theories exhibit enormous longevity regardless of the criticisms they provoke

Certainly, most neuroscientists today are aware of French philosopher René Descartes' (1596-1650) 17th-century model of brain functioning [33].

Most researchers agree that his quest for the centre of brain control in the pineal gland raised more questions than it actually answered in the first place, his model running into severe troubles ever since it emerged (Figure 1). Nevertheless, Descartes' radical differentiation between matter and mind, i.e. between the

physical world (*res extensa*) and the mind (*res cogitans*), has proven incredibly problematic to overcome, even though most neuroscientists today would probably accept that Cartesian dualism is better understood as a strategy for highlighting problems than to giving answers to them. However, these deliberations belong more to the problem field of the philosophy of mind [34].

Similarly, if we take Franz Joseph Gall's 18th-century *organology* or *phrenology* theory (Figure 2), which is frequently interpreted as an "embarrassing" starting point for cerebral localizationism [35], it is easy to ridicule his idea of reading personality traits and mental faculties from the skull when his program is not interpreted appropriately and thus not sufficiently historicized (as I have argued on other occasions) [36,37]. Gall's research program, moreover, supposed a strict correspondence between cerebral activity and mental or psychic phenomena.

Since then, it has proven methodologically invaluable to the progress of modern neuroscience and continued to guide research towards the search for cortical representations

Table 1.

Visual Tradition: mimetically representative and homomorphic	Language Tradition: symbolically representative and homologous
Physics: particle research in bubble chamber	Physics: stochastic interpretation of fusion or chain reactions
Neuroscience: morphological tradition (structure & connectivity)	Neuroscience: physiological tradition (function & development)

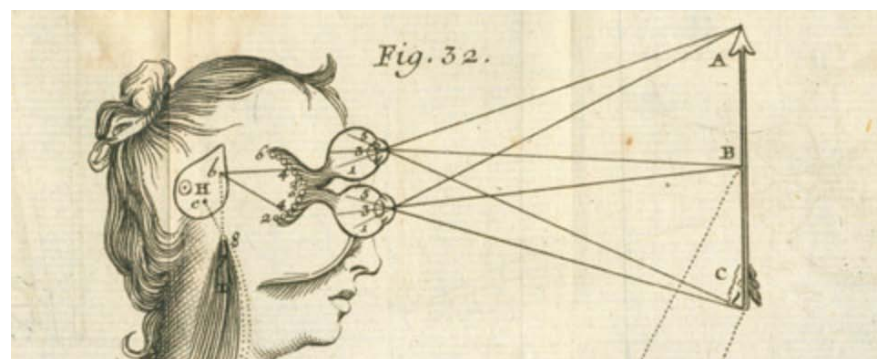


Figure 1. René Descartes' representation of how the visual nervous system perceives external objects. Image taken from: Descartes R., *L'Homme*, Paris, Charles Angot, 1664, fig. 32, n.pag. (Courtesy of the Mackie Family Collection of the History of Neuroscience, University of Calgary, Alberta, Canada).

Along this historical development of increasing complexity of the brain, the solution to the “riddle of consciousness” and to “free will” has, indeed, always been “just around the corner”, “just beyond the reach” of present-day instruments and available scientific data, yet theoretically assumed to be on the horizon. Based on this perspective, one could argue that neuroscientists have good reason to believe that this unresolved situation will continue for the time being.

This could well be the case, but a more powerful argument needs to be crafted here from the very productivity of the neurosciences themselves. Based on the productivity of brain research, the dynamic of a shifting frontier may simply continue, as suggested by the examples above. Tens of thousands of neuroscientists literally work on “making the brain more complicated” – consider the meetings with up to 40,000 researchers and scholars at the Society for Neuroscience – [52], because by doing so they advance their training, research, and academic careers. Scientific innovation is not mere rhetoric of the day, as it transcends boundaries by moving the neurosciences away from earlier solutions to ever more elaborate research questions: “Clinical payoffs from basic research, and progress in fundamental knowledge of brain mechanisms, suggested that neuroscience was reaching a watershed [in the late 1950s] and that a revolution was already underway in prevention and treatment of disorders such as schizophrenia, manic-depressive psychosis, multiple sclerosis, stroke, mental retardation, and many other genetic and developmental disorders of the nervous system. Perhaps, even more importantly, neuroscience offered hope that a better understanding of the biological roots of human nature would enhance prospects for well-being, social welfare, and even the survival of human life on this planet” [53].

A comparison to the field of molecular biology shall be allowed here for illustrating our point further [54]: When the Human Genome Project was about to come to an end, some academics and teachers assembled an online collection of key publications from the history of molecular biology, including the groundbreaking article by James D. Watson (b. 1928)

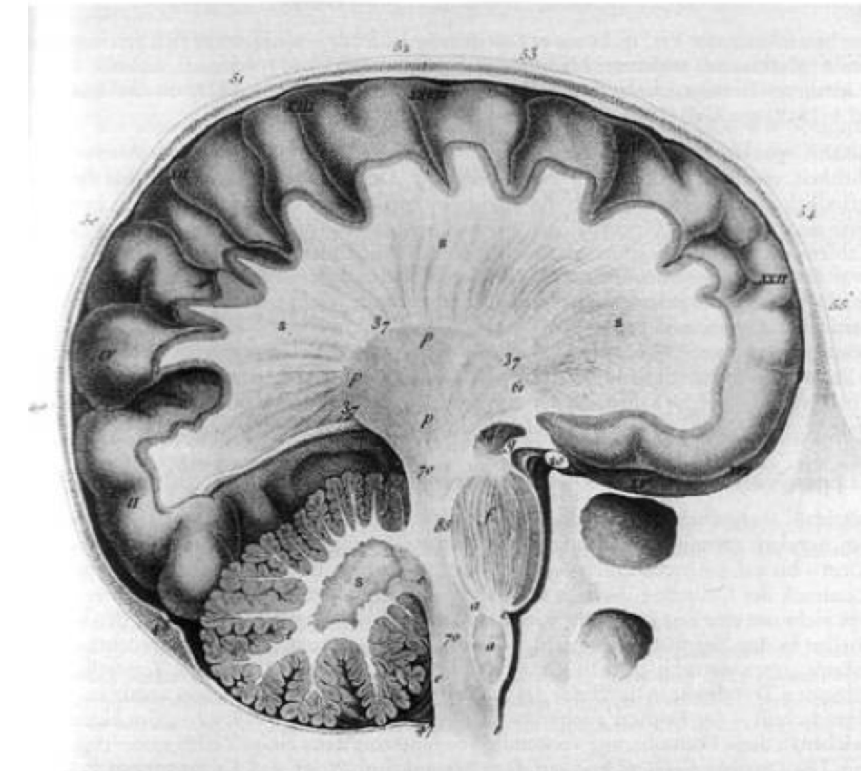


Figure 3. Representation of the medial part of the brain – showing the brainstem, cerebellum, and the thalamus with all the thalamocortical tracts in a gross anatomical fibre preparation form. This lithograph is taken from Soemmerring, S. T., *Ueber das Organ der Seele*, Koenigsberg, Friedrich Nicolosius, 1796, fig. 1, n.pag.

and Francis H. C. Crick (1916-2004) about the supposed structure of DNA [55]. With only the best intentions, they formulated the respective introduction to their online collection: “The year 1953 could be said to mark – in biology at least – the end of history” [56]. Certainly, the publication of the full gene sequence of the human genome marked a historical break, but neither the Watson and Crick paper, nor the completion of the sequencing of the human genome alone could be interpreted as an “end of history” [57]. Quite to the contrary, progress and transformation accelerated in the field of the life sciences, and genomics was quickly replaced by post-genomics and then by epigenetics. The many active researchers in this area, alongside the critically engaged historian of science, are best positioned to discuss the shortcomings of the existing lines of research and to develop new investigative programs [58]. However, we need to emphasize that the sheer availability of genomic data has

given rise to more and more questions, while at the same time revealing a fundamental scientific dynamic: Investigations into human nature never appear to end – or conversely, any conclusion or definitive answers would render the process of scientific inquiry to stop.

The intrinsic dynamics of brain research bring about immediate consequences for progress in the neurosciences and the visual brain

The neurosciences not only comprise a very heterogeneous conglomeration of research fields, sub-disciplines, and agendas, as is implied by the plural of the name, but the sheer identification of “The” paradigm in current neuroscience also misrepresents this endeavour as too simple a case [59]. How then can a critical assessment of the material culture of the neurosciences be developed if this is such a complex subject? A first answer

is likely a negative one, a critique of the much too rapid application of neuroscientific data and hypotheses to ordinary life problems. Many such ready-made answers are apparently ill advised and likewise often redundant. They frequently employ glossy research data to confirm already independently established knowledge, as becomes evident from media proclamations, social applications, as well as political statements made on the basis of neuroscience knowledge [60].

In addition, many of the most popular brain theories are utterly superficial, when we think, for example, of the dogma that a normal human being uses only ten percent of his/her mental power [61]. Another example concerns the theory of the lateralized brain [62], which, in its wider cultural appropriation of the left versus the right brain, reflects deeply embedded cultural stereotypes, such as the typically gendered dichotomy of abstract, language-based thinking (~ male psychology) *vis-à-vis* an assumed emotional and concrete way of reasoning (~ female psychology). A quick search for available knowledge regarding the informational processing of the remaining ninety percent of the brain, or the functional specialization of left and right brain centers, substantiates a suspicion that such brain theories reflect more the desire to find neuroscientific justifications for social presumptions than exemplifying the state of neuroscientific understanding [63]. This is, however, not a main issue for the historiography of neuroscience, and my article does not intend to defend the neurosciences against certain popular misunderstandings. Philosophers and sociologists of neuroscience might be in a better position to deal with such problems, after all [64]. The central issue remains, nevertheless, how to assess the knowledge as it is generated in the neurosciences *per se*, and how to understand the interdependence of technology-based data in the modern neurosciences?

I therefore want to return to my original questions raised at the beginning of this article: How should we interpret the approaches to neuroimaging from a historical perspective?. The respective methods do not only allow to observe the “mind at work” [65],

which was the basis for earlier fascination with the instrumental neurophysiological approaches of the 19th and early 20th century [66]. Pneumencephalography and electroencephalography also provided early and useful information on the topographical and functional understanding of the brain, i.e. the localization of a pathological process or a physiological activation. And yet, many of these new methods have quickly become criticized only as a “new phrenology” for emphasizing cerebral representation over functional integration [30]. Neuroimaging techniques are certainly powerful tools and provide breathtaking new insights into the workings of the brain. But whenever such information is used to reify a complex process into a simple spot of localized activation, the power of the visual evidence is used to enhance the *current* understanding of mind and brain. In order to find some more adequate answers, it is necessary to delve deeper into the emergence of modern neuroscientific visualization techniques [68]. The history of science is a rich resource to supply philosophical debates with contextual density, specific detail, and the exploration of temporal dimensions of nerve actions. A critique of functional neuroimaging as neo-phrenology is meaningful, when it relates the reductionism, for example, of many fMRI studies to their specific context in the present (see also Figure 6) as well as the past. In contrast to the presupposed realism of neuroscientific representations that stands in for mental and psychic phenomena, the new tradition of neuroimaging strives to capture the multidimensionality of the human world in which material interactions represent psychosocial events respectively [69].

Modern brain research as an Image Science and its contribution to societal and cultural applications

In this part of my article, I will attempt to pursue a *tour d'horizon* of visualizations in the history of neuroscience, following some representations of modern brain research back to their historical origins. I would like to present the selection of imaging practices under the

heading of the “*visual brain*”, a term introduced into medical historiography by Lisa Cartwright from the University of California in 1995 [70] and subsequently used by other scholars in the field, such as Cornelius Borck [71] and Fernando Vidal [72]. In the medical context, images often described instantaneous and highly intentional perspectives, for example of anatomical preparations, the pathological dissection site, or organs in the preservation glass (Figure 3). The medical image essentially amounted to a conceptual “freezing in” or a “slowing down” of the biomedical processes at the workbench of pathological laboratories or in the clinic with a patient [73]. In this form, medical images have appeared in ever-greater numbers from the late 19th century, when printed drawings or representations of plaster casts in the tables of textbooks and scientific journal articles became publishable and thus available. In contrast to the artistic genre of the “still life,” however, the intentional separation of continuous research processes in the laboratory put the specific sequences of experimental investigation into focus [74]. Paradigmatic examples were images of the individual surfaces of the brain, fibre preparations of the deeper cerebral layers, or depictions of the evolving growth of brain tumours [75]. The “reproductive technologies” of microphotography, the projection diapositives, or the X-ray imagery of the second half of the 19th century disconnected the reproduction of the image in modern brain research from its traditional contexts [76].

What appears to be a fairly abstract subject is not so when it becomes more closely aligned with the historical perspective: With the increasing introduction of medical publications in the newly created scientific journals of the 19th century – the first specialized journal for (neuro-) physiology: the *Journal de Physiologie Expérimentale et Pathologique*, was founded by François Magendie (1783-1855) in 1821 in Paris [77] – the process of mass reproduction of medical images began. Other exemplary journals in the brain sciences included, for example, the *Neurologisches Centralblatt*, produced by Wilhelm Braune (1831-1892) and Emanuel Mendel (1839-1907) in Berlin [78], or the *Zeitschrift fuer die gesamte Neurologie und Psychiatrie* later edited by the Breslau

neurosurgeon Otfried Foerster (1873-1941), which increasingly included many anatomical and pathological figures [79]. This trend to include ever more medical images, continuing up to the present day, has reached an unanticipated dimension and obtained a broad media presence. From here, I shall return to my first question; namely, which conceptions and representations were actually inscribed into the practices of visualization in the neurosciences – *avant la lettre* – and are thus even recognizable today?

Especially since the “American Decade of the Brain” [80], neurological images have gained an enormous attraction. Central publications – such as the British science journal *Nature* with its recent article entitled “Looking for the hidden signs of consciousness” – suggest that the imaging techniques could even introduce new forms of medical explanations in the brain sciences [81]. Representations, which are taken from the history of science, have gained enormous popularity. This has often occurred because of widespread curiosity regarding neuropathological and neuropsychological phenomena – and this is largely because of the mystical attraction of the still poorly understood functions of the human brain [82]. The development might even be distinct from the fact that the majority of the public does not fully understand what brain research really is about or what the notion of neuroscience clearly means. At the same time, it may not be too presumptuous to conceive that a small number of randomly selected lay people nowadays, bystanders on the street, could pass introductory neuroanatomy exams for medical students as handed out in the 1950s [83]. As I already described at the beginning of this article, the contemporary neurosciences – in the specific visual disciplines like cognitive brain research and neuroradiological diagnostics – have been transformed into an *image science*, to use the phrasing of Swiss-German media scientist Gottfried Boehm [84]. I now want to follow these perspectives into the practical media and image uses in the active research processes of the neurosciences: With respect to the technological mass production of modern images, the conceptual analysis of Boehm enables us to look at distinct empirical disciplines, such as

the neurosciences, essentially as an image science, because it is fundamentally rooted in semiotics, classification, and representation of natural and pathological phenomena through the depiction of images [85]. Historically, the increasing use of images has given rise to visual forms of nosology in the 18th century and justified the translation of clinical observations into laboratory phenomena in the 19th century. It dramatically changed, for example, the signs of multiple sclerosis to a reduction of the myelin layers of the nerve sheaths or to behavioural phenomena, thereby providing a visual grounding for new doctrines of signatures in the various areas of the contemporary brain sciences [86].

Today, brains have come to be omnipresent in contemporary research endeavours, as well as in the public sphere, showing that a more in-depth observation of their history, development, and interaction with technology really matters to the interested public [87]. Astonishingly, a lot of what is discovered by contemporary neuroimaging techniques does not yet have much in common with the physical structure of the brain itself; one may say even less so than the ink drawings from the stained microphotographs during the late 19th century and early 20th century like those provided by Santiago Ramón y Cajal (1852-1934) (Figure 4) [88].

Maybe our historical predecessors would

have looked at us in a quite unbelieving manner if we had had the chance to show them the modern images of the brain compared to those of 150 years ago. Counterfactually, they may have accused us of giving them “representations of neuromythology” in much the same way as contemporary neuroanatomists criticized the visualization strategies (~ histology and microphotography) of their own peers [89]. Based on the two major branches of experimental evidence in the neurosciences, the morphological and physiological tradition [90], functional imaging is an example of an almost perfect integration of the two as its principle centers in bringing together of hitherto distinct strands of knowledge. However, from this analysis of the method’s architecture and systematic structure, it does not follow that it is automatically employed to its full potential – in a way that experiments would always yield structural and functional information together. Rather, the morphological tradition differs in the type of information emanating from its set of methods. These methods aim at identifying and characterizing the shapes and structures of the brain’s various parts, whereas functionalist approaches aim at the recording and observing of an organ’s operations over time [91].

As a tendency, the new research method of fMRI could rather be characterized by the absence of the “image-and-logic-integration

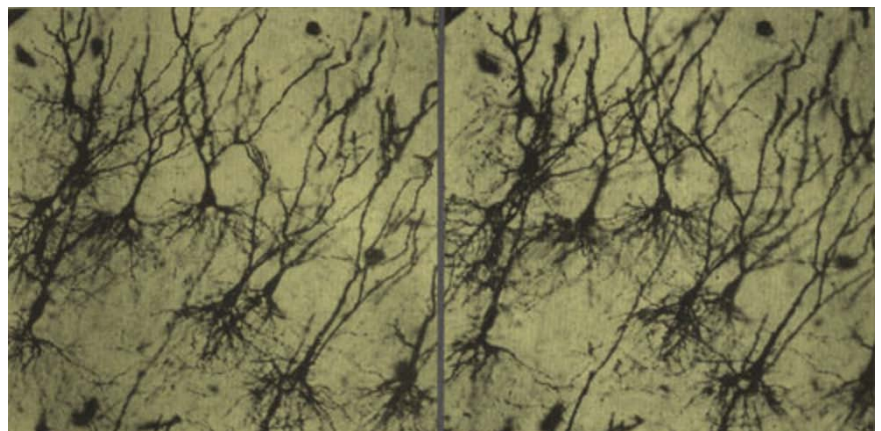


Figure 4. Stereoscopic photograph by Santiago Ramón y Cajal of cortical neurons as histologically presented by a derivative Golgi stain (produced ca. 1904). The stereophotograph is taken from: Bergua, A., *A Stereoscopic Atlas of the Nervous System*, Hamburg, Wittig Books, 1999, frontispice, cover page. (Courtesy of Prof. Antonio Bergua, Clinical Department of Ophthalmology of the Friedrich Alexander University, Erlangen-Nuernberg, Germany).

mode”, while preference is given to generate images which are functional only “by proxy” – images that subordinate the language of visual representations to localization [92]. This claim needs to be further substantiated: When following the conventional separation of research in the neurosciences into the *morphological tradition* and the *physiological tradition* (such as described by Oxford-trained physiologist John Fulton (1899-1960) [93] or American historian Elizabeth Haigh [94]), I am not setting out a disciplinary matrix, but rather providing a classification based on types of information which can be gathered with particular methodologies. Indeed, the very purpose of this classification is to arrive at a distinction that cuts across disciplinary landscapes and allows identifying similarities or analogies between institutionally distant branches of research, such as in Berlin neurohistologist Korbinian Brodmann’s (1868-1918) morphological cytology (Figure 5) [95] or Frankfurt psychiatrist Karl Kleist’s (1879-1960) clinical neuropathology [96].

The recent “debate” about fMRI techniques thereby provides a welcome opportunity to reconsider major methodological approaches from the history of the neurosciences with respect to the relative dominance of either structural or functional information provided by them [97]. Sorting the neurosciences according to such forms of information generated also ties together their different branches to methodological clusters of instrumentation (here; cutting, slicing, staining, lesioning, stimulating – there; recording, filming, probing, testing, training) [98] (see also Table 1).

Certainly, the neurosciences were never as clearly divided into experimental and theoretical areas [99] to the extent that the field of physics had been. Like research in particle physics, the neurosciences have been very much organized around instrumental practices. In contrast to physics, however, all branches of the neurosciences rely on one form of visual evidence or another and there is hardly any “anti-visual” strand in brain research today [100]. When following Peter Galison [13] in this characterization, the first tradition – *visual representations* – can be seen as a mimetic and homomorphic mode of representation,

preserving the form of objects as they occur in the world; while the second – *the language of the brain* – can be interpreted as a homologous mode of representation. And with these characterizations, it seems possible to construe the neuroscientific analogues. The mimetic mode of representation is central for the phrenological tradition [101], which starts with Gall and runs from there, via cortical localization [102] and the cytological microanatomy of Oskar (1870-1959) and Cécile Vogt (1875-1962) [103], to the alleged neophrenology of functional imaging.

The material culture of morphological neuroscience includes anatomical preparation techniques like cutting, slicing and staining; the macroscopic and microscopic identification of bodies, parts, and structures; the intra-operative stimulation of specific points on the brain; and various other approaches. The second group, the homologous tradition comprises approaches that focus on functional analogues regardless of formal and structural differences. We can see this group as originating with Julien Offroy de LaMettrie’s (1709-1751) machine theory of the human body, which also led to functional brain

theories and their underlying experimental methodologies [104], i.e. the reflex model and the cerebral inhibition concept [105], associationism, general reflexology, the code of neural information processing [106], along with the computer analogy [107]. Probably also included in this group would be neural plasticity, especially in light of its earlier conceptualization of LTP along with Hebbian learning [108]. This homologous tradition of brain research, studying “function” instead of “structure,” relies on the observation of changes over time, primarily on the basis of some recording techniques such as the kymograph for determining nerve-impulse velocities [109], the oscillograph for testing the all-or-none principle, and various kinds of analyzers (mechanical or electronic) for uncovering patterns, rhythms, or regularities within otherwise unreadable recordings.

Perhaps a more precise investigation of the character, status, and epistemic function of images needs to be developed. In the mimetic approach, images stand in for themselves, providing evidence of cells, fibres, tracts, and structural specializations; they show where and what structural element means

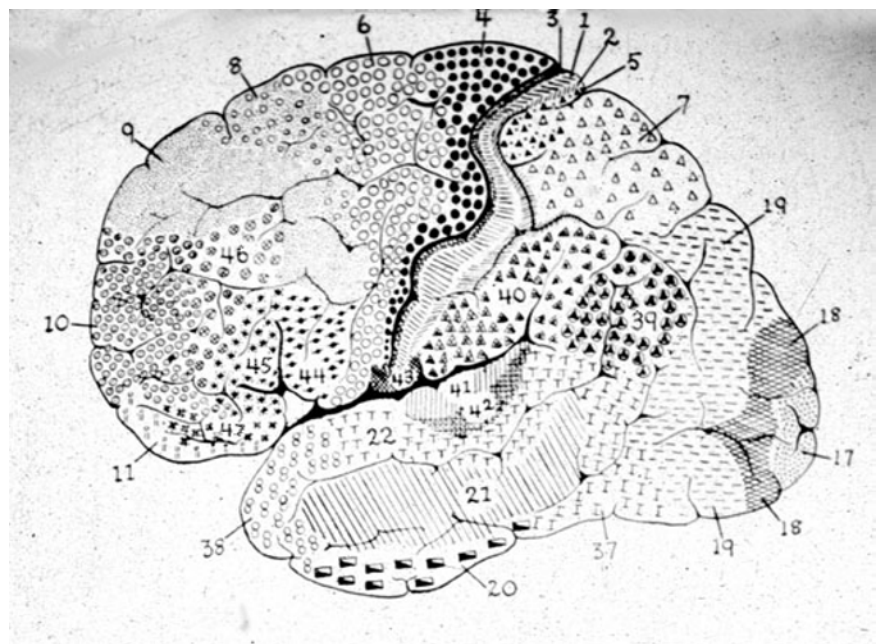


Figure 5. Functional specialization of the human cortex as described on the basis of myeloarchitectonical mapping and analyses of the neuronal cell types. Brodmann K., *Vergleichende Lokalisationslehre der Grosshirnrinde in ihren Prinzipien dargestellt auf Grund des Zellenbaues*, Leipzig, Johann Ambrosius Barth, 1909, fig. 85, p. 110.

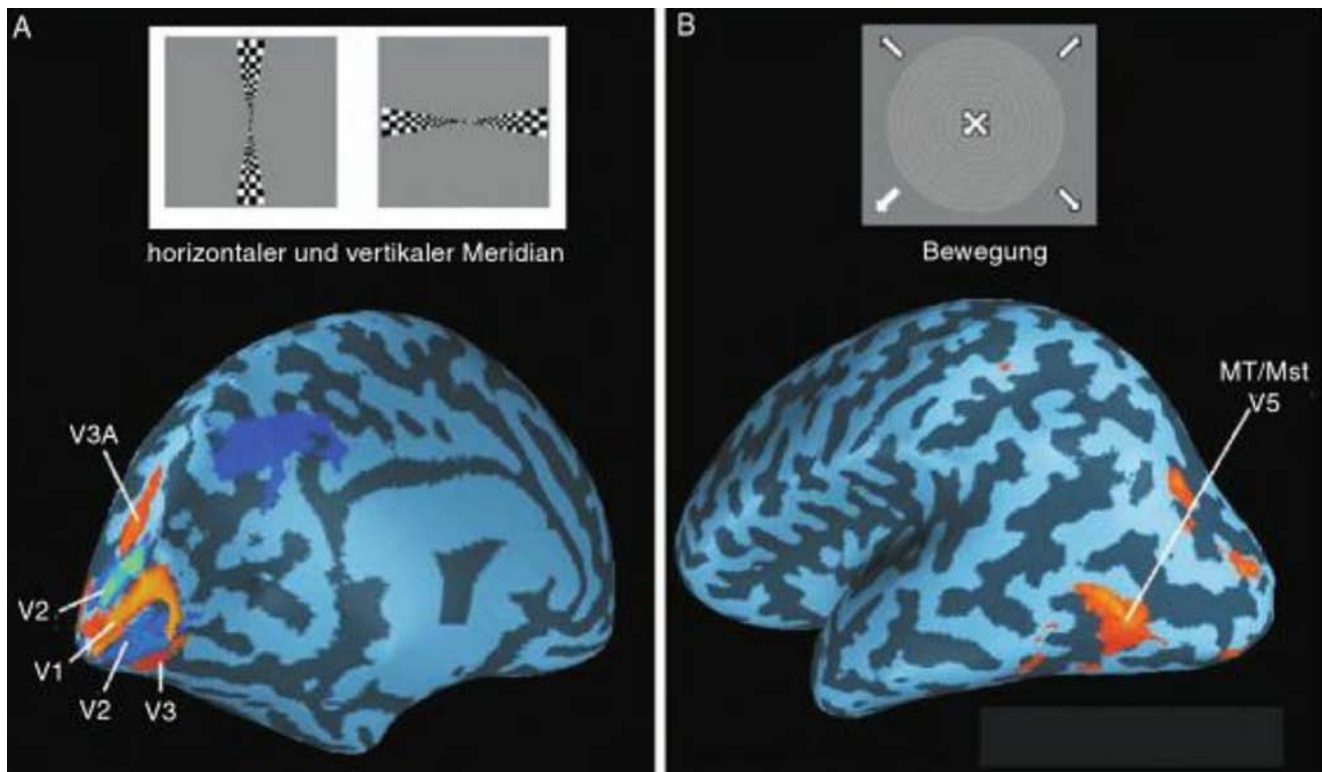


Figure 6. Functional MRI of the visual areas of the human cortex. (A) Horizontal and vertical rods (meridians) are shown and (B) movement patterns are presented to the test person. The functional activation of the visual areas are colour-coded in these cortical maps (courtesy of Prof. A. Vilringer, University of Berlin). Image taken from: Bechmann I., Nitsch R., under participation of Pera F., Winkelman A., Stahnisch F. W., Zentrales Nervensystem, Systema nervosum centrale, Gehirn, Encephalon, und Rueckenmark, Medulla spinalis, In: Fanghaenel J., Pera F., Anderhuber F., Nitsch R. (Eds.), Waldeyer: Anatomie des Menschen, 17th gen. revised. ed., Berlin, DeGruyter, 2003, fig. 5.87, p. 461.

for the integrative whole. The dimension of representation is the objectivity of the scientific image; its information dimension is the physical interaction (see Figure 6). In the homologous tradition, by contrast, visual evidence rarely emanates as an image of an entity, but more often as an image of a process. Although here, as well as in the mimetic tradition, the images are spatial objects, their status as functional visual evidence hinges on their ability to capture temporal relations. They are prototypical time images of representations of processes, and they preserve functional dynamics, while their spatial resolution is primarily weaker. Because of the almost complete absence of a mimetic relation between the visual evidence and captured phenomena, the images from this tradition typically do not reveal or display their content at first glance [110]. Their information is coded and must hence be extracted, not by looking at them, but through a form of reading. In this tradition, images are not photographed

but written as visual representations in symbolic language.

Conclusion

The purpose of this article has not been to convince neuroscientists of the general usefulness of the homomorphic-mimetic classification for research in history of neuroscience, but to provide a theoretical bridge to the enterprise of critical neuroscience [111]. It has been argued that the mimetic tradition engages with representational reductionisms because of its intimate connection between visual data and phenomena [112], whereas the homomorphic tradition is frequently employed by the neuroscientific community in a physiological mindset, which also includes various branches of non-reductive physicalism [113]. In looking at the history of neuroscience as a way of investigating the long-term emergence

of brain imaging, it has been shown here that the exploration of the continuities and transformations serves more often to render things more complicated than to free modern brain research of all of its philosophical problems. Hence, the perspective from the history of science offers rich insights for the reconstruction of current theoretical debates [114], including contextual depth, further details, and the temporal contingencies of assumed non-historical truth-values. A critique of functional neuroimaging as a form of neo-phrenology can be seen as valid in so far as it remains a critique of the reductionism implied in many interpretations of modern neuroimaging studies, such as its application in neurolaw [115]. In contrast to the anticipated realism of neuroscientific representations visualizing mental and psychiatric phenomena [116], neuroimaging should strive to capture the heterogeneity, multiplicity, and multi-dimensionality of the

human world in general [117]. Here, much more work is needed in the future.

My argumentation for a critical and historically informed approach to modern neuroimaging is intended to raise a respect and acknowledgment for interdisciplinary approaches rather than accepting the domination of certain subdisciplines over others [118]. Simply because of the ever-changing nature of neuroscientific knowledge, societies would be poorly advised to seek for an overly rapid "translation" of postulated consequences from neuroscientific research [119]. It may well be the case that research about the structure functional processes of neurocognition is at odds with standard assumptions about human agency and free will. To conclude from here, however, that human societies need to adapt their legal and philosophical standards should be thought through again. Such standards

reflect complex and deep historical processes of social negotiation and adaptation [120]. The history of the neurosciences offers to create such a critical awareness for the various episodes from the vast corridors of the recorded past which can illuminate the contingencies of the current understanding of the human brain and its place in our societies, as has been shown here by focusing on the enduringly ambivalent relationship of the morphological and the physiological tradition in modern neuroscience.

Acknowledgements

Earlier versions of this paper have been presented at the meetings of the History of Neuroscience Interest Group (HONIG) at the University of Calgary, Canada; at a recent conference of the International Society for

the History of the Neurosciences (ISHN) in Charleston, SC, United States; and a seminar at the Berlin School of Mind and Brain, Humboldt University, Germany. The author wishes to thank Cornelius Borck (University of Luebeck, Germany), Stephen Casper (Clarkson University, New York), Patrick Wilken (Humboldt University, Germany), as well as the discussants of the above-mentioned events for their constructive feedback. The author is further grateful for support from the Mackie Family Collection in the History of Neuroscience, the Hotchkiss Brain Institute, and the Institute for Public Health (all Calgary), as well as for the adjustment of the English language of this paper by Mr. Stephen Pow (Calgary). The study has been supported by a bridge funding grant (no. 10024392) of the Faculty of Medicine at the University of Calgary.

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