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Master's Thesis

How we became our brains

An analysis of the relation between brain imaging technologies and beliefs in brain research

Anne Nelissen (5495903)

First supervisor: dr. Brandt van der Gaast

Second supervisor: dr. Jesse Mulder

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Introduction

"Neural correlates of interspecies perspective taking" may come across as an ordinary title of a brain research paper. It is similar to other titles that present brain research, such as "A fast link between face perception and memory in the temporal pole" (Landi et al., 2021) and "A prefrontal network integrates preferences for advance information about uncertain rewards and punishments" (Jezzini et al., 2021).[1] These titles of recent brain research papers published in *Science* and *Neuron* correlate cognitive abilities with (neural) structures in the brain. Such titles might sound fairly familiar and often go together with the appealing depiction of brain activity in images of the brain. The ability of brain research to correlate cognitive capabilities with neural structures in the brain is one of the reasons why this field of research has become quite popular in the past decades.

However, the first title presented above is incomplete. Not a human being or any other living animal was part of the study. Instead, the study used a dead salmon as a participant. The actual title is "Neural correlates of interspecies perspective taking in the post-mortem Atlantic Salmon" (Bennett et al., 2009). Whilst the incomplete title is reasonably familiar to common brain research titles, the complete title is quite absurd and questions what these brain research titles actually mean and represent.

Although it might sound ridiculous, Bennett et al. do in fact report a functional magnetic resonance imaging (fMRI) study with an Atlantic Salmon as a participant. The dead salmon was informed of the task and was shown several images of humans depicting a certain emotion. Activity in the dead salmon's brain was recorded using fMRI during the condition in which photographs were shown compared to a rest condition. It might not be surprising that the researchers were not actually interested in the reaction of a dead salmon on photographs of humans showing any emotion. Instead, the researchers used this study as a warning for the risk for false positives in fMRI studies and argued for more sophisticated statistical methods.

Besides this critical argument made by the authors, this example also points to a more general observation. It shows that brain imaging technologies are not able to present an objective, transparent look into the brain. The links between face perception and memory and activity in the temporal pole (Landi et al., 2021), or between information preferences and the prefrontal network (Jezzeni et al., 2021) are put in a different light by the salmon example. All these correlation are statistically validated measurements. There is no such thing as the temporal pole *lighting up* when a participant is shown a picture of his grandmother. Sophisticated technologies such as fMRI do not give a neutral, objective depiction of the brain. Instead, the technologies are closely involved in depicting the brain. The salmon experiment highlights that the role of

[1] These two headlines were presented as top headlines in the Mind & Brain News in Science Daily on July 9th 2021.

these brain imaging technologies cannot stay unnoticed and unclarified. This thesis aims to analyze how we can understand the role of technologies in brain research.

Brain research has become increasingly popular in the past decades. The popularity of brain research is reflected in several initiatives. In the 90s, the US Congress established the 'Decade of the Brain.' This initiative aimed to increase funding in this research area and create public awareness for brain research, specifically neuroscience. In 2007, a group of scientists established the 'Decade of the Mind' as a follow-up of the Decade of the Brain (Albus et al., 2007). The researchers believed that increasing the understanding of cognition is of great scientific and public importance. In 2013, the Obama administration started the BRAIN initiative, a public-private research initiative that again increased the popularity of brain research.

The advancement in brain imaging technologies has undoubtedly been a driving force for brain science and its popularity. Technologies, such as fMRI, have made it possible to study brain processes *in vivo* (Ward, 2015, chapter 1). Such new and advanced technologies tend to present a new window to the truth and can be quite fascinating. Brain scans do not only appear in high-ranking academic journals but are also present in large numbers in popular science. However, all brain imaging technologies have their own way of representing the brain. Therefore, I believe that awareness of how the technologies influence the way the world is represented is needed.

The popular science book, *We are our brains*, written by the well-known Dutch brain researcher Dick Swaab, presents a specific view on the brain. In short, Swaab argues that all our emotions, feelings, thinking, etcetera are nothing more than processes in the brain. The story of life is the story of the brain, so he argues (Swaab, 2014). This view has gained momentum in the past decades. Like every view, such a view is connected to future research directions. This way of understanding cognition mostly enforces looking closer and closer into the brain. In this thesis, I ask how such a view arises in relation to the technologies involved in the research. How are research technologies related to the way a phenomenon is represented and investigated? How do research technologies relate to the beliefs in science and to the future research that this view on the brain suggests? As Swaab argues that we are our brains, I ask: How did we become our brains?

The main research question in this thesis is: How can we understand the relation between brain imaging technologies and beliefs in brain research? Additionally, an important sub-question in this thesis is: How can postphenomenology contribute to an understanding of the relation between brain imaging technologies and beliefs about the brain in brain research? Postphenomenology is a recent trend that has mostly developed in the philosophy of technology at the end of the 20th century. This view is empirically oriented and aims to give a situated perspective of the relation between the human and the world. Because postphenomenology employs an inter-relational ontology, it describes technologies neither as neutral nor as fully determining. It aims to understand technology, the subject, and the world in relation to each other: as interrelated (Ihde, 2015; Rosenberger & Verbeek, 2015). Since postphenomenology has developed decent insights in the philosophy of technology, I believe that it is interesting to see whether these insights can be extended to our understanding of the role of instruments in science.

This thesis presents a rather traditional theoretical study. I will first situate my project within the broader context of the philosophy of science. I will clarify how this project aligns with other approaches in the study of science, and I will build on the science-as-practice tradition. I will provide a literature review of the most important insights from postphenomenology. These insights will be analyzed by examining a few examples of studies that use these insights in their study of science and I will compare these to a few case studies that do not use postphenomenology in their analysis.

In the first chapter, I will set out the background of my thesis in the philosophy of science. I propose a view on science that sees science as a practice and, thus, necessarily includes material, temporal and social factors in describing science. This view paves the way for a central role for scientific instruments. *Epistemic virtues* and *scientific horizons* will be introduced as valuable notions to understand trends or beliefs in scientific practice that are interdependent on science's material, temporal, and social aspects. Then, this first chapter addresses the role of scientific instruments using Patrick Heelan's notion of *readable technologies*. This chapter concludes that science should be understood as an intertwined web of practices, beliefs, instruments, and scientists.

The second chapter introduces the postphenomenological framework for understanding the role of scientific instruments in the relation between the scientist and the world. This framework builds on phenomenology. First, phenomenology and the main phenomenological insights on technology in the human-world relationship will be introduced. Then, postphenomenology and its main concepts will be discussed. Postphenomenology conceptualizes technologies as mediating the relationship between the subject and the world. The intentional relation between the subject and the world is extended through technology. The last part of this chapter relates the postphenomenological insights to the philosophy of science by discussing Don Ihde's *material hermeneutics*. This theory claims that technological mediation is constitutive of scientific knowledge by preparing and structuring reality into the scientific objects that are studied.

Some examples of studies using the postphenomenological method to investigate the relationship between brain images, brain imaging technologies and beliefs in brain research are discussed in the third chapter. It will be shown that the postphenomenological framework can be used to explain the multiple possible interpretations of brain images, and to conceptualize the role brain imaging technologies have in constituting phenomena as a scientific object. Several studies that do not build on postphenomenology but are also concerned with brain imaging are also discussed in this chapter and related to the postphenomenological approach. It will be shown that the different approaches agree on many aspects. Additionally, the non-postphenomenological accounts also contribute in their own way to the discussion of brain imaging technologies.

The fourth chapter builds on various insights gained in the third chapter. This last chapter firstly reflects on the use of postphenomenology. Furthermore, it reflects on the understanding of brain images as multistable and on how this idea fits in the scientific practice of brain research. Then, technological intentionality is re-introduced as a useful concept to understanding the role of brain imaging technologies in relation to research trends in brain research. It is suggested that functional imaging can be understood as presenting a trajectory of reductionist research questions. Lastly, the insights from chapter three are related to the concept of epistemic virtues.

Chapter 1:

Scientific practice, epistemic virtues and instruments

In order to understand the relation between brain imaging technologies and beliefs about the brain in brain research, it is helpful to conceptualize science as a practice and to situate instruments within this scientific practice. In this chapter, I briefly discuss the broader context of science studies, introduce the science-as-practice tradition and discuss concepts and ideas relevant to my analysis of brain imaging technologies in brain research. First, the common threads in the philosophy of science are discussed and related to the science-as-practice tradition. Then, the idea of epistemic virtues is introduced as an important theoretical concept for the analysis of scientific practices. I discuss different perspectives on objectivity that encouraged specific epistemic virtues in science. Following, I show that these perspectives are still present in current practices in brain research. Lastly, I focus on how instruments are incorporated in the view on science.

Science as practice

Scientific practice, its instruments, and its systems of belief are studied from a variety of perspectives. The sociology of science, history of science, and philosophy of science are somewhat distinct fields but also, without a doubt, closely related. Various insights from these fields are important to my current project, which is primarily philosophical. Although it is important to consider these perspectives' theoretical background and scope, I will not elaborate on the exact differences between these perspectives. Rather, I discuss the relevant ideas to situate my view within the field.

I rely on a view of science for which scientific practices are no lesser object of study than theories, methods, the truth, or any of the other more conventional topics of discussion in the philosophy of science. This perspective has become more prominent in the philosophy of science since the second half of the twentieth century, when the focus of the philosophy of science radically shifted after Thomas Kuhn's publication of *The Structure of Scientific Revolutions* (1992). Before Kuhn's famous work, the philosophy of science was fixated on science's method, on how true knowledge could be derived from observational facts. It aimed to describe science's logic. Science's logic was the rationality or set of rules which regulates theory-choice on the basis of observational facts. The development of science was seen as a progressive path towards the truth. This traditional philosophy of science is highlighted by the influential contributions of the Vienna Circle and Karl Popper (Pickering, 1990). By virtue of the contributions of thinkers such as Pierre Duhem and Willard Van Orman Quine, the traditional philosophy of science began to lose ground.[2]

Thomas Kuhn, Imre Lakatos, and Paul Feyerabend built on these ideas and lay the ground for a new focus in the philosophy of science. Kuhn's theory focuses on the notion of scientific paradigms. Within a paradigm, most scientists are involved in *normal science*, scientific research that adheres to the established theories, methods, and practices. Findings or theories that are not compatible with the standard of science within a paradigm are called *anomalies*. In some cases, anomalies gain support and eventually lead to a paradigm shift. An important notion from Kuhn's work is *incommensurability*. Kuhn argues that different paradigms are incommensurable. With this claim, he pointed to the difficulty of comparing different paradigms. There is no easy measure outside of the paradigms that can determine which one is 'more true' (Kuhn, 1992). This idea clashed with the views of Kuhn's predecessors, who believed in science as a progressive path to the truth. Lakatos developed a theory about research programs which is quite similar to Kuhn's idea of paradigms (Lakatos, 1970). Feyerabend made even stronger claims. He attenuated the idea that the rules governing science were exceptional and objective. He describes his aim as follows: "One of my motives […] was to free people from the tyranny of philosophical obfuscators and abstract concepts such as 'truth,' 'reality,' or 'objectivity'" (Feyerabend, 1995, p. 179). Furthermore, he emphasized that there are various possible systems of belief (Feyerabend, 1993).

These new insights from these influential philosophers had a significant impact on the view of science. Kuhn's idea of incommensurability strikingly highlights that science was not an independent inquiry for the truth but that science's working objects, methods, and goals depend on a specific worldview. As a result, not only the scientific method but also science's material and social aspects became essential parts of the study of science. For example, in Kuhn's description of the Scientific Revolution, material aspects such as Galileo's resources for designing and building a more advanced telescope, and social aspects like the catholic church's obstruction to the heliocentric worldview, were essential in describing and explaining the course of scientific practice.

Andy Pickering describes these different approaches in the studies of science in his article "Knowledge, Practice and Mere Construction".[3] He distinguishes the pre-Kuhn, *science-as-knowledge* tradition, and the post-Kuhn, *science-as-practice* tradition (Pickering, 1990). In the remainder of this thesis, I will use Pickering's terms to distinguish between the different traditions in the philosophy of science.

[2] Duhem and Quine (although their individual accounts differed in the strength of their claims and the scope of their critique) both state that the empirical test of a hypothesis relies heavily on auxiliary assumptions. In other words, not only one but multiple hypotheses are tested in empirical experiments (Duhem, 2013; Quine, 2013).

[3] Pickering's article responds to Paul Roth and Robert Barrett's critique on his book *Constructing Quarks* presented in their article "Deconstructing Quarks" (1990).

The pre-Kuhn science-as-knowledge tradition thus focused on science's logic. The science-as-practice tradition instead focuses on the situatedness of science and takes the material, temporal and social factors in scientific practice seriously. In contrast to the science-as-knowledge tradition, the science-as-practice tradition studies science as a dynamic practice in which scientific knowledge is inextricably bound to the practice by which it is produced (Pickering, 1990). I situate my view in the science-as-practice tradition as I consider material, temporal and social factors to be primary determinants in scientific practice. In this thesis, I emphasize the importance of the material aspects – in my case, instruments – in science. Since my thesis builds on the science-as-practice tradition, I believe it is useful to look at a concrete example within this tradition to clarify its ideas.

Pickering formulates his stance based on the science-as-practice tradition. His case study of the research on the weak neutral current presented in his paper "Against putting the phenomena first" demonstrates his perspective on science and experiments. He argues that an experiment should be seen as part of an open system in which phenomena, interpretative practices, and scientific practices are interdependent. The acceptance of the existence of the weak neutral current was by no means a result of straightforward verification. With his detailed case study, Pickering reveals that the acceptability of phenomena is dependent on the acceptability of the practices that investigate them. The acceptability of the practices is dependent on all kinds of factors. In different times and places, different practices can become standard. Pickering states that the interpretative practices in the 1970s were crucial to the weak neutral current's discovery. The preceding interpretative framework did not support the existence of the weak neutral current (Pickering, 1984).

Besides the traditional, mere conceptual dimension of science, Pickering thus adds material, temporal and social dimensions to the study of scientific practice. Ultimately, Pickering emphasizes the historicity of science. This historicity is:

> "a way of acknowledging that facts and phenomena, concepts and theories, as well the instruments and institutions of science, all owe their existence and character to a genuinely historical process. They are all bound to the wheel of what happened" (Pickering, 1990, p. 703-704) .

While discovering and trying to make sense of the world, a scientist is, simultaneously, part of this world and interacting with it (Pickering, 1990). This idea explains how knowledge can be understood as being constructed in scientific practice in interaction with conceptual, material, social and temporal factors. Pickering's notion of historicity can be related to the view of Lorraine Daston and Peter Galison, who explain this idea strikingly with the concept of epistemic virtues (Daston & Galison, 2007). I will turn to their view in the next section.

The idea that the acceptability of phenomena is dependent on the acceptability of scientific practices and the corresponding notion of historicity is, in my opinion, crucial to an adequate understanding of science. My analysis of different understandings of the brain in relation to brain imaging technologies focuses on how material factors interplay with constituting and studying phenomena.

Objectivity as epistemic virtue

Daston and Galison introduce the concept of epistemic virtues in their book *Objectivity*.[4] Although Daston and Galison do not explicitly mention the science-as-practice tradition, their notion provides a valuable tool for analyzing the character of scientific practices within this tradition. Epistemic virtues prescribe first and foremost how the world can and should be known. Because the knower and scientific instruments take a position in the relation between knowledge and the world, the scientific self and scientific instruments are at issue as well. Epistemic virtues are, thus, not only reflected in scientific norms but also in the set of practices in science: what instruments are used, how data is selected and prepared, and what is expected from a *good* scientist (Daston & Galison, 2007, chapter 1).

Daston and Galison's primary example of an epistemic virtue is scientific objectivity. As an epistemic virtue, scientific objectivity presents the idea that science should adhere to specific rules and practices to be able to give an objective representation of the world. The authors note that many aspects of scientific objectivity are still influential in scientific practice nowadays, even though objectivity has often been the topic of philosophical debates (Daston & Galison, 2007). In this section, I will restrict my explanation to a discussion of the forms of objectivity introduced by Daston and Galison. In the next part, I will lay the grounds for a connection between these epistemic virtues and the field of brain research.

Daston and Galison provide a solid conceptual basis for a discussion of objectivity. In their book, they present a history of objectivity. This fascinating history, based on atlas images, shows the variety of the social, epistemological, and ethical views present in the different chapters of the chronicle of objectivity. These views, which are part of the epistemic virtues Daston and Galison discuss, incorporate ideas about the perfect scientist, what counts as valuable knowledge and how this knowledge should be obtained. As Daston and Galison's argument shows, all these ideas are reflected in atlases and entangled with notions of objectivity and subjectivity. Their account explicitly opposes the use of objectivity as a panhistorical honorific. They thus oppose the idea that objectivity is a static ideal that has not changed over time. Instead, they show that objectivity has a history that needs to be told (Daston & Galison, 1992, 2007). This idea

[4] Daston and Galison's book *Objectivity* (2007) builds on their earlier article "The Image of Objectivity" (1992).

relates closely to Pickering's emphasis on historicity. As an epistemic virtue, objectivity is itself part of a historical process and situated in a scientific context.

In order to understand the ideas surrounding objectivity, it is necessary to get a grip on its subjective counterparts. Daston and Galison present objectivity and subjectivity as closely connected in their account. Subjectivity takes a necessary position in the definition of objectivity since objectivity always counters a specific aspect of subjectivity that has come to be seen as a troubling feature of subjectivity. Objectivity can, for example, aim to limit the scientist's subjective perception or to prevent a reader's subjective interpretation. In this way, objectivity is defined by pointing to the subjective characteristics that are to be censored. Thus, the character of objectivity as an epistemic virtue can only be understood in relation to this subjectivity (Daston & Galison, 1992, 2007).

In their book, Daston and Galison discuss four different epistemic virtues: the eighteenth-century truth-to-nature, the mid-nineteenth-century mechanical objectivity, the early-twentieth-century trained judgment, and the early-twentieth-century structural objectivity. Truth-to-nature and trained judgment are epistemic virtues that rely on expert knowledge. These epistemic virtues do not strictly aim for objectivity but rather embrace authoritative interpretation. Truth-to-nature presented the scientist as the ideal observer. Based on their experience and expertise, scientists use their own judgment to present the typical, characteristic, ideal or average. There was no contradiction between aesthetics and accuracy or between perfect and just. Trained judgment positioned the scientist as the observer that had acquired the ability to interpret scientific objects correctly (Daston & Galison, 1992, 2007). In my reading, these epistemic virtues point to a specific idea of what a *good* scientist is. The scientist is either expected to be a born genius (truth-to-nature) or a trained expert (trained judgment). Mechanical and structural objectivity also incorporate ideas about the scientist, but, additionally, they strongly focus on the instruments used in scientific practice. Because my thesis also focuses on science's instruments, these two epistemic virtues will be most important to my thesis. I will briefly introduce these two epistemic virtues, as presented by Daston and Galison, before connecting them to cognitive science.

Daston and Galison first sketch the history of mechanical objectivity. In the mid-nineteenth century, objectivity evolved as a guiding principle for examining nature. In this same century, machines became the exemplar of scientific virtues. Machines are patient, and they are exact, whereas scientists can be distracted, inaccurate, and have interfering emotions. "The phenomena never sleep and neither should the observer" captures the main idea of mechanical objectivity (Daston & Galison, 1992, p. 83). Daston and Galison strikingly coin the epistemic virtue in this period: mechanical objectivity. This kind of objectivity seeks to replace the observing scientist's interpretation, judgment, and interference with the strict, static mechanical reproduction routines. Machines, thus, perfectly fitted this picture of objectivity. The machine suited the standardization goal, it embodied the ideal observer, and it produced images freed from interpretation.

Daston and Galison state that "the machine was fundamental to the very idea of mechanical objectivity" (1992, p. 119). The machine had a constitutive as well as a symbolic function to mechanical objectivity. No wonder that photography, camera obscura tracings, and self-registering instruments became the exemplars of mechanical objectivity (Daston & Galison, 1992, 2007, chapter 3).

Daston and Galison highlight the ideological strength of mechanically reproduced images within this view of mechanical objectivity. Especially the photograph thrived on the idea of being a neutral and accurate representation of truth. Because photography removed individual judgment from the representation of nature, it was seen as superior to drawings and schemata, which necessarily incorporated human interpretation. This perspective on technologies such as the photograph reflects a substantial trust in mechanical representation, which relates to the longing for the absence of the observer's interpretation (Daston & Galison, 1992). Consequently, instruments have a crucial role in science. Not the expert scientist, but the instrument provides the window to the objective truth.

The other kind of objectivity Daston and Galison discuss is structural objectivity. Structural objectivity was one of the responses to mechanical objectivity. It became an influential idea in the late-nineteenth and early-twentieth-century. Whereas mechanical objectivity counters the scientific observer's subjectivity during observation and the composition of an image, structural objectivity opposes the individual subjectivity in the perception and interpretation of images. Each individual is biased by his own thinking in observing an image. Therefore, structural objectivity pleads against the use of images in science. Rather than in images, structural objectivity finds its grounds in structures. Structural relations rather than individual objects predominate. The main goal of structural objectivity is that science should be communicable everywhere and always. A famous example of a representative of structural objectivity would be Rudolf Carnap and his colleagues from the Vienna Circle. They pursued enduring, structural relationships in their construction of a formal language. Science should be restricted to so-called structure statements rather than using language bound to a specific discipline and embedded in a certain period. Structural relationships, rather than specific phenomena and images of these phenomena, were the enduring products of science (Daston & Galison, 2007, chapter 5).

Thus, structural objectivity opposes individual variability as an unwanted aspect of subjectivity. The historical context of structural objectivity shows that this view was embedded in a period in which psychology and physiology argued for sensory experience's incomparability. It can never truly be known whether the perception of the color red is a similar sensation for multiple individuals. This became the paradigmatic example of the subjectivity that hindered science's true, objective account of the world. Thinking and science should become detached from this individual variety. Whereas mechanical objectivity had cheered self-restraint, structural objectivity applauds renunciation. In other words, mechanical objectivity asked the scientist to restrain his judgment and emotion in producing science, and structural objectivity pursued a form of science production that would make individually differing interpretations less plausible. The personal context of the individual should be removed from interpretation (Daston & Galison, 2007, chapter 5). This latter perspective, encouraged by structural objectivity, could also be captured in Thomas Nagel's famous words: "the view from nowhere" (Nagel, 1986, p. 5).

Objectivity in practice

Daston and Galison's account has a strong historical emphasis. They solely focus on historical examples and on how the epistemic virtues are connected to a specific scientific self. Still, their theoretical concepts of objectivity provide a useful tool for understanding and explaining the epistemic virtues at play in scientific research. In this part, I link the notions of mechanical objectivity and structural objectivity to the focus area of this thesis: brain research and brain imaging technologies. Anne Beaulieu similarly relates Daston and Galison's concept of mechanical objectivity to current brain imaging representations (Beaulieu, 2000). Her critical discussion of brain images shows how the notions of mechanical objectivity and structural objectivity are relevant to brain research.

Beaulieu presents an analysis of the meaning of brain scans. She distinguishes two contexts in which brain scans play a role: the popular media arena and the scientific context. In both contexts, the understanding of brain images is embedded in what is expected from technologies and what we believe images can teach us. Beaulieu argues that brain scans are regarded as an objective representation of the brain, especially in the popular media arena. She connects this image of brain scans explicitly to mechanical objectivity. Brain imaging technologies seem to have a similar magic veil of objectivity and technological superiority as photography, the primary exemplar of mechanical objectivity, had. The technology goes beyond human flaws and gives an impartial and transparent peek into the brain. Although Beaulieu argues that this view is primarily present in the popular context, she notes that it is not absent in the scientific context (Beaulieu, 2000). Instruments, e.g., brain imaging technologies, are, thus, considered to adhere to the norms of mechanical objectivity. They seem to exclude human interference and look directly into the brain.

Besides the mechanical objective view on brain scans, Beaulieu also presents a different, prominent perspective on brain images in the scientific context. In this other perspective, brain scans are not seen as pictures but as statistical representations. Rather than providing an image of the brain, brain scans present a statistically validated measure of the brain's activity. The mechanical objective view on brain scans uses the metaphor of photography to understand the use of images and technologies. This metaphor reflects the idea of being able to *see* the brain. The second view, which relies on pictures as statistical representations, presents the idea of being able to *measure* rather than being able to *see* the brain. Brain scans should be regarded as statistical maps in this view. These statistical maps show a structural relation rather than a unique snapshot of the brain (Beaulieu, 2000).

Beaulieu does not explicitly relate this tendency in the scientific context to structural objectivity.[5] Nevertheless, I believe this approach shares some attributes of structural objectivity. Rather than presenting images, structural objectivity aims to represent structural relations. So, instead of presenting an objective image of the brain, the brain scans represent the relation between a function of the brain and the activity in certain parts of the brain. This representation is statistically validated and, thus, considered to be objective. By statistically validating the measurements, individual flaws are ruled out of the representation. Besides, statistical outcomes prevent the possibility of diverse interpretations of the results since it incorporates a consensus in interpreting results by using statistics. So, following this view, brain scans represent structural relations. Thus, this view does not reflect an idea of mechanical objectivity but can be compared to Daston and Galison's notion of structural objectivity.

Both interpretations of brain scans start with an image produced by brain imaging technologies. However, brain scans have a different meaning in the context of different epistemic virtues. The popular context interpretation is close to mechanical objectivity as epistemic virtue and interprets brain scans as a neutral, transparent peek into the brain. Brain imaging technologies are then conceptualized as the ideal observer, independent of any interfering factors. In the context of structural objectivity, brain scans present structural relations. The brain imaging technologies are no less involved but are assigned a different role. In this case, brain imaging technologies translate the phenomena into a structural relationship that does not allow for a wide variety of individual interpretation.

I believe that Beaulieu's research shows that the concepts of mechanical objectivity and structural objectivity apply to the current trends in cognitive science. These theoretical concepts provide a useful tool to analyze the current dominant epistemic virtues in this field. In the final chapter, I will elaborate on the relationship between imaging technologies, epistemic virtues, and brain research.

Instruments as readable technologies

In the theories about scientific practice and objectivity discussed above, instruments have been portrayed as essential factors in scientific practice and as inextricably related to the epistemic virtues. However, in these theories, instruments did not yet become the center of attention. In my thesis, I aim to focus on the

[5] At the time of writing her article, Beaulieu could base her account solely on the earlier article Daston and Galison wrote in 1992 (”The image of objectivity”). This article presented roughly the same idea as what was later presented much more extensively in *Objectivity*. Daston and Galison already coined the epistemic virtues truth-to-nature and mechanical objectivity but did not yet include the discussion of the other epistemic virtues: structural objectivity and trained judgment.

role of instruments in relation to the set of views and practices in science. In the philosophy of science, several accounts have explored the role of instruments in science. Patrick Heelan is a philosopher of science who is influenced by phenomenology. In his theory, instruments have a central position. His ideas introduce the relevance of phenomenology for the study of instruments in science and provide a good starting point for conceptualizing instruments in science. His ideas are also related to what he calls the more "praxis-oriented epistemologies" (Heelan, 1989, p. 176). In this part, I will first introduce his main view and conception of realism before discussing his view on instruments in science.

Concerning the distinction between science-as-knowledge and science-as-practice, Heelan's work is situated in the science-as-practice tradition since he focuses on perception and praxis in science and opposes what he calls the traditional objectivist epistemology, which is comparable to the science-as-knowledge tradition. Heelan coins his view *horizonal* realism. With this view, Heelan counters scientific realism. Scientific realism is a trend in epistemology that seeks to find the truth and believes that science can be an objective inquiry. Scientific realists believe that science is an inquiry that can progressively lead to more knowledge about *the real* (e.g., the world out there). According to scientific realists, the real and knowledge of the real are independent of any human relation to it. Heelan opposes the idea that we can come to know the real as unrelated to human life and culture (Heelan, 1989, chapter 10). However, he does not reject structural realism since he believes that scientific entities "have relationships among themselves which prescind from human cultures, and which are defined by scientific theory" (Heelan, 1989, p. 174). So, Heelan avoids relativism by avoiding the claim that scientific entities are nothing but cultural entities.

In his perspective (horizonal realism), Heelan emphasizes that knowledge about the world is always known in relation to the perceiver. Different perspectives on the world do not need to be identical since the world can be grasped differently in different *horizons*. A horizon is a structured part of reality. A horizon represents the different possible profiles in which an object can present itself. On the side of the subject, a horizon offers ways of perceiving the object that incorporates possible responses to the profiles in which the object is presented. Heelan builds on Wilfrid Sellar's distinction between *manifest images* and *scientific images*.[6] Heelan describes manifest images as socially or culturally constituted and connected to an individual's mental life. Scientific images are constituted within a system of theories and in relation to other constituted scientific entities. This scientific horizon is a culture with a language that should be acquired by training. Within this culture, judgments can be made with a certain degree of certainty. Thus, the scientific horizon is a framework in which scientific objects and concepts are theoretically postulated (Heelan, 1989, chapter 1 & 10).

[6] Wilfrid Sellars describes this distinction between manifest images and scientific images in "Philosophy and the scientific image of man" (Sellars, 1963).

Heelan's account of instruments is embedded in this description of scientific images. The scientific horizon is inextricably related to a system of instruments that present measurements using theoretical models. Heelan explicitly notes that scientific images are "encountered only through the mediation of instruments or technology" (Heelan, 1989, p. 177). Objects are isolated from their background and constituted in the scientific context. Technologies are essential in isolating phenomena from their background. Additionally, the instruments define the new context in which the scientific entity is to be understood (Heelan, 1989, chapter 10).

Heelan introduces the concept of *readable technologies*. Aided by readable technologies, theoretical entities of science, which cannot be perceived by the human eye, become perceptible. Heelan introduces the thermometer as an example of how readable technologies function. When reading a thermometer, one does not involve all the knowledge on which a thermometer is based. One does not use thermodynamics to infer the temperature from the position of the mercury. Instead, the instrument becomes the new standard to which, in this case, the temperature is perceived (Heelan, 1989, chapter 10). Heelan explains: "Provided the instrument is standardized, and so can function as a readable technology, the instrument itself can define the perceptual profiles and essence of temperature." (Heelan, 1989, p. 193) Heelan's understanding of instruments is embedded in a hermeneutic view on understanding. Therefore, he uses terms like *reading* and *text* when describing the interpretation process of the products produced by instruments.

According to Heelan, to be able to read the text produced by instruments, one needs scientific training. When students first look through a microscope, for example, what they see will not yet make sense. However, when embedded in a workable scientific horizon, texts produced by instruments will become transparent. Since the scientist, as well as the instrument, are embedded in the same context of the scientific horizon, instrumental perception is equal to unaided perception (Heelan, 1989, chapter 11). Heelan states that "entities are or become directly *perceivable* […] because the measuring process can be or become a "readable technology," a new form of embodiment for the scientific observer" (Heelan, 1989, p. 203). Heelan argues that the instrument becomes an extension of the scientist's perception. He states that the scientist is even embodied in the technology. Physically and intentionally, the scientist and the instrument have become one. Thus, in Heelan's account, the instrument takes an important position between the knower and the world.

Heelan provides a detailed account of the position of instruments within a scientific horizon. Understanding the instrument is linked to the familiarity with the scientific horizon a scientist is working in. This idea can be related to Daston and Galison's idea of epistemic virtues. They also claim that instruments are closely related to epistemic virtues. Familiarity with an epistemic virtue is necessary for a scientist to relate to the scientific objects within this epistemic virtue and to be able to work within this context of the scientific practice, including its instruments. Building on these perspectives, I propose that scientific horizons, scientists, and instruments are closely intertwined. Scientific practices are intertwined with the instruments that are used in these practices. Likewise, the understanding of the scientific practice, its instruments, and the objects of study are intertwined as well. In the remainder of this thesis, I want to explore the intertwined relationship between the theoretical frameworks and beliefs in science (e.g., scientific horizons and/or epistemic virtues) and scientific instruments.

This chapter has situated my thesis in the science-as-practice tradition and discussed different perspectives on scientific practice and scientific instruments. Pickering's notion of historicity and his idea of the parallel dependency of the acceptability of scientific practice and the acceptability of phenomena, Daston and Galison's concept of epistemic virtues, and Heelan's perspective on the connection between the scientific horizon and its instruments all point to a similar conclusion: to study science, one needs to dive in the complex network of practices, beliefs, instruments, and scientists. Although all authors discussed in this chapter have given some attention to instruments, I aim to elaborate more on how the relation between instruments and beliefs in science can be understood in the following chapters. Heelan's account of the relation between science, scientists, and instruments provides ground for further elaboration on this intertwined relationship. Additionally, I have introduced two notions of objectivity and argued that these forms of objectivity are still present in today’s brain research. In the next chapter, postphenomenology will be introduced as a framework for understanding the role of instruments in science.

Chapter 2:

The subject, technologies and the world

In the previous chapter, I have argued that science's working objects, practices, and instruments are all interconnected. What science studies and how it is studied are interdependent. Heelan argued that instruments are embedded in a scientific horizon. So, instruments have a prominent place in science's network. The previously discussed accounts focused on how instruments are embedded in scientific practice and that scientists need to become familiar with the scientific practice before they can properly use and understand the scientific instruments. So, the understanding of scientific instruments is embedded in the scientific practice. This chapter's focus lies in the opposite direction. Is scientific practice to some extent also embedded in the instruments? Do instruments influence scientific practices, beliefs, what scientific objects are studied, and how the scientific objects are understood?

To answer this question, this chapter provides a short overview of relevant insights on technologies and scientific instruments from phenomenology and postphenomenology. In the postphenomenological framework, technologies are neither conceptualized as neutral intermediaries nor as determining factors in science. I will look at several authors that have written about the role of technologies in our perception of the world. These insights are extended to the role of scientific instruments in science in the last part of this chapter. First, I introduce phenomenology and its prominent thinkers. By discussing the founding father of phenomenology, Edmund Husserl, the most important insight from phenomenology – the interrelation between the subject and the world – will be introduced. Then, I discuss the main ideas on technology within phenomenology. I present Maurice Merleau-Ponty's analysis of the embodiment of tools and Martin Heidegger's tool analysis. Heidegger's most important work on technology will also be discussed. After this, I relate the insights from phenomenology to postphenomenology. After discussing the differences and similarities with phenomenology, I will present the main ideas from this trend. Finally, this trend is related to the philosophy of science, and it will show to be a generative framework for the study of instruments in science. Departing from the overview of the postphenomenological ideas in this chapter, chapter three will analyze how the postphenomenological framework can contribute to an understanding of the relation between brain imaging technologies and beliefs about the brain in brain research.

The subject and the world

A short overview of the main ideas in phenomenology is needed to grasp the position of technologies in these accounts. In my introduction to phenomenology, I limit the discussion to three core thinkers in phenomenology: Edmund Husserl, Martin Heidegger, and Maurice Merleau-Ponty. Husserl is seen as the father of phenomenology and central to an understanding of this trend. Husserl founded phenomenology, and many influential phenomenologists have formulated their ideas on the basis of, or as a reaction to Husserl's work. Heidegger is also an influential thinker in the phenomenological tradition. His contribution significantly transformed phenomenology (Moran, 2000). Besides, Heidegger cannot be excluded from a phenomenological discussion about technologies since he is one of the few early phenomenologists who has focused on technologies in his writings. Merleau-Ponty mainly contributed to phenomenology with his account of perception. However, the relevance of his ideas lies in his interesting example of tool use that he provides in his analysis of the spatiality of one's body and instruments one uses.

Phenomenology is a trend in European philosophy, which developed in the twentieth century. Phenomenology is an umbrella term covering various views that cannot easily be summarized in one coherent perspective. Although phenomenology includes a variety of perspectives, some general characteristics of this tradition can be mentioned. The main objective of phenomenology is to describe phenomena in the way they appear to the experiencer. Thus, phenomenology rejects a representationalist account of our experience of the world. In a representationalist account, knowledge of the world can be explained as a mental representation of the outside world. Instead of such a representationalist account, phenomenology is involved with the subject's direct experience and engagement with the world. An experience should not be described as the world, existing prior to the experience, appearing to the experiencer's consciousness. Rather, phenomenology emphasizes the importance of the experiencer being in the world and the act of experiencing as constituting factors of the experience. Phenomena should be described as how they appear to the experiencer. The experiencer is essential to experience: an experience is always an experience to some experiencer (Moran, 2000).

Besides emphasizing the subject's role in the experience, phenomenology also writes about the object of the experience. Husserl summarizes his ideas on the object of experience in his notion of *intentionality*. Husserl's idea of intentionality is an idea of aboutness. Every experience is an experience *of* something. A perception without something that is perceived is not a perception. Whether the object really exists or not does not matter. A non-existing object has a form of being in being an object of experience. Regardless of whether an object is in itself, it is for us as an object of experience. That an object is, is only experienced in the experience. The object is constituted in the experience. So, objects are necessarily connected to consciousness (Husserl, 2001; Moran, 2000, chapter 3 & 5).

Another important notion of Husserl, which is connected to intentionality, is the *horizon*. Besides experiencing an object, a perceiver also experiences the object's horizon. The horizons, which are present in perception, structure the experience. Horizons present the context of anticipations and possible future acts of an experience and, thus, give structure to this experience. The horizon includes the expectations one can have in perception. On the basis of future actions or perceptions, these expectations are confirmed or disconfirmed (Moran, 2000, chapter 4). For example, when you perceive a stove, this perception is related to the possibilities of turning on the stove, preparing dinner, and to knowledge that it is hot when turned on. Often, these kinds of expectations are confirmed. However, when you encounter a stove in a furniture shop, these expectations are disconfirmed since the stove is not connected to any gas or electricity, and there is no food to be found in the refrigerator next to it. Thus, the expectations are replaced by a different horizon of other possibilities; you can now consider buying the stove.

Heidegger does not adopt Husserl's notion of intentionality since Heidegger believes that intentionality is itself a theoretical construct, whilst Husserl aims to discard theory in order to focus on that what is given directly in experience. Instead, Heidegger uses the idea of *Being-in-the-world*. This idea is pre-theoretical (and pre-intentional) and points to an openness to the world. Where Husserl focused on aboutness, Heidegger focusses on directedness of the subject towards the phenomena. Although many more pages could be spent on this difference between Heidegger and Husserl, I will not dive into this issue. What I take from these two thinkers share the idea that both subject and object have a direct role in experience and are intertwined in their constitution. Additionally, Heidegger also emphasizes being in the world. Experiences are practical and embodied and situated in a context to the background of an unquestioned horizon of acceptance constituted by culture. (Heidegger, 1962; Moran, 2000, chapter 7).

Phenomenology opposes the objective, aperspectival ideal of knowledge. The emphasis of phenomenology on the influence of background perceptions in knowledge production recalls the science-as-practice tradition. It rejects the idea that science could achieve a view from nowhere. Instead, all knowing is embodied and embedded in a pregiven domain. In acts of understanding, horizons and background assumptions are always present. Phenomena are always encountered through experience that is embedded in background perspectives (Moran, 2000). So, even if a view from nowhere would be possible, it would make no sense since it would not be part of our familiar structures and knowledge of the world.

Like the science-as-practice tradition, phenomenology does not agree with the view of science as a progressive inquiry to the truth in which the accumulation of knowledge is not influenced by the context of the scientific practice. Where the science-as-practice tradition emphasized the importance of science's material and social aspects, phenomenology adds that knowledge only makes sense in relation to these background aspects. Phenomena are constituted in the experience and are thus necessarily intertwined with the nature and context of this experience. The subject matter of science is thus constituted in the context of science's investigation of this subject matter.

In the previous chapter, Heelan's horizonal realism was introduced. Husserl and Heelan thus share this idea of horizons structuring the subject's experience.[7] Although Husserl uses primarily ordinary, everyday examples to explain what he means with the horizon in an experience and Heelan uses this notion in the analysis of the scientific context, I believe that their conceptions point to the same idea. When observing an object, an experiencer will, besides perceiving the object, also be aware of this object's possibilities and contextual features. The valuable contribution of Heelan on this point is that he states that the scientific horizon differs in contextual features from the everyday context, which he explains by referring to Sellar's distinction between manifest images and scientific images. Objects are constituted in the scientific context differently, and Heelan sees a crucial role for scientific instruments in this process (Heelan, 1989, chapter 10).

The subject, *Technology* and the world

In Husserl's work, there is not much to be found on the topic of technologies. Husserl focuses on embodiment and perceptual experience, but technologies do not enter his analysis. Maurice Merleau-Ponty, an influential French phenomenologist, does present an analysis of tools in his account of embodiment. In his work, Merleau-Ponty focuses on perception and emphasizes the embodiment of perception. He claims that our embodied perception of the world is prior to our conceptual, rational encounter with the world. Embodiment is central to perception. One experiences the world as a situated body and surrounded by the possibilities within their situation. Because of its embodied nature, perception is actional and oriented (Moran, 2000, chapter 12).

Merleau-Ponty's emphasis on embodiment is also present in his conception of tools. He conceptualizes tools as an extension of the body and the senses. He first explains this idea with the example of driving a car: "If I possess the habit of driving a car, then I enter into a lane and see that "I can pass" without comparing the width of the lane to that of the fender, just as I go through a door without comparing the width of the door to that of my body" (Merleau-Ponty, 2012, p. 144). In his other example, the example of the blind man's cane, he further elaborates on how the tool becomes part of the subject's embodied experience of the world. Merleau-Ponty states:

> "The blind man's cane has ceased to be an object for him, it is no longer perceived for itself; rather, the cane's furthest point is transformed into a sensitive zone, it increases the scope and the radius of the act of touching and has become analogous to a gaze. In exploration of objects, the length of the cane does not explicitly intervene nor act as a middle term: the blind man knows

[7] Since Heelan builds his epistemology on phenomenology, it is not surprising he similarly uses the notion of horizons.

its length by the position of the objects, rather than the position of the objects through the cane's length" (Merleau-Ponty, 2012, p. 144).

In this example, the cane is not perceived as an object in the world: it becomes part of the subject's relation to the world. The tool is embodied and becomes part of the habit of the perceiving subject (Merleau-Ponty, 2012, p. 143-148).

Not only Merleau-Ponty includes tools in his phenomenology, Heidegger also presents an analysis of tools. Moreover, Heidegger has by far written the most on the topic of technology. Heidegger makes a sharp distinction between ready-to-hand (*Zuhandensein*) and present-to-hand (*Vorhandensein*) in his tool analysis. An object that is ready-to-hand reveals itself in use. It is not grasped as a thing but as an object *in-order-to*. It points to the manipulability of the thing. Heidegger uses the example of a hammer. A hammer is ready-to-hand because it refers to its uses. It refers to the nails, the wood, and to its use for constructing something. It points to its possibility of hammering. If an object is present-to-hand, it has called attention to itself rather than to its use and becomes an object of knowledge. In this case, the object is perceived theoretically. When the hammer, for example, is broken, the focus shifts from its hammering use to the object (the hammer) itself (Heidegger, 1962, sect. 15; Large, 2008).

Heidegger's most notable work on technology is his article "The Question Concerning Technology". In this paper, he reverses the relationship between technology and science. Technology is ontologically prior to science, rather than the other way around. To get a grip on this claim, I will briefly go through the main steps in his argumentation. First, it is important to know that Heidegger distinguishes technology or the technological from the essence of technology. The essence of technology is nothing technological. Second, Heidegger broadens his conception of *causes*. Rather than using *causes* to point to solely effecting, Heidegger uses it to point to being responsible in the sense of "an occasioning or an inducing to go forward" (Heidegger, 2014, p. 307). Heidegger links the occasioning with bringing-forth (*Her-vor-bringen*) and revealing. Bringing-forth means the revealing of the concealed. Taking these two points together, Heidegger argues that this revealing *is* the essence of technology.

After these first claims, Heidegger's argument becomes more dystopian. Modern technology neglects the bringing-forth, but instead, it challenges the world; it sets upon nature. In this demanding mode of revealing, modern technology forces nature to stand by for any ordering. Heidegger coins this the standing-reverse (*Bestand*). Humans are then also challenged to take part in this ordering of nature. Humanity is not also wholly transformed to standing-reserve, but humans are neither responsible for the ordering mode of revealing. Instead, it is the essence of technology that gathers humans into revealing in the mode of ordering the standing reverse. This whole way of revealing is coined enframing (*Gestell*).

To turn back to Heidegger's claim of the ontological priority of technology over science, it is the essence of modern technology, the enframing, that is prior to science. As said before, this essence is nothing technological and has been concealed for a long time before modern technologies came into being. Heidegger counters with this story the idea (he even calls it an illusion) that modern technology is applied to physical science.

Heidegger's story sketches a dystopian view on technology. He believes that the bringing-forth revealing will show the truth, and only in truth we can find freedom. Enframing blocks this bringing-forth and thus blocks the truth. Therefore, enframing, the essence of modern technology, is "the extreme danger" (Heidegger, 2014, p. 314).

The subject, technologies, and the world

Merleau-Ponty and Heidegger argue for a conception of technology that presents technology as more than merely an instrument or neutral intermediary. As Merleau-Ponty shows in his example of the blind man's cane, this tool becomes part of the relationship between the subject and the world. The cane is not merely a separate, disengaged instrument that is neutral with respect to the relationship between the subject and the world. In addition to Merleau-Ponty's analysis of the cane, Heidegger's notion of ready-to-hand shows that tools are conceived as relating to context features and possibilities of future actions with that tool. So, the world is perceived in relation to the tool and the possible actions with the world that the tool suggests. These ideas, which present a view on tools in which the tools have an important role in the relationship between the subject and the world, are useful for analyzing the role technology. However, Merleau-Ponty merely focuses on tools and does not elaborate on the role of technologies any further. Heidegger does expand on the subject, and although he is seen as one of the first philosophers of technology, his account includes some limitations.

First of all, Heidegger does not write about any specific technologies. In "The Question Concerning Technology," technology remains an abstract phenomenon. He talks about *Technology* and the essence of technology that is the *bringing forth*, and, in the case of modern technology, the *challenging* of the world. Disappointingly, Heidegger does not clarify the relationship between this essence of technology and concrete technologies that are part of our everyday life.

A second limitation is that Heidegger sees technology as something radically different and dangerous to our former existence in the world. As "The Question Concerning Technology" shows, Heidegger conceptualizes modern technology as something alien, something that intervenes with our relation to the world. His view presents technology as a dominating force. He thus holds a dystopian view of technology. In this thesis, I propose a less dystopian view of technology. The postphenomenological view sees technology as taking part in the intertwined relationship between the subject and the world rather than as a determining, dangerous force. Technology is neither a disturbing force that determines our experience of and interaction with the world nor a neutral intermediary. Technology does take part in this relationship and significantly impacts the interrelation between the subject and the world. I believe that this view on technology as taking part in the relationship between the subject and the world is more beneficial for presenting a detailed analysis of a concrete technology that is used in scientific practice than Heidegger's analysis of technology. However, Heidegger's work has formed the basis for a new trend in phenomenology, which was coined postphenomenology. Postphenomenology is based on phenomenology but is also radically different from phenomenology.

An important difference between phenomenology and postphenomenology is that postphenomenology tends to study concrete technologies rather than the abstract concept *Technology*. This tendency of postphenomenology can be related to the empirical turn in the philosophy of technology. Hans Achterhuis writes about this shift. According to Achterhuis, the empirical turn shifts the focus to the intertwined relation between technology and society. The emphasis lies on an empirically oriented philosophy of technology that attempts to understand this intertwined relationship, the co-evolution of technology and society rather than that it attempts to give an a priori evaluation of technology (Achterhuis, 2001, p. 1-10). Peter-Paul Verbeek, who is part of the postphenomenological tradition, adds that the philosophers of this new tradition approach concrete technologies and analyze their role in specific situations rather than searching for the essence of technology as Heidegger did.

Together with Verbeek, Don Ihde is an influential thinker in postphenomenology. Ihde himself introduced the term postphenomenology to point to a departure from phenomenology and, at the same time, to highlight a radical break with this tradition. (Verbeek, 2005, chapter 4) Ihde conceptualizes postphenomenology as a combination of pragmatism, phenomenology, and the philosophy of technology. Both pragmatism and phenomenology present an ontology in which the subject has a strong interrelation with the world. The relationality to the world is an ontological feature of the experiencer and his knowledge. Postphenomenology combines this perspective with the philosophy of technology, an analysis of technologies by studying concrete instances of technologies (Ihde, 2009). So, postphenomenology provides an account of the interwovenness of the subject, technologies, and the world.

Postphenomenology claims that technologies have a role in technologically mediating the relation between the subject and the world. Technological mediation is conceptualized as an extension or stretching out of the intentional relation between the subject and the world through technology. Technological mediation structures reality in our perception (Ihde, 2009; Verbeek, 2001). Ihde differentiates four different relations of technological mediation between the subject, technology, and world. First, he describes the embodiment relation ((I – technology) → world). In this relation, the world is perceived by a subject through a technology. In this way, technology mediates our perception. The technology needs to have a certain transparency since it should not be at the center of attention. The blind man with his cane, described by Merleau-Ponty, can be categorized as an embodiment relation. Also, Heidegger's hammer that functions perfectly and is ready to be used can be put in this category. Second, there is the hermeneutic relation (I → (technology – world)). The hermeneutic relation is somewhat similar to the embodiment relation. However, in the hermeneutic relation, the technology does not appear transparent. Rather, it provides a representation that requires reading or interpretation. The subject reads the world through the technology. The world is perceived by means of the technology. Heelan's readable technologies, discussed in the previous chapter, would be part of this category. Ihde recognizes the similarity with Heelan but is also critical of Heelan's ideas. According to Ihde, Heelan collapses the embodied relation and the hermeneutic relation into one hermeneutic relation. Instead, Ihde claims that not all perception involves reading nor measurement. Thus, not all perceptions can be captured in a hermeneutic relation (Ihde, 1991, chapter 4). Third, Ihde names the alterity relation (I → technology (world)). In this relation, the technology becomes a quasi-other. It is autonomous and able to interact. Fourth, there remains the background relation (I (- technology/world)). In this relation, the technology is not the center of attention and is often not consciously experienced. This relation describes how technologies mediate the context of our experience (Ihde, 1991, chapter 4, 2009; Verbeek, 2001). This last form of relation is reminiscent to the phenomenological notion of horizons.

Phenomenology presents a view in which subject and object are constituted in their interrelation. In this sense, the interrelation precedes the subject and object. The four different kinds of relations presented by postphenomenology provide insight into the role of technology in this interrelation. Technologies have a mediating role in the interrelation between subject and object. In other words, technology mediates experience. Since the interrelation precedes the subject and object, the mediation of technologies also precedes the constitution of subject and object. Ihde captures this in his notion of technological intentionality. Ihde rejects the determinist view on technology. He neither accepts a neutral picture of technologies. Instead, he speaks about technological intentionality. Technological intentionality points to the idea that technologies frame the actions between the human and the world. Technologies promote a certain trajectory; they provide an inclination to do something in a specific way or to look at the world in a particular manner (Verbeek, 2001). A mobile phone, for example, promotes a different trajectory than a landline. The landline limits the user in his calling location. Opposingly, a mobile phone presents the possibility of walking around while calling, or calling en route. A mobile phone 'asks' users to be available anywhere, where the landline did not. A mobile phone does not force you to call from outside, but it does present a different trajectory than the landline did and, by doing that, plays a role in our actions.

However, technologies do not always have to afford the same trajectory since, according to Ihde, technologies are multistable. Simply said, multistability means that technologies are what they are in use.

Following the notion of multistability, the essence of a technology will stay undetermined. Moreover, the essence is not what we should look for. Rather, an object or technology can be several different things depending on its context. With multistability, Ihde does not mean to say that technologies are unstable nor indeterminate. Instead, a technology can be stable in one context and can be differently stable in another. Ihde uses the analogy of a Necker cube to explain his notion of multistability. The Necker cube is a visual illusion that presents a three-dimensional cube that can be reversed. So, two possible images can be seen in only one drawing. However, both these images are stable, and neither one is more true or real than the other. Ihde explains that the same is the case for technologies. He expands on this notion with the example of archery. Many different forms of archery were developed: the English longbow, the Mongolian mounted archery, and the Chinese Artillary bow. None of these bows is more bow-like than the others. Rather, the various forms in which archery has developed are shaped in relation to a specific context. For example, the bodily technique of holding and firing the Mongolian horse bow has gotten its shape in the context of it being used by Mongolian horsemen mounted on speeding horses as opposed to the English soldiers who fired their longbow from a stable position (Ihde, 2009; Verbeek, 2001). The same technology can thus develop into multiple stable forms and is, thus, multistable. A technology does not have a determined essence but can develop multiple stable forms in different contexts.

Postphenomenology and the philosophy of science

Ihde distinguishes two levels of perception: microperception and macroperception. Microperception is bodily, sensory perception. Microperception grasps the immediate, bodily experience of the world. It is involved with the literal meaning of *seeing*: I *see* a tree. Macroperception is cultural, hermeneutic perception. In macroperception, interpretation is involved. Often, macroperception does not consciously interplay with our experiences. It is taken for granted. Macroperception relates to a different meaning of the verb *seeing*: Now that I know the truth, I *see* things differently. Here, an interpretation of the situation, or in other words, the world, is involved. Although Ihde distinguishes these two dimensions of perception, he also states that they are inseparable (Ihde, 1990, chapter 2, 1991, chapter 2; Verbeek, 2001). Verbeek clearly explains how Ihde believes these two to be intertwined: “A bodily perception can no more exist without being interpreted than an interpretation can exist without something to be interpreted” (Verbeek, 2001, p. 124). Ihde explains this with an example. The ancients saw the moon as having an even, mirror-like surface. Even though our microperception (perceiving the moon with the naked eye) is similar to the ancients’ perception, we are not able to unsee a textured moon. Our bodily perception has become post-telescopic perception. Because our interpretation of the world (macroperception) has changed, our bodily perception (microperception) has changed (Ihde, 1998, chapter 12).

Ihde links his philosophy of technology to the philosophy of science. Ihde parallels his notion of macroperception with Kuhn's *paradigms* and Michel Foucault's *epistèmè*. All three notions emphasize the importance of scientific knowledge's dependency on its material, social, and – in the case of Foucault – linguistic context. Ihde even claims that Kuhn approaches the notion of intentionality (Ihde, 1991, chapter 2). He explains: "If the "world" changes in a paradigm shift, the object or reference of perception within its entire field changes; it *reflexively* implies a change of some kind in the perceiver" (Ihde, 1991, p. 16). So, after a paradigm shift, the way a scientific community *sees* the world has changed. In other words, the macroperception of a scientific community has changed, which is inextricably bound to microperception.

Furthermore, on the microperceptual level, Ihde argues that scientists' perceptions are mediated by technologies. Instruments are the conditions for and mediators of scientific knowledge. Although the philosophy of science has shifted its attention to scientific knowledge's dependency on context, it has paid little attention to this microperceptual level that emphasizes the material embodiment of science, according to Ihde. The ways of seeing in science are grounded in technologically mediated perception. Modern science is, according to Ihde, embodied in its instrumentation. It is technologically embodied. From this view, Ihde arrives at his position of instrumental realism. In short, this view holds that scientific reality is constituted in relation to the subject and the instruments used for observation. So, the scientific objects that are studied are constituted in the context of the scientific instruments used (Ihde, 1991).

Ihde elaborates on this view in *Expanding Hermeneutics*. He arrives at an interesting view on the instrumental mediation of scientific knowledge. In the last part of this book, Ihde argues that science prepares reality into scientific objects using scientific instruments. He argues that scientific reality is prepared in the technologically embedded experience. Ihde extends hermeneutics to the realm of things, a hermeneutics of things, or, in other words, material hermeneutics (Ihde, 1998).

Ihde distinguishes within material hermeneutics two programs: the weak and the strong program. In the weak program, instruments are believed to partly determine the interpretation of reality. In science, the subject "sees *through, with, and by means of instruments*" (Ihde, 1998, p. 159). This view refers back to the embodiment and hermeneutic relation and is similar to Heelan's idea of readable technologies. Ihde similarly states that instruments turn reality into readable scientific objects. Instruments can make reality readable to scientists in roughly two ways, according to Ihde. First, instruments can make the invisible visible. Often, this transformation involves magnification or the translation of invisible measurements into something visible, such as X-rays. Second, reality can be translated into text-like structures. Ihde presents the same example for this manner of making reality readable as Heelan used in his explanation of readable instruments; the thermometer (Ihde, 1998, chapter 12).

The strong program is more radical than the weak program. The weak program shows that there is a hermeneutic dimension in the instrument's translation of scientific objects, which guides the interpretation of the scientist. The strong program states that this hermeneutic dimension is essential to the constitution of scientific objects and knowledge. The instruments involved in this hermeneutic dimension are thus constitutive of scientific objects. Ihde terms this *technoconstitution*. Objects are technologically mediated. The scientific instruments prepare an object for investigation. Ihde explains: “Things have been prepared to be seen, to be “read” within the complex set of instrumentally delivered visibilities of scientific imaging” (Ihde, 1998, p. 183). An object is, thus, made readable as a scientific object (Ihde, 1998, chapter 13).

Ihde makes in *Expanding Hermeneutics* some broad claims about imaging technologies. He states that science is dominated by imaging technologies and the visualizing practice. Having the appeal of the visual in mind, Ihde warns for ‘naïve image realism’. Visualizations are not a transparent representation of reality. Instead, he emphasizes: “[I]mages don’t just occur. They are made.” (Ihde, 1998, p. 180).

This chapter has introduced the postphenomenological view on technologies and scientific instruments. Husserl, Merleau-Ponty, and Heidegger were discussed as the relevant phenomenological thinkers on whose insights the postphenomenological authors build their ideas. Merleau-Ponty’s ideas highlight the importance of the embodiment of perception. His example of the blind man’s cane can be described as an illustration of an embodiment relation. Heidegger’s tool analysis points to the embeddedness of a tool. The subject relates to a tool in a specific manner depending on the context.

Building on the phenomenological ideas, postphenomenology introduces an interesting framework for understanding the relationship between technologies, the subject, and the world. This framework revolves around the idea of technological mediation. Technologies can fulfill different mediating roles. Especially the embodiment relation and hermeneutic relation are of importance for understanding the role of scientific instruments. In their position in between the subject and the world, technologies can present certain trajectories for action. Here, it is important to note that technologies are multistable and, thus, they do not present one necessary trajectory of proceedings.

In the last part of this chapter, the postphenomenological framework was related to the philosophy of science. Ihde proposes a material hermeneutics, which can be understood on two levels. First, science incorporates a hermeneutic dimension in which instruments play an important role by making aspects of the world visible. Second, Ihde argues that instruments prepare the scientific reality in this hermeneutic dimension. So, the perception of scientific reality is technologically mediated, and thereby the technological mediation constitutes scientific knowledge.

In order to grasp the use of the postphenomenological framework for understanding the role of brain imaging technologies, it is useful to consider some examples of studies that have applied this framework to their study of instruments and beliefs in brain research. Several examples will be discussed in the next chapter.

Chapter 3:

Studying brain images and brain imaging technologies

In the previous chapter, I introduced and explained the postphenomenological view on technology. Postphenomenology positions technologies within the subject-world relationship. In this chapter, I will analyze a few postphenomenological studies in which this framework is applied to scientific practices in brain research. In addition, these accounts will be analyzed in relation to some other accounts that do not build on postphenomenology.

Postphenomenological studies of brain images and brain imaging technologies

In this first part, I will discuss two different uses of the postphenomenological method to analyze scientific practice in brain research. The first example focuses on the multistability of images and the hermeneutic strategies involved in the different interpretation of these images. The second example focuses on how scientific technologies have a role in the constitution of scientific objects by differently managing epistemic norms.

Understanding brain images: mediation, multistability and material hermeneutics

Two articles written by Robert Rosenberger provide the first illustration of the postphenomenological method being applied to the study of brain research. Rosenberger is himself part of the postphenomenological tradition and has written two articles on the use of images in neurobiology: "Quick freezing philosophy" (2009) and "A case study in the applied philosophy of imaging" (2011). Rosenberger builds on Ihde's postphenomenological philosophy of technology and aims to contribute to an 'applied philosophy of imaging.' With an applied philosophy of imaging, Rosenberger has the ambitious goal of contributing to contemporary scientific work and debates in society by providing insights into image-making and image interpretation.[8] According to Rosenberger, building on Ihde's postphenomenology of technology is one way to contribute to an applied philosophy of imaging (Rosenberger, 2009, 2011).

[8] Based on Google Scholar references to Rosenberger's articles, it does not look like his applied philosophy of imaging has had any direct impact in the field of neurobiology.

According to Rosenberger, the added value of phenomenological and hermeneutic accounts of image-making and image interpretation lies in the thorough analysis of a scientist's experience of image perception (Rosenberger, 2011). The experience is central to a phenomenological account, which considers the relation between the perceiver and the perceived as being constituted in this experience. The tradition Rosenberger builds on thus regards neither the scientist nor the scientific image as stable entities.

Rosenberger adopts Ihde's concepts of *mediation*, *multistability*, and his idea of *material hermeneutics* for his analysis of image interpretation in science. Technological mediation refers to the role that technologies have in altering the relationship between the subject and object (Ihde 1998). Rosenberger holds a narrow interpretation of mediation. He explains: "In scientific practice, this kind of mediation occurs as researchers use instruments […] to make otherwise unobservable phenomena visible in the form of images" (Rosenberger, 2011, p. 13). This interpretation of mediation is very similar to Heelan's idea of *readable technologies*, which I have introduced earlier. Readable technologies make imperceptible entities visible to the human observer. In this process of translation, of the unobservable to something observable, the readable technology presents new standards in reference to which the phenomenon is observed (Heelan, 1989). Other interpretations of Ihde's mediation are much broader. For example, Verbeek explains mediation as conceiving the world *through* an artifact. In this interpretation, a technology can, besides being involved in a translation process of the observed entity, also magnify or isolate aspects of the world (Verbeek, 2001).

Multistability points to the idea that technologies can have various stable forms depending on the context. As Rosenberger explains, multistability asks for an investigation of these variations of an image or a technology. With his material or visual hermeneutics, Ihde compares the interpretation of a technology or an image to the reading of a text. As one needs to understand the language of a text in order for the text to be meaningful to them, certain knowledge, skills, and familiarity with the context are also needed to have a meaningful interpretation of a technology or an image (Ihde, 2009). Rosenberger connects this to scientific images. He explains that familiarity with the context of an image is needed for a meaningful interpretation of the image (Rosenberger, 2011).

With mediation, multistability, and material hermeneutics in mind, Rosenberger elaborates on the idea of a *hermeneutic strategy*.[9] This idea is connected to both material hermeneutics and multistability. The various stable forms of an image are made possible by different hermeneutic strategies. Rosenberger defines a *hermeneutic strategy* as "the framework of interpretation and the interpretive skills one brings to a multistable image to enable a particular variation" (Rosenberger, 2011, p. 14). So, different hermeneutic strategies make different interpretations of an image possible.

[9] This term originates from Ihde's work (*Experimental Phenomenology*, 1986) but is further developed by Rosenberger (2011). The latter is of importance here.

Whilst Ihde extends the idea of multistability to technologies, Rosenberger focuses on images in science. An image is interpreted in the context of a specific hermeneutic strategy. This strategy includes a certain theoretical framework and is related to imaging technologies. According to Rosenberg, and in line with postphenomenology, viewing an image as multistable and investigating the available hermeneutic strategies is a useful approach to understanding scientific debates. Although Rosenberger focuses on images, he also considers imaging technologies as an important part of the scientific practice since these technologies play an important part in developing hermeneutic strategies (Rosenberger, 2009, 2011).

Based on Ihde's concepts, Rosenberger formulates "a postphenomenological methodology for the interpretation of scientific debates over technical images" (Rosenberger, 2009, p. 67). He distinguishes three steps in this methodology. First, images should be conceptualized as multistable. So, there are multiple, reasonable interpretations of an image. Second, the different variations and their hermeneutic strategies should be identified. Third, the role of mediating technologies in the different hermeneutic strategies should be examined. Imaging technologies can reframe the phenomenon studied spatially or temporally. Spatially, the object can, for example, be reframed by being magnified. A phenomenon can be reframed temporally by, for example, presenting a dynamic process in still snapshots. What role this transformation has in the hermeneutic strategy should be examined in the third step of this methodology (Rosenberger, 2009).

Rosenberger uses this methodology to analyze the synaptic vesicle debate in neurobiology. A synaptic vesicle is an organelle in neurons, which is responsible for neurotransmission. Synaptic vesicles fuse with the cell membrane to release neurotransmitters into the synapse. In neurobiology, there is debate about whether exocytosis – the fusion of a vesicle with the cell membrane – and endocytosis – a vesicle separating from the cell membrane – should be regarded as one event or as two separate events. One side of the debate claims that the vesicle fuses entirely with the cell membrane when releasing neurotransmitters before a new vesicle is developed and released from the membrane. The other side argues that the vesicle never fully collapses into the cell membrane and detaches as soon as it has released its neurotransmitter (Rosenberg, 2009, 2011).

Using advanced imaging techniques (freezing technologies and electron microscopy), scientists can make an image of synaptic vesicle fusions. Although the different sides of the debate agree on the use of these imaging technologies, they differently interpret the image. The one side argues that the image shows the vesicles completely fusing with the membrane. The other side argues that the image shows a vesicle that temporarily fuses with the membrane to release the neurotransmitter and that it would immediately pinch off again (Rosenberger, 2009, 2011). Following Rosenberger in the first step of the postphenomenological methodology, these images are thus multistable and can be interpreted in line with two different neurobiological theories.

Additionally, Rosenberger distinguishes the two sides of the synaptic vesicle debate as two hermeneutic strategies that make these variations meaningful. The theoretical background and previous studies provide the substantiation for these two hermeneutic strategies. Rosenberger furthermore believes that instrumentation has a role in these hermeneutic strategies by transforming the phenomenon that is investigated. As most important, he points to the temporal transformation of the vesicle fusion. Vesicle fusion happens at a speed not perceivable to the human observer. Using the freezing techniques, moments during this process can be made visible by translating the process into a representation of a single moment within this process. Because of the absence of a representation of the dynamic process, both interpretations of the image are reasonable (Rosenberger, 2009, 2011).

With this analysis and by critically questioning these hermeneutic strategies that make the scientists interpret the images differently, Rosenberger believes that productive trajectories for further research can be found. The careful consideration of both hermeneutic strategies encourages researchers to test the crucial aspect of these two theories. So, in this way, these postphenomenological concepts can be used for an applied philosophy of imaging (Rosenberger, 2009, 2011).

So, in short, Rosenberger uses postphenomenological concepts to develop an applied philosophy of imaging. By considering scientific images as multistable, the different hermeneutic strategies involved in interpreting these images can be dissected. As a third step in Rosenberger's methodology, the mediating role of the scientific instruments in these hermeneutic strategies can be investigated. With this strategy, Rosenberger hopes to point out the crucial aspects of different sides in scientific debates and contribute to ongoing research.

Understanding brain imaging technologies: constituting scientific objects

The article "Constituting 'visual attention'" written by Bas de Boer, Hedwig te Molder, and Peter-Paul Verbeek shows a different use of postphenomenology in the study of brain research (2020). In this article, the postphenomenological approach is used to investigate the relation between scientific instruments and scientific reality rather than that it focuses specifically on images. The article claims that scientific phenomena are constituted within the experiment and depend on the mediation of the scientific technologies used.

Like Rosenberg, the authors use postphenomenology as a framework for this analysis of the role of technologies in the constitution of scientific objects. The concepts of technological mediation and material hermeneutic processes are essential to their analysis. Their analysis does not relate to the idea of multistability.

This paper follows the broad, instead of Rosenberger's narrow, definition of technological mediation. The authors emphasize that this technological mediation is not a determination. Rather, the relation between the scientist and the scientific object is mediated by technology. Both the subject and object are constituted within this relation. The authors explain: "understanding how scientists relate to technologies becomes a way to understand how scientists and the objects of study mutually constitute one another" (De Boer et al., 2020, p. 4). So, they argue that different technologies result in the constitution of different scientific realities and scientific observers. In their paper, they explicate how instruments are connected to the constitution of scientific objects. How the scientific observer is constituted in relation to the instrument and scientific object remains underexposed.

In line with postphenomenology, the authors believe that scientific instruments translate objects of research into readable objects that can be interpreted by scientists. The translation can be seen as a technological mediation. In this process of translation, the scientific object is constituted and thus shaped. The process of translation is a material hermeneutic process and is thus related to the process of interpretation of the scientific object.

The authors argue that postphenomenology lacks translation to empirical findings. Therefore, they combine insights from postphenomenology with a *Conversational Analysis* (CA). CA studies the social interaction and language used by a group of participants. It analyses how participants orient themselves towards norms and thereby construct their reality. The authors believe that scientific objects, such as visual attention, emerge in the scientific process and its social interaction. So, with their CA, it is analyzed how the scientists construct a meaningful reality and, additionally, the postphenomenological tradition emphasizes the importance of taking technologies into account.

The case study of this paper is an investigation of how 'visual attention' as a scientific object is constituted in studies. This scientific object is differently constituted in studies that only use Non-Invasive Brain Stimulation (NIBS) compared to studies that combine NIBS with electroencephalography (EEG). According to the authors, visual attention as a scientific object is constituted based on the scientific norms of causality and reality. The analysis shows that these scientific norms are not straightforward but need to be oriented. Scientific objects art not fixed but are constantly revised in experiments.

In studies using only NIBS, the causal structure of the experiment is not questioned. The stimulation of a brain area is causally related to the behavioral change following this stimulation. This causal relation is carefully maintained and unproblematic. The difficulty in the experiments using NIBS is connecting causality to reality. So it is questioned how this unproblematic causal relationship within the experiment relates to reality, the world outside the laboratory.

When NIBS is combined with EEG, the norms of causality and reality are differently managed. The combination of methods introduces a new variable: neurophysiological change recorded using EEG. The causal relationship between the stimulation and the behavioral change can now be measured by observing neurophysiological changes. Because of that, causality within the experiment is questioned. The reality of the causal relationship between the stimulation and the behavioral change is problematized.

With this case study, the authors show that the orientation of the scientists to the norms of causality and reality is not fixed and needs to be taken into account. Based on this, they argue against the idea that different neuroscientific practices can be combined unproblematically. The difference between studies using only NIBS and the studies using NIBS and EEG shows that using different technologies leads to a different constitution of a scientific object. Consequently, various research using different instruments cannot simply converge into one explanation of cognition.

Thus, De Boer, Te Molder, and Verbeek aim to show in their analysis that scientists manage epistemic norms in relation to the instruments they use. Scientific instruments thus mediate the constitution of the scientific object within the experiment. Therefore, different research using different instruments cannot be unproblematically combined.

To recapitulate, the two postphenomenological views discussed are quite different in many respects. Rosenberger focuses on differences in the interpretation of scientific images, whilst De Boer, Te Molder, and Verbeek analyzed how scientific objects are constituted in accordance with the technologies used. Rosenberger did not make any claims about the constitution of the synaptic vesicle as a scientific object in these experiments. He only mentioned that the process of transmission was transformed into a single snapshot in the experiment, which was as far as the concept of mediation was used in his analysis. In De Boer, Te Molder, and Verbeek's analysis, the interpretation of the representations is not part of the discussion. Their use of the notion of mediation focuses on an extensive description of how visual attention is constituted as a scientific object.

Although both papers base their conception of material hermeneutics on Ihde's work, there is an interesting difference in the use of the idea of material hermeneutics between the two accounts. Rosenberger focuses on the role of hermeneutic strategies that give rise to the different interpretations of images, whilst De Boer, Te Molder, and Verbeek use material hermeneutics to describe the processes that create scientific objects. Rosenberger talks about hermeneutic strategies as "the interpretive frameworks that enable different image readings" (Rosenberger, 2011, p. 7). Contrastingly, De Boer, Te Molder, and Verbeek write: "we must focus on these hermeneutic processes that give rise to the existence of scientific objects" (De Boer et al., 2020, p. 3). This difference can be related to the distinction between Ihde's strong and weak program of material hermeneutics. The weak program is concerned with how instruments are involved in creating different interpretations of reality and thus similar to Rosenberger's use of material hermeneutics. De Boer, Te Molder, and Verbeek seem to be closer to the strong program since they focus on how instruments co-constitute scientific objects within the hermeneutic process.

Rosenberger's analysis leans mainly on the postphenomenological concept of multistability, whilst De Boer, Te Molder, and Verbeek hinge on the idea of technological mediation. I believe that this difference results in a different approach to the analysis of technological mediation. Rosenberger aims to arrive at a discussion of technological mediation by first establishing the multistability of an image and by dissecting the hermeneutic strategy involved in the interpretation of the image. This third step remains subordinate in his analysis of the synaptic vesicle debate. Contrastingly, De Boer, Te Molder, and Verbeek start their analysis by investigating the technological mediation of visual attention as a scientific object.

Although Rosenberger explicitly states that the third step of his postphenomenological methodology investigates the role of technologies in the hermeneutic strategies, it strikes me that this part of his analysis stays behind. In his case study, the involved technologies are freezing technologies. I claim that his analysis shows how this technology results in an image that is multistable, instead of showing how this technology is related to the specific hermeneutic strategies involved. Because freezing technologies present a snapshot of the process, instead of giving a dynamic representation of the process, multiple interpretations of the image are possible. If the technology would record the whole process in detail, only one of the interpretations present in this debate could be fitting. So, the freezing technologies are involved in creating a multistable image. However, Rosenberger does not explicate how technology plays into the constitution of these two different beliefs.

Non-postphenomenological studies of brain images and brain imaging technologies

Having introduced two examples of postphenomenological studies of scientific practice in brain research, I will turn to two similar accounts of images and instruments in brain research that do not build on postphenomenology. The first non-phenomenological analysis focuses again on images, similar to Rosenberger's. The second is more similar to De Boer, Te Molder, and Verbeek's analysis and focuses on the relationship between instruments and scientific beliefs.

Understanding brain images: contexts and suites of technologies

Beaulieu discusses the role of brain scans in scientific research and the popular media in her article "The brain at the end of the rainbow" (2000). Both the role of images and the view on technologies are central to this discussion. She does not build on postphenomenology. She is active in the field of science and technology studies and mentions that her approach is endorsed by a feminist methodology that focuses on the contextualization of scientific knowledge. In addition to this paper by Beaulieu, the article "Networked neuroscience" written by Sarah de Rijcke and Anne Beaulieu adds the interesting concept of *suites of technologies* to the discussion (2014). This notion points to the idea that brain scans need to be understood as embedded in a digital and networked context. De Rijcke and Beaulieu investigate brain imaging atlases as part of the suite of technologies of brain scans. This analysis is based on ethnographic research and archival analysis of brain atlases.

Beaulieu writes about various interpretations of brain scans. She does not use the term multistable, but her analysis does suggest that different interpretations of brain scans exist in different contexts. Beaulieu aims to show with her analysis that the visual character of brain imaging technologies is approached in various ways. There is a “mosaic of understanding of images.” (Beaulieu, 2000, p.43). Beaulieu's analysis differs from Rosenberger's in that it focuses on the difference between the interpretation of brain scans in the popular and in the scientific context, instead of looking at differences within the scientific context.

In the popular context, brain scans are mostly regarded as an image of the brain, Beaulieu argues. The brain is understood as a network of connections. Machine metaphors are often used in describing the brain, such as *output and input*, *wired*, *network*, and *processing*. As mentioned in the first chapter, Beaulieu relates the popular understanding of images to the idea of *mechanical objectivity* proposed by Daston and Gallison. In this popular understanding, images are seen as objective, and the technologies are seen as impartial. Technologies are unbiased and are therefore able to give an undistorted picture of the object. In this approach to brain scans, the directedness and wiredness of the brain are omnipresent.

Beaulieu distinguishes three different kinds of transformations of brain scans as they move from the scientific to the popular context: simplification, discrimination, and interrelation. Brain scans used in popular contexts are often simplified. As a result of this simplification and making the representation apprehensible, new objects become visible. The simplification also presents new relations between different brains. Brain scans are often paired with an opposing example. These instances are easily taken to be identical to the labels put on these scans (such as ‘healthy brain’ and ‘abused brain’). The images are often seen as presenting the label, while in fact, often the different instances belonged to the different labeled groups before the start of the scanning.

In the scientific context, it is emphasized that a representation of the brain is realized by careful statistical measurements. Visualizations can contribute to an understanding of a representation, but brain scans are not near a photograph of the brain. Brain scans provide a measurement of the brain. The bright colors in images of the brain are not the real brain activity but are the measured and statistically endorsed variation in brain activity. However, also in the scientific context, it is acknowledged that brain scans are impressive and compelling. This is seen as a dangerous aspect of these scans. She states: “Many visual technologies have been shown to participate in the creation of new forms of social control or of new objects of study” (Beaulieu, 2000, p. 43).

Beaulieu believes that this difference in understanding these representations of the brain is caused by a difference in the view on images. Beaulieu captures this difference as follows: “Images are an epistemically new approach to the brain ("we can now see it") in popular accounts, while they have a heuristic role for neuroscientists ("we can now make measurements of it")" (Beaulieu, 2000, p.45). What images have to say, how they are interpreted, and what they mean thus derives from this distinction.

In their paper, de Rijcke and Beaulieu ask how the authoritativeness of brain scans is actively constituted. This authority is constituted in the *suites of technologies*. The suites of technologies incorporate all kinds of tools in which a brain scan is embedded. They state that the suites of technologies "include digital images, data models, databases, screen-based interfaces, and electronic networks" (de Rijcke & Beaulieu, 2014, p. 132). What an image means is dependent on its suite of technologies. How scans are constituted and what scans mean is embedded in a network of related technologies. They argue against the view on brain scans as giving a mechanical objective representation of the world. Rather brain scans are complex and contextual features have to be taken into account in constituting the meanings of brain scans. That the meaning of brain scans depends on its suites of technologies emphasizes this claim that scientific representations should not be seen as fixed, objective representations of the world (de Rijcke & Beaulieu, 2014).

They show that in the context of digital brain atlases, brain scans are transformed using standardized protocols to organize scans using different technologies and make them comparable and aggregated. The suite of technologies is essential to understanding the epistemic and ontological meaning of the brain. Digital atlases organize and display their information spatially. Images of the brain are constituted as a set of voxels that emphasize the spatial organization of the brain. Spatial aspects of the brain can be highlighted, labeled, or compared across different instances. These images thus present the spatial structure of the brain and are often regarded as expressing brain functions or even cognition (de Rijcke & Beaulieu, 2014). The brain as an epistemic object is thus constituted in these images that are dependent on the suite of technologies.

Suites of technologies emphasize the mutual dependency of scientific observers, the scientific object (the brain), the technologies involved, and the institutional context. It is important to note that these suites of technologies consider a broader scope of technologies than only scientific instruments. Not only the use of brain scanners but also the use of digital images or networked computer is part of the suite of technologies. Shifts in the suites of technologies result in shifts in the relation between the scientist, object, technology, and institution. De Rijcke and Beaulieu show with their analysis that technological developments do not only affect "the way data is processed, integrated, and visualized" (de Rijcke & Beaulieu, 2014, p. 134) but also constitute various roles for the scientific observer. They claim: "the kinds of brains produced are changing along with the kinds of instruments, kinds of work and kind of experts needed" (de Rijcke & Beaulieu, 2014, p. 145).

Beaulieu thus shows how brain scans can be differently interpreted in the popular context and the scientific context. In these different interpretations, brain scans have a different meanings. De Rijcke and Beaulieu additionally emphasize that the suites of technologies have an important role in the constitution of brain scans.

The comparison between de Rijcke and Beaulieu's ideas and postphenomenology shows the value of their idea of suites of technologies. (Post)phenomenological accounts are often quite individualistic. They emphasize the relation between *the* subject, *the* technology, and *the* object. De Rijcke and Beaulieu add an important factor: the suite of technologies. With this concept, they highlight that the relation between the subject, the technology, and the object is always part of a larger context. In this context, a scientific instrument is embedded in a network of other technologies. The meaning and workings of a technology depend on this context of technologies.

Rosenberger's analysis and de Rijcke and Beaulieu's account are quite similar in some aspects. Both speak about images and their interpretation. Rosenberger emphasized the multistability of scientific images. Beaulieu similarly emphasized how brain scans can be interpreted differently in various contexts. Also, in this context, the idea of suites of technologies is of interest. If the idea of multistability is extended to Beaulieu's analysis, suites of technologies also turn out to be a useful concept. Different suites of technologies could shape different hermeneutic strategies – to talk in Rosenberger's term – which will constitute different interpretations of images. I suggest that the idea of suites of technologies could provide a useful addition to the analysis of hermeneutic strategies.

De Rijcke and Beaulieu are also close to the postphenomenological trend in that they note that the meaning of brain scans is actively constituted. They claim, for example, that the visuality of brain scans has contributed to the authoritativeness of these images and of brain research. This is similar to Ihde's warning against naïve image realism. Images do not just appear, but they are actively made.

Understanding brain imaging technologies: shaping theorizing

Cornelius Borck emphasizes the role of instruments in shaping theorizing about the brain in his article "How we may think" (2016). He investigates how instruments are entangled with the world that is investigated. His analysis focuses on brain research. He aims to show that the use of a certain kind of instrument results in the use of a certain research methodology. Subsequently, the use of specific instruments and methodologies shape theorizing about the brain. He claims: "The mobilization of particular instruments and specific technologies opens up distinct avenues of investigation, shaping the respective theories of thinking." (Borck, 2016, p. 119) These epistemological effects of scientific instruments are central to Borck's investigation.

Borck's position is not built on phenomenology or postphenomenology. Rather, his ideas are related to the history of science and rely on the German and Canadian schools of media theory. The media theory schools focus on the epistemologically constitutive role of technologies instead of the history of science's focus on the interaction between the scientist and the instruments. In this view, instruments are more than mere means of communication; they are media of information, perception, and representation. Borck regards scientific instruments as having a double role. Instruments make specific parts of reality visible to the scientific observer, and they shape the research object in making it visible (Borck, 2016).

Borck aims to present a historical epistemology of the use of scientific instruments in brain research. Using the ideas from media theory, he groups different methods with their specific investigative tools into his historical epistemology. Borck aims to describe how instruments and research methodologies interact with theorizing about the brain. He aims to describe the research technologies' *epistemic effect*. This approach does not aim to describe the relationship between research technologies and the 'real' entity. Instead, it aims to describe the role of research technologies in constituting the brain as a scientific object and how research technologies thereby shape theorizing and direct further research (Borck, 2016).

In his historical epistemology of neuroscience, Borck distinguishes the *imaging* and *writing* approach. Borck relates this idea to Peter Galison's differentiation between image and logic. Galison makes the distinction between two experimental traditions. The image-tradition represents reality through images of singular events. This tradition relies heavily on the visual. The logic-tradition focuses instead on statistical methods and large amounts of quantitative data (Galison, 1997). The imaging and writing approach deviate somewhat from Galison's distinction since both relying on imaging. Nevertheless, the approaches Borck distinguishes still present a different mode of visualization that relates to Galison's distinction. Borck equates the distinction between the imaging and writing approach with the distinction between iconic and indexical signs. The imaging approach presents a mimetic representation of the brain, while the writing approach presents a measured and often encoded representation of the brain. The imaging approach is related to morphological investigations and focuses on the spatial organization of the brain. Contrastingly, the writing approach is related to functional investigations into the brain and focuses on temporal aspects (Borck, 2016).

The imaging approach looks for spatial structures in the brain. Typical methods in the imaging approach are anatomical and histological preparations. More recent developments in the imaging approach are electron microscopy and in-vivo techniques such as magnetic resonance imaging. The imaging approach focuses on morphology, on the spatial structures in the brain. Borck describes a few historical examples to demonstrate how different techniques supported different brain theories.

First, preparation and staining techniques were only able to show the macroscopic structures in the brain. In the late nineteenth century, Theodor Meynert developed a technique that made him able to tear the brain's structures apart. By doing this, he was able to follow the regular fiber paths. Based on these observations, Meynert developed a theory about the brain's infrastructure. Sensory impulses would travel along these fibers into specific parts of the brain. Here they were processed and resulted in output signals that traveled from the brain to the muscles and organs.

At the beginning of the twentieth century, staining techniques were improved and resulted in the discovery of an intracerebral fiber system with no direct connections to the outside world. This resulted in new theories about the brain. Since this internal system only developed during the first years of childhood, it resulted in theories about learning and developing a sense of reality.

When Camillo Golgi and Santiago Ramón Cajal developed the silver staining method, scientific practices changed dramatically. Using this method, Golgi and Cajal were the first to reveal the microstructures of the brain. Borck explains: "Beyond adding the micro- to the macro-dimension, the research method opened avenues of investigation that provided the basis for epistemologically new ways of theorizing." (Borck, 2016, p. 114) For example, research into individual differences in the microstructures of the brain was performed. Oscar Vogt declared Lenin a 'brain athlete' upon investigating his brain post mortem. So, the slicing and staining techniques interacted with a theoretical framework where claims about character and cognition were made based on anatomical observations.

Summarizing the imaging approach, Borck notes that instruments are often perceived as extending the perceptibility of humans. However, the scientific objects only come forward by means of preparation techniques.

The other approach, the writing approach, focuses on function. It focuses on finding regularities and on observing changes over time. Borck describes the writing approach as presenting mechanical objectivity (Borck, 2005). In the graphical method, the brain could speak for itself. However, Borck claims the graphical method should rather be understood as using the instrument's language. The brain is understood through this language. Because the writing approach lacks a mimetic resemblance to the object it represents, the representation needs to be read or even decoded. He argues that in the writing approach, the technology is closely connected with the mode of representation. Translating the observed bodily process into a stable representation determines the kind of visualization. As Borck explains: "By its technological nature, the writing approach lends itself to speaking of instruments as media of the research process, and analogously, research technologies as media of theories." (Borck, 2016, p. 115).

The rise of EEG in the 1930s was crucial to the writing approach (Borck, 2005). Being able to record changes in blood circulation within the skull, researchers started to attempt to relate changes in blood flow with cognitive processes. With the introduction and success of EEG, the brain could be investigated independently of its spatial structures. EEG emphasized the functional, instead of the spatial, organization.

The brain as a scientific object was conceived and defined by its electrical signals. Patterns in electric signals were related to cognitive processes.

The writing approach mediated between brain and mind by relating physiological signals to cognitive activity. Borck explains: "As research technology, electroencephalography mediated between physiological processes and the recorded signs, but it also mediated between the recorded signs and more fundamental expectations from brain research." (Borck, 2016, p. 117). Being able to conceive the brain's electrical signals caused an interest in comparative investigations in order to find the neurophysiological ground for the rhythms in electrical signals. So, EEG mediates the representations of the brain and, thereby, what is expected from brain research.

Borck mentions a third approach in neuroscience, which resulted from the rise of functional imaging. Functional imaging seemed to be the perfect synergy of the imaging and writing approach. It is able to combine the spatial with the functional. Activation patterns and their spatial organization can be observed over time. However, critics argued that the spatial localization still ruled over the focus on function. Borck similarly claims that functional imaging failed to provide the perfect hybrid mode between the imaging and writing approach. He argues that the attractive visuality of functional imaging became dominant over the functional aspects. The appealing visual aspects of brain scans wrongly conflated the anatomical information with the functional, physiological significance. The representations of the measured activity became to be seen as a photography-like real image of the brain instead of a statistical representation of the brain's activity.

Borck concludes that functional imaging created new scientific objects. Concepts such as fairness, empathy, and cruelty have been constituted as visualized entities in the brain. Borck sees functional imaging as the main driving force of these new ontological understandings of the brain.

So, Borck argues that different technologies each shape the approach to brain research in their own manner. The imaging approach hoped to reveal the organic structure of the brain. The writing approach attempted to record the brain's activity. Borck claims that different visualization techniques constituted distinct scientific objects. (Borck, 2016) So, the technologies shape how scientists look at the brain and what is expected from brain research.

Remarkably, Borck uses a terminology to describe the roles of scientific instruments that is similar to that of the postphenomenologists. Borck also uses the idea of *mediation*. He explains this concept "as the articulation of instruments, objects, and concepts" (Borck, 2016, p. 113). So, scientific instruments do not only have a role in communicating the world to the scientist but also shape the articulation of these scientific objects and the concepts derived from them. Whilst Borck here uses the term 'articulation,' the similarity to the phenomenological idea of 'constitution' can be seen.

Later in his article, he describes the idea of 'constitution' more clearly. In explaining the epistemological effect of scientific instruments, he writes:

> "The media of brain research are comprised of the tools and instruments employed; their entanglement invites specific epistemological perspectives on the brain's nature and operation as guided by the respective research technologies. As media of brain research, the instruments and research technologies constitute specific objects and phenomena to be observed and investigated. In addition, the media of brain research situates this experimental practice in the larger socio-cultural fabric, furbishing scientific representations with the realism of a true-to-nature appeal or with the symbolic secrets of writing" (Borck, 2016, p. 117).

It is remarkable how similar the second sentence is to claims made by (post)phenomenologists. The notion of *constitution* is crucial here. As described in chapter 2, the postphenomenologists believe that technologies take part in the subject-object relation and thereby shape the constitution of both subject and object. Similarly, Borck here claims that the instruments constitute the scientific objects, which suggests that these objects only come into being in the way they are presented because of the technology.

The second aspect of Borck's claim I want to highlight is the view he presents at the end of his quote. Not only do the scientific instruments shape the scientific object, but they also contribute to a larger trend of understanding scientific representations. His idea of the instruments creating a 'true-to-nature' appeal is very similar to the ideas of mechanical objectivity by Daston and Galison. The next chapter further elaborates on the similarities between Borck's observations and Daston and Galison's idea of objectivity.

Borck conceptualizes the two different roles of scientific instruments as instruments serving as "media in research methodologies" and as being part of the "larger media infrastructures in epistemic regimes" (Borck, 2016, p. 113). These two different roles are very similar to Ihde's weak and strong program of material hermeneutics. Borck argues that instruments mediate scientific information in making aspects of reality visible as media in research methodologies. In this role, the mediation is related to how the technological features of the instrument open up the space of investigation. This idea of making the invisible visible and preparing the object for scientific investigation is similar to Heelan's conception of readable technologies and Ihde's explanation of the weak program of material hermeneutics. In all three frameworks, the instruments translate an aspect of reality into something that can be observed and investigated by the scientist.

The second role of scientific instruments Borck discusses results from their first role. A research object is investigated in the research space mediated by the instrument. Thereby, instruments "shape the materialization and conceptualization of the research object within the space opened and mediated by the technology employed" (Borck, 2016, p. 113). Borck claims that the instruments guide interpretation of the observed scientific object and, moreover, materialize and conceptualize the scientific object. In other words, the scientific object is constituted in the research space. Scientific instruments are involved in theorizing. Although this claim derives from a completely different background, it is very similar to the postphenomenological claim that technologies mediate experience and that the object is constituted in the mediation. An instrument structures reality in a research space in which the research object is constituted as a scientific object (Ihde, 1998; Verbeek, 2001).

This chapter has reviewed several examples of studies that examine brain images or brain imaging technologies. The chapter started with examples that derive from the postphenomenological framework. The articles written by Rosenberger present an examination of multistable images of the synaptic vesicle fusion. He argues that these images are interpreted following specific hermeneutic strategies. De Boer, Te Molder, and Verbeek's research show how NIBS and EEG technologically mediate the phenomenon of visual attention and constitute it as a scientific object. While Rosenberger mainly focuses on the interpretation of images, De Boer, Te Molder, and Verbeek make claims about the constitution of scientific objects and, thereby, scientific knowledge. This difference in focus can be related to Ihde's weak and strong program in material hermeneutics.

After these postphenomenological examples, some non-postphenomenological studies of brain images and brain imaging technologies were introduced. De Rijcke and Beaulieu focused, similarly to Rosenberger, mostly on scientific images. They also state that the meaning and interpretation of brain scans can differ. An interesting addition to the postphenomenological account is their notion of suites of technologies. This idea that technologies are always embedded and connected to a technological context contributes to their analysis of how the meaning of scientific images can be differently constituted.

Borck's non-postphenomenological study of brain imaging technologies presented the compelling distinction between the imaging and writing approach in neuroscience. He shows how these approaches are inextricably linked to the scientific instruments used. In functional imaging, the two approaches are combined. However, here lies the danger of the imaging approach ruling out the writing approach understanding of the brain scans. Interestingly, Borck uses similar terminology to the postphenomenologists. He also talks about 'mediation' and the 'constitution' of phenomena as scientific objects. His description of the roles of scientific instruments shares many characteristics with the postphenomenological depiction of scientific instruments. In the end, Borck argues, in line with Ihde's strong program, that scientific instruments are involved in the constitution of the brain as a scientific object and, thereby, shape theorizing about the brain.

Chapter 4:

Understanding brain research

In the previous chapter, I have explicated several examples of studies that attempt to understand how brain imaging technologies are related to the meaning and understanding of brain images, to the constitution of scientific objects and to the shaping of beliefs. In this chapter, I will elaborate on the insights gained by the analysis presented in the previous chapter.

First, I will reflect on what postphenomenology contributes to the understanding of the role of brain images and brain imaging technologies in brain research. Then, I will reflect on the understanding of scientific images in brain research as multistable. It is argued that the multistability of images should always be understood in relation to the technologies involved. After that, I re-introduce Ihde's idea of technological intentionality. This idea remains unnoticed in the postphenomenological studies discussed in chapter three. However, technological intentionality relates nicely with Borck's insights on technological trajectories and can be a fruitful notion for understanding brain research. Finally, I relate the insights on the role of scientific instruments to the notion of epistemic virtues that was introduced in the beginning of this essay.

Why postphenomenology?

Interestingly, the examples in chapter three that did not build on the postphenomenological tradition showed similar ideas as the postphenomenological studies. Both the postphenomenological study by Rosenberger and the non-postphenomenological research by de Rijcke and Beaulieu claimed that brain images could have different meanings and interpretations in various contexts. Additionally, the postphenomenological study on visual attention showed that scientific phenomena are constituted in relation to the scientific instruments used. Building on media theory, Borck made similar claims. He claimed that different approaches constitute the scientific object differently. So, if non-postphenomenological accounts point to roughly the same ideas, what does postphenomenology specifically contribute to our understanding of the relationship between instruments and beliefs in science? What do these complicated notions add to our understanding?

The two postphenomenological studies discussed in chapter three use various postphenomenological terms; multistability, mediation, and material hermeneutics. In my opinion, material hermeneutics is the most interesting idea that postphenomenology brings. Multistability and mediation can be seen as the building blocks of this overarching idea of material hermeneutics.

In my view, multistability is mostly a useful label to describe certain characteristics of an image or a technology. Multistability simply describes that there are multiple valid interpretations or meanings of an image or a technology. As long as one does not tend to believe that all objects have one stable state or essence, this notion should not be too surprising. Beaulieu does not use this specific term but is able to point to the same idea. She conceptualizes the difference in the meaning of brain scans in the popular context and in the scientific context as follows:

> "Rather than seeing differences as the result of "dumbing-down" of scientific work for lay consumption, the meaning of brain scans in each setting will be shown to be embedded in different understandings of what can be learned from images and what can be expected of technology" (Beaulieu, 2000, p. 40).

In line with the postphenomenological idea of multistability, Beaulieu focuses on understanding the meaning of brain scans in different contexts rather than making claims about which understanding of the brain scan is more true.

In chapter two, I introduced mediation as a postphenomenological concept. Interestingly, Borck uses the exact same wording in his paper. In understanding and describing the role of technology in the constitution of scientific objects, I believe this concept to be very useful. The concept points to the involvement of the technology without suggesting that technology fully determines human action. With the use of mediation, technology is conceptualized as becoming part of the human-world relationship, rather than as some separate, external force merely influencing a process in which the technology itself does not have a part.

I believe that most of the use of postphenomenology in understanding brain imaging technologies relies on the theory of material hermeneutics. Material hermeneutics incorporates all the notions described above. The multistability of images and objects and the mediation of the relation between the scientist and phenomena are prerequisites of the main material hermeneutic idea that technological mediation constitutes scientific objects and that in doing that, a certain trajectory (technological intentionality) is presented. So, material hermeneutics describes the process in which mediation, technological intentionality, and multistability all play their role. In this process, instruments have an important role in understanding the world and the constitution of knowledge. Material hermeneutics relates brain imaging technologies to the meaning of the brain as a scientific object and the way the brain is understood. Thus, in my view, postphenomenology's use can mostly be found in the overarching framework of material hermeneutics. I believe that this is a useful framework including various notions to describe the use of instruments in scientific practice.

As the examples of studies in chapter three showed, postphenomenology is differently applied in the different studies. For example, specific notions, like mediation, are differently interpreted by the different studies. De Boer, Te Molder, and Verbeek interpret technological mediation as structuring the reality observed by the scientist. They conceptualize technological mediation “in terms of the constitution of a specific perceptual object” (De Boer et al., 2020, p. 4). Rosenberger understands technological mediation more in terms of translation and making the invisible visible. He states: “this kind of mediation occurs as researchers use instruments […] to make otherwise unobservable phenomena visible in the form of images” (Rosenberger, 2001, p. 13-14). So, it seems like multistability is even applicable to postphenomenology’s own notions. As they argue that science should be aware of the different interpretations of phenomena studied, I pose that the ‘postphenomenological method’ should be aware of their own differences and try to work towards one coherent framework in order to merge all the insights into one fully coherent view.

Multistability in brain research

The science-as-practice tradition in the philosophy of science stretched the importance of the material, social and temporal aspects of science. The studies discussed in the previous chapter give insights into how we can understand the role of material factors in meaning-making and beliefs in science. Both Rosenberger’s postphenomenological analysis and de Rijcke and Beaulieu’s analysis show that the meaning of scientific images can be differently constituted. Within the scientific context, different interpretations of an image can arise. Also, outside of the academic context, an image can evolve a separate meaning.

Both Rosenberger and de Rijcke and Beaulieu see a crucial role for technologies in the constitution of the meaning of an image. Rosenberger terms all the contextual features in which the meaning of an image arises the *hermeneutic strategy*. As he stated, hermeneutic strategies are closely connected to the technologies used in scientific practice. De Rijcke and Beaulieu similarly point to technologies as having a role in the constitution of the meaning of an image. Additionally, they state that what a brain scan means is embedded in its *suite of technologies*. The role Rosenberger ascribes to technologies can be understood in relation to Heelan and Ihde’s ideas. Heelan’s notion of readable technologies and Ihde’s description of the hermeneutic relation between the subject, technology, and world both describe how technologies translate certain aspects of the world. The way a technology translates these aspects makes some interpretations of the image possible and excludes others.

Ihde argues that the multistability of images makes various true interpretations possible. His analogy with the Necker cube and his example of the different forms of archery suggest that the multiple stable forms of an image or technology can coexist effortlessly (Ihde, 2009). However, I believe that

Rosenberger's analysis shows that science cannot easily cope with these different interpretations being possibly true. In neurobiology, the different views are rigorously debated with the eventual goal of understanding what actually happens during a synaptic vesicle fusion. Rosenberger even states that a postphenomenological analysis could aid science in pointing to the core of the disagreement. Then, science can progress and hopefully come to a consensus on the topic.

Rosenberger's analysis suggests that there is a tendency in science to eventually solve the multistability of scientific images. Rosenberger's article suggest that if the technologies were more advanced it would be clarified which side of the debate is actual right. So, there is a difference in the use of multistability. When talking about the multistability of technologies, such as the archery example, different developments of the same technology can be described, and there is no need to reunite these different utterances of the same idea. However, if multistability is applied to the discussion of scientific images, it is not only used to describe the different meanings of the images but also to examine how these different interpretations are made possible and how science can progress to give clarity on what the images actually show.

In brain research, technologies often translate some aspect of the world that cannot be observed by an unaided human observer. So, the technologically presented phenomenon stands alone or only in relation to other technologically produced representations of the phenomenon. Scientists have to relate to the image constituted by the technology in a hermeneutic relation between the subject, technology, and world. In this sense, what is known about the phenomenon is what is known about the scientific images mediated by technologies.

So, these examples of studies discussed in chapter 3 have shown that the relationship between instruments and beliefs in science can be understood as closely intertwined. Instruments mediate how the scientific object is constituted and how the meaning of an image arises. Therefore, I argue that the meaning of an image cannot be disconnected from the technologies involved in visualizing the phenomenon represented.

Whilst there is an urge in science to solve the multistability of images, Beaulieu shows that differences can exist between the scientific and popular context. One could argue that the scientific interpretation of brain scans is 'more real'. However, Beaulieu shows that it is valuable to understand these different interpretations as different constructs in different contexts rather than asking which interpretation is more real.

Here, the suites of technologies also show useful. The postphenomenological remains, in my opinion, too individual. Postphenomenology is mostly concerned with the scientific observer, technology, and world. However, de Rijcke and Beaulieu's notion of suites of technologies shows that the meaning of a scientific object is not only dependent on the scientific instrument, the readable technology, that makes the phenomenon visible to a human observer, but also on the context of technologies. So, as has been argued, a brain scan shows the brain as a scientific object constituted in the relation between the observer and the instrument, for example, fMRI, and, additionally, the image produced is interpreted in a larger context of technologies.

Technologies are, thus, connected to the different interpretations of images. De Rijcke and Beaulieu, De Boer, Te Molder and Verbeek, and Borck go even one step further. They do not only argue that an image is a technological translation or representation of a phenomenon, but they also emphasize that technologies are involved in the constitution of scientific objects. Of course, the constitution of the image of an object and the constitution of a scientific object are related. However, they are fundamentally different. An image is, for example, a brain scan. This image is a representation of the scientific object. The scientific object is, in this case, the brain. The brain as a scientific object is related to how scientists understand, approach, and reason about this object. How we understand, approach, and reason about the brain are thus related to how the brain is constituted as a scientific object.

De Boer, Te Molder, and Verbeek make an important claim in saying that the variations in how a phenomenon is constituted as a scientific object, dependent on the research technologies involved, cause doubts about merging different studies using different instruments. It is, therefore, crucial to acknowledge the mediation of technologies in how we understand a scientific object. That a phenomenon is differently constituted in a different context is not necessarily a problem. However, when studies want to merge their findings and contribute to a broader conclusion, these differences need to be considered.

Technological intentionality in brain research

The studies discussed in chapter three have shown that brain imaging technologies have an important role in the constitution of the brain as a scientific object. How a scientific object is constituted influences how the object is analyzed and influences what is expected from research. Ihde captures this idea in his notion of technological intentionality. Technological intentionality holds that technologies frame the relationship between the human and the world. Technologies present a particular trajectory. They promote certain actions or incline a particular way to approach the world. The notion of technological intentionality is grounded in the phenomenological idea of intentionality. In relation to Husserl’s ideas, technological intentionality is an interesting stretch beyond the human-world relationship into the realm of technology. In this context, technological intentionality frames technology as neither neutral nor determining but as taking part in the human-world relationship. Outside the strict phenomenological framework, describing technologies as 'affording' certain responses or actions is, in my opinion, very similar to the idea of technological intentionality.[10]

Rosenberger related the constitution of scientific images to different theories about what that image shows in neurobiology. De Boer, Te Molder, and Verbeek showed how the instruments posit certain scientific norms the researchers adhere to. However, neither Rosenberger nor De Boer, Te Molder, and Verbeek zoomed in on Ihde's idea of technological intentionality. Both accounts did not make any claims about how this different understanding of images and different constitutions of scientific objects suggest particular trajectories of further research. They did not relate their findings to broader trends and beliefs in science.

Technological intentionality does suggest linking the way scientific objects are constituted to the broader trends in science. Brain imaging technologies present the brain as a scientific object in a particular manner. The way the technologies present the scientific objects inclines a specific way of understanding the phenomenon and, thereby, suggests trajectory for further research. I believe that this idea is very similar to the idea Borck presents. In Borck's examples of the imaging and writing approach, different 'technological intentionalities' can be found that 'ask' for these two different approaches of doing research. Borck shows that anatomical and histological preparations of the brain lead to structural specification and localization of parts of the brain (Borck 2016). Prepared brain slices ask questions such as where certain parts of the brain are localized rather than how certain stimuli lead to certain behavior. The instruments belonging to the image approach, including more complicated and recent technologies such as magnetic resonance imaging, are conceived as extensions of human visibility (Borck 2016). These technologies, thus, present a trajectory for investigation accordingly; when you are able to look into the brain, questions about where aspects of the brain are localized arise.

The other approach, the writing approach, is related to inscription and self-recording instruments (e.g., EEG) and focuses on process and change. These instruments ask questions related to change over time rather than focusing on spatial localization. Opposing the imaging approach, the representations in the writing approach do not have a mimetic resemblance to what is represented (Borck, 2016). Visual questions like the 'where'-question are thus subordinate in this trajectory. Rather, questions about function arise. In *what* and *how* these technologies translate the phenomenon studied, the instruments present a certain trajectory for investigation. This is similar to Ihde's notion of technological intentionality.

I suggest that these insights can be extended to a broader tendency in brain research, the trend to explain the brain by explaining its smallest parts. I will refer to this trend as reductionism. This trend

[10] The idea of affordances comes from James J. Gibson's work *The senses considered as perceptual systems.* Gibson points with affordances to something that refers to both the subject and the world. Simply said, affordances are what actions or responses the environment offers or suggests to the subject.

attempts to explain higher mental functions by explaining the neuronal processes in the brain. I believe that this trend fits the trajectory proposed by the technological possibility of functional imaging. In the nineteenth century, Emil du Bois-Reymond tried to find support for his reductionist research project into the molecular astronomy of the brain. However, his ambitious idea did not correspond with the instrumental possibilities of that time. In other words, it did not fit the technological intentionality present at that time. Instead, the ruling framework was behavioristic. For the behaviorists, their research started with observable behavior and ended with the resulting observable behavior. Descriptions of the neuronal structures of the brain were not needed, nor wanted (Draaisma, 1995).

More than a century later, at the end of the twentieth century, functional imaging was developed. Borck elaborates on how this new development seemed to unite the imaging and writing approach. The optimists believed that functional imaging would present "the perfect visualization of the neural substrates of every possible psychic and cognitive process and thereby the dissolution of human ideas or philosophical concepts to the status of mere epiphenomena of neurophysiological signal processing" (Borck, 2016, p. 118). Quite obviously, these optimists, thus, held a reductionist view and even wrote a manifesto against humanist traditions to brain research. In this manifesto, they stated that they could finally achieve what philosophers had failed to do for centuries (Elger, 2004). Now, they were able "to solve the ultimate riddle of consciousness, intentionality, and language by means of new research tools with scientific rigor" (Koch, 2004, p. 229). Borck argues against this extensive optimism. He states that new visualization techniques will not suddenly solve the long-standing questions about the mind and the brain. Instead, new techniques provide a new picture of understanding the brain (Borck, 2008).

In my view, functional imaging technologies present a reductionist trajectory by merging functional investigations with the imaging approach. Functional imaging succeeds in combining the imaging and writing approach. Now, scientists can see *where* something happens in the brain and, importantly, *what* happens in the brain. The functional activity in the brain cannot only be recorded but also located in the brain. So, the technological intentionality of functional imaging presents a trajectory of explaining behavior, cognition, and emotions by localizing the related activity in the brain. Functional imaging inclines to explain behavior, cognition, and emotion by explaining or reducing it to the smallest activity inside the brain.

Beaulieu also points at reductionism in their analysis. She similarly notes that, in the scientific context, brain imaging technologies made it possible to map certain functions to specific brain areas. Also, more vague ideas such as emotions or even consciousness are involved in the mapping research. Beaulieu argues that brain scans function as visual arguments for the mapping approach. The spatial visuality of brain scans has focused on finding the neurobiological substrates of differences in mental states (Beaulieu, 2000). This same argument reappears in De Rijcke and Beaulieu's paper. Here, they state: "The discrete, mapped-out bright bits seem to provide visual proof for the existence of material substrates of behavioral mechanisms, and for the claim that the basis of the mind is biological" (de Rijcke & Beaulieu, 2014, p. 131). De Rijcke and Beaulieu argue that brain scans are involved in the constitution of the brain as a scientific object and enforce the idea of the mind as being located in the brain. The visuality of brain scans has had an important effect on the attention of the neurosciences (de Rijcke & Beaulieu, 2014).

So, the insights from the examples in chapter three can be extended by using Ihde's notion of technological intentionality and Borck's similar idea of technologies presenting a particular trajectory. In my opinion, this analysis suggests that functional imaging can be understood as actively taking part in the constitution of a reductionist research trajectory. Further analysis of the role of functional imaging in constituting the brain as a scientific object and investigating how functional imaging suggests a reductionist research trajectory by mediating the relationship between the scientist and the brain in a particular manner could support the claim that functional imaging affords a reductionist view of the brain.

Scientific instruments and epistemic virtues

At the beginning of this thesis, I introduced Daston and Galison's idea of epistemic virtues. To briefly re-introduce this concept, epistemic virtues describe what is expected from science. How science is practiced, what is researched, what is expected from a good scientist, and what instruments are used. Epistemic virtues prescribe how science should approach the world, in other words, how science understands the world. Daston and Galison use this term in their historical description of 'objectivity.' In their historical description, they are not necessarily concerned with how technologies relate to the constitution of these epistemic virtues. However, I suggest that with the insights from the analysis in the previous and this chapter, the idea of epistemic virtues can be connected with the role of technologies in constituting how the world is known.

In the first chapter, I introduced two epistemic virtues that Daston and Galison distinguish: mechanical objectivity and structural objectivity. These different approaches to objectivity present a certain approach to scientific objects and to the world. These are quite similar to the two approaches Borck describes. Mechanical objectivity strives for objectivity in mechanical routines rather than in a subjective observing scientist. The machine was the ideal observer. Technologies such as photography were believed to be able to give a true representation of the world. Borck's imaging approach also leans heavily on mechanical images of the brain. Via the instruments, scientists can 'look' into the brain. These instruments have a similar photographic appeal. The ultimate goal for an instrument or technique was to be invisible in representing the object (Borck, 2016). Borck himself links mechanical objectivity to the writing approach since in the writing approach was expected the phenomena speak for themselves, for example, in the tracings of an EEG (Borck, 2005). In my opinion, the writing approach can also be linked to structural objectivity, which prefers structures or graphs over images.[11] I believe that this sort of difference between mechanical and structural objectivity is comparable to the difference between the writing and imaging approach.

I do not aim to identify the imaging and writing approach with the different kinds of objectivity introduced by Daston and Galison. Instead, I aim to point out the similarity between the epistemic virtues and the different approaches Borck describes. Both prescribe how science is expected to be done, what instruments are commonly used, and what scientific objects are studied. these similarities shed light on how we can understand the role of technologies in the creation of epistemic virtues. Daston and Galison's epistemic virtues and Borck's two approaches share that they all describe how the scientist is expected to approach the world; how the scientist should understand the world.

Although my analysis cannot make any substantial claims about the role of technologies in either mechanical objectivity or in structural objectivity, I do believe that there is a link to be made between the role of technologies in Borck's approaches and the role of technologies in epistemic virtues. As explicated above, Borck's approaches are closely connected with the technologies that formed part of these approaches. I suggest that epistemic virtues can be understood in the same way. Daston and Galison already stated that machines were both the exemplar and constitutive of mechanical objectivity. So, in their view, there is room for a role for the technologies involved. I suggest that a similar analysis would be possible about the relation between technologies and the rising epistemic virtues in science.

In this chapter, I have reflected on various aspects of the analysis in chapter three. First, I have argued that postphenomenology offers a valuable framework in its theory of material hermeneutics. This framework unites different useful concepts for understanding the role of scientific instruments in science, such as the multistability of images and objects, technological mediation, and technological intentionality. Next, I emphasized the role of instruments in the various meanings and interpretations of multistable images. The meaning of an image is constituted in relation to the instruments that produce the image and the relating context of technologies. Also, scientific objects should be understood in relation to the scientific instruments that are involved in their constitution. Rosenberger's studies show that there is a tendency in neurobiology to solve the multistability of images. This finding differs from Ihde's idea that images and objects can be unproblematically multistable. Additionally, I pointed out that technological intentionality has remained undervalued in the studies discussed in chapter three. Borck's analysis of different approaches and brain imaging technologies suggesting particular trajectories can be linked to the idea of technological

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[11] Borck bases his work solely on Daston and Galison's article 'The image of objectivity' from 1992. Structural objectivity was only later introduced in *Objectivity*, which was published in 2007.

intentionality. These ideas can be extended to understanding functional imaging as inclining a reductionist trajectory in brain research. Lastly, I related the insights from chapter three back to the notion of epistemic virtues. This notion and the approaches Brock distinguishes both prescribe what is expected from science. From the analysis in chapter three, it can be concluded that brain imaging technologies are intertwined with these approaches.

Conclusion

In this thesis, I have tried to analyze how the relation between brain technologies and beliefs in brain research can be understood. An important part of this inquiry was concerned with understanding and reviewing the postphenomenological framework for understanding the role of technologies in the human-world relationship and, more specifically, for understanding the role of scientific instruments in mediating the relationship between reality and the scientist.

This thesis departed from a science-as-practice view. This tradition approaches science as a complex practice involving many social, material, and temporal factors. Instead of solely focusing on science's method, the science-as-practice tradition aims to describe science in relation to these social, material, and temporal factors. In this thesis, I have focused on scientific instruments as important material factors in scientific practice. Closely related to the science-as-practice tradition is the notion of epistemic virtues. With this concept, Daston and Galison describe periods in science as answering to a trend or idea of what science should be, what it should investigate, and how. To develop a framework for understanding instruments as material factors in science, I introduced Heelan's notion of readable technologies. As a readable technology, scientific instruments translate reality into something observable to the scientist.

With this background in mind, I turned to the postphenomenological theory in chapter two. Postphenomenology builds on phenomenology, but it is less dystopian in its view on technologies, and it aims at analyzing concrete examples of technologies. Postphenomenology introduced many new notions and insights. It suggests that technologies technologically mediate the relationship between the subject and the world. This technological mediation can take different forms. Among other things, technologies can be embodied by the observer or hermeneutically present reality to the subject. Building on the idea of technological mediation, postphenomenology develops the notion of technological intentionality. Technologies take part in the human-world relationship by suggesting certain actions or inclining ways to look at the world. One more important concept from postphenomenology is multistability. According to the postphenomenologists, objects and images can be multistable, meaning that they can develop in various stable forms in different contexts.

All these insights were related to the context of science with the idea of material hermeneutics. Material hermeneutics has a weak and a strong program. The weak program is reasonably similar to Heelan's readable technologies. The weak program suggests that reality is perceived through, with, and by using the scientific instrument. The scientific instrument makes parts of reality visible or translates certain aspects of reality into something that can be interpreted by the scientist. The strong program goes one step further. This program suggests that phenomena are constituted as scientific objects in this translation of reality by the scientific instrument. It suggests that the instruments structure or even prepare reality for scientific investigation. The strong program thus suggests an even more significant role for scientific technologies.

These various notions and ideas from postphenomenology were related to brain research in chapter three. This chapter presented multiple examples of studies in brain research that focused on the role and use of brain images and brain imaging technologies. Some of these examples derived from postphenomenology and others did not. Interestingly, both the postphenomenological and non-postphenomenological studies made a similar observation. The studies showed that scientific images can have various meanings and can be interpreted differently in diverse contexts. All the studies argued for a significant role for brain imaging technologies in making these different interpretations possible. Additionally, the studies argued that brain imaging technologies are involved in the constitution of the brain as a scientific object and in shaping theorizing about the brain.

The last chapter discussed the insights from chapter three. This chapter presented the main conclusions of the analysis. In the beginning, this chapter turned to the sub-question of this thesis: How can postphenomenology contribute to an understanding of the relation between brain imaging technologies and beliefs about the brain in brain research? While the non-postphenomenological accounts were able to produce similar insights to what the postphenomenological studies concluded using the concepts of multistability and mediation, postphenomenology has additional value in the overarching framework of material hermeneutics. This framework offers a rich understanding of how the role of scientific instruments can be understood. However, as the examples in chapter three showed, the postphenomenological concepts are not applied similarly in all studies. Some alignment in the understanding and use of the postphenomenological concepts would contribute to the value of this framework.

In order to turn to the main question, the different studies analyzed in chapter three present consensus on two conclusions. First, brain images are multistable. Different meanings and interpretations can be attributed to these scientific images in various contexts. Additionally, this difference in meaning and interpretation of an image cannot be detached from the brain imaging technologies involved in the production of this image. The meaning of an image develops in relation to the imaging technology that produced it. Second, brain imaging technologies are intertwined with the constitution of scientific objects. By translating or visualizing the brain, the imaging technologies constitute the brain in a particular manner. The way the brain is presented is, consequently, related to how this phenomenon is investigated. So, in preparing reality for scientific investigation, brain imaging technologies constitute the brain in a particular way that suggests certain trajectories for further investigation.

This idea of brain imaging technologies presenting particular research trajectories was extended to explaining functional imaging as affording a reductionist approach to understanding the brain. Following this idea, I would suggest that we would have never become our brain if it was not for functional imaging. Further analysis into functional imaging and reductionist approaches in brain research would be necessary to fully support this claim. Nevertheless, the analysis shows that how we understand the brain is dependent on how the brain is presented to us by scientific technologies. In this way, scientific technologies have a role in developing a trend in how science is done, what is researched, and what is expected of science.

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