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Some critical remarks on the epistemology of functional magnetic resonance imaging (fMRI)

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Abstract

The article examines epistemological and ontological underpinnings of reasearch performed by means especially of functional magnetic resonance imaging (fMRI). It takes as its guiding line the thesis, set forth by Rom Harré, that instruments such as barometers or thermometers do not cause the states they measure into existence, whereas apparatuses cause the material states into existence which are subsequently processed (treated, measured, etc.) according to suitable methods (e.g. algorithms). Accordingly, when the objects of examination (brains, e.g.) are subjected to 2 or more Tesla in fMRI (a strength of magnetic field never occuring in earthly nature), the technical means literally create the states to be examined.

Close examination of the functioning of fMRI indicates that brain states, e.g., are not simply read as degrees of temperature or measured on some scale. Thus, mental functions as fMRI outputs remain invisible, for the outputs have been semantically processed on the basis of quantum mechanical events according to translation procedures built into the fMRI device.

Keywords: apparatus; instrument; measurement; imaging; experiment; fMRI.[3]

1. Introduction

The *decade of the brain* would have been inconceivable without some groundbreaking technical means such as functional magnetic resonance imaging (fMRI). This technique yields images of human and non-human brains with colorful blobs that are supposed to (strictly speaking)

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differentially *signal* areas of cerebral activity. Though differing in outlook and size, all MRI machines are doing the same job when performing imaging tasks especially for cognitive neuroscientists. These machines are conventionally described and propagated as devices designed for *capturing* areas of brain activity.[4] ‘To capture’ is merely a different word for ‘to measure.’ However, the process of measuring brain activity by way of fMRI (if we stick to the conventional terminology) differs greatly from measuring temperature by means of quicksilver thermometers or from measuring atmospheric pressure by means of barographs. The difference turns out to be not of linguistic, but rather of *ontological* as well as of *epistemic* nature. In what follows, we reconstruct the said difference and thereby focus on the distinction, suggested by Rom Harré (2003), between instruments and apparatuses.

Why deal with fMRI techniques against the background of the instrument vs. apparatus distinction? The outputs of fMRI, the brain images with colorful blobs, have induced some neuroscientists to believe that scanners permit them to “watch the mind at work”, as Hobson & Leonard (2001, 14) put it. This and similar claims indisputably enhance fascination by, and admiration for, fMRI based neuroscience in the general public. However, they also have been contradicted by other neuroscientists who concede that “fMRI is not and never will be a mind reader” (Logothetis, 2008, 869). This contradiction cannot be solved by better techniques, better equipment, better computer programs, or better experimental designs. The purpose of our contribution is to argue for the need to avoid the contradiction at stake from the outset by reflecting on what fMRI data are.

More often than not, neuroscientists interpret fMRI outputs in a way that what they *see* does in fact also occur in nature. Whenever a fMRI scanner is operating, the device is said to provide a “window into the brain” (Parry & Matthews 2002, 50). To put it differently, a fMRI scanner is perceived and used as if if its purpose were to lift some kind of curtain in order to disclose the brain *as it really is*. Following a proposition of Harré (1998, 353-354), we believe that many neuroscientists uncritically adopt the classical account of scientific experimentation according to which experiments reveal some aspect of the world *as it is* (here: the brain and/or brain function *as is*). However, the underlying assumption then entails that the experimental setup can be *eliminated from the interpretation* for good, in the very same sense that thermometers are eliminated from the act of collecting data by reading temperatures.: When the thermometer within a glass of water displays 25° C, one interprets this as the device showing the real state of something real in the real world (i.e. the water in the glass) and not as the state of the device itself. In other words, we would say that “the temperature of the water has 25° C"

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[4] See Siemens’s homepage: https://www.healthcare.siemens.de/magnetic-resonance-imaging as well as Phillips’s homepage: https://www.usa.philips.com/healthcare/solutions/magnetic-resonance.

and not "the subjects of the thermometer is 25° C" because the top of its quicksilver column has come to rest at the 25° C mark. According to this underlying assumption of *transparency*,[5] the experimental procedure can be *epistemologically discarded*. Applying the principle of transparency to any fMRI scanner generated data output, one expects that the device reveals some state of affair on something in the natural world *as it is*, in the very same way as the thermometer gets epistemologically discarded in the above example of taking the temperature of the water. The interpretation of fMRI data along these lines as revealing *brain activity as it is* is likely to have contributed to fMRI's growing popularity and its suggestive power in the larger public. In the remainder of this contribution, we argue that such a transparency favoring interpretation of fMRI is both mistaken and misleading. Hence, if follows from this thesis that the underlying epistemology of fMRI − an epistemology not yet adequately described − must be different. Following Harré's (2003) conception of scientific experimentation, we will endeavor to show that fMRI provides models of brain physiology by means of a sophisticated technique of data production, whose relation to the natural phenomena (the phenomena of brain physiology) is opaque and indissolubly melted with the machinery's workings in their entirety.

2. (Functional) Magnetic resonance imaging

Our main argument rests on the basic difference between instruments (such as thermometers, seismometers, barographs, myographs, and similar devices), on the one hand, and apparatuses (such as MRI-machines or particle accelerators and similar devices), on the other hand (according to Harré 2003).

The key issue is as follows: in what sense does an apparatus such as a MRI device truly differ from an instrument such as a thermometer? There is no simple, straightforward answer to this question. Technical information is indeed not only useful, but truly necessary in order to understand one characteristic feature of MRI machines, viz. that these machines first *cause material states* into existence which are subsequently processed physically and digitally. In contradistinction, thermometers *do not cause* material states that they are expected to measure. To put it differently: understanding the ontological and epistemic specificity of a device such as a MRI machine, one needs to know first what it does, technically speaking, in order to grasp and further process analytically what it has previously done.

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[5] This is both Harré's (1998, 355) terminology and the argument that rests on the concept of transparency.

So let us look for a while into the standard MRI device in action in a neuropsychological lab or in a neurological/neurosurgical ward. The object of investigation is living matter (the brain of a human or non-human animal)[6] subjected to a magnetic field of one or more tesla (T).[7] The intensity of magnetic fields within the range of 1,5 T to 4 T or more produced by the magnetic coil of the scanner is *absolutely uncommon* in nature (of the planet we inhabit), for one T corresponds to the intensity of earth magnetism multiplied by 20,000. Which is to say that a human being undergoing MRI (and/or fMRI) examination is exposed to 30’000 or 40’000 or 60’000, and sometimes even stronger natural magnetic fields that cause innumerable single modifications in the living matter of the head.[8] *But note*: the brain (or, for that matter, the hip, the gut, etc.) is *not* (i.e. without intermediate procedures) made the key target object of MRI machines in action; rather, any magnetic field of e.g. 2, 2.5, 3, or 4 T aims at changing the behavior of protons. Thus, the immediate target objects are the protons and their changing behavior in atoms in molecules within bunches of molecules within tissues within organs such as brains within organisms such as humans.

Indeed, it is a fact (well confirmed by modern physics, but here grossly simplified in its rendering), that the subatomic particles called protons may also be defined as displaying the properties of magnets. An external magnetic field thus causes their orientation to change accordingly. Moreover, protons possess a spin, which adapts to the presence of a magnetic force. These two properties are at the base of well working MRI machines. The protons inside the living organism, excited by the oscillating magnetic field, emit, in reaction to the ‘artificial’ magnetic field, radio frequency signals that are registered by the receiving coil of the scanner. The signals thus received are processed in such a way as to encode position information obtained by means of gradient coils, the function of which consists in varying the magnetic field.

Though quite incomplete, the basic information on MRI given here is sufficient to purport our thesis that scanners are not instruments that permit one to proceed to any ‘brain reading,’ and even less so to any ‘mind reading.’ Scanners *cause* phenomena into existence that are destined to be processed so that information extracted from the processing be then conveyed to observers. What observers ‘read,’ if they read anything in the strict sense of the term, on screens or photograph-like outputs, are visualizations of proton configurations that are brought to behave according to what we might call a ‘physico-technico-digital experimental protocol.’ Thus, in MRI, *nature as it is* and

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[6] However, MRI is also good for the study or the diagnosis of other parts of a living body, such as the belly of a dog, the broken knee of a hippopotamus, or the painful bladder of a patient in some hospital.

[7] Experimental MRI machines of the most recent generation work with up to 8 T; we discard them here as well as so called ‘open’ MRI machines which run on low magnetic fields.

[8] In comparison: any human being, and thus any human brain, is exposed e.g. in California, USA, to a magnetic field of 35 microtesla.

nature as read by observers are, strictly speaking, *ontologically incompatible* with one another. They are nevertheless *epistemologically related to one another* by means of highly complex ensembles of physical equipment, signal creating and signal receiving devices, signal processing, statistical algorithms, and visualization programs implemented into the scanner and its assistant devices such as desktops to be looked at, but designed so as to turn the final output into nicely readable images.

The presence of protons in organic molecules determines the amount of signals received by the receiving coil. This is to say that tissues, differing from one another by their chemical composition, and thus by the amount of protons ready to specifically react to the magnetic field produced by the machine, emit signals of different radio frequency depending on their chemical properties. In the case of fMRI, the key neurological theorem underlying the imaging procedures tells us that active brain regions demand higher affluence of blood than less active regions. Increments of blood in circumscribed brain regions cause an increase of signals emitted by the protons in the molecules of both the living matter in action in that cerebral area and the blood whose quantity has increased due to the cerebral activity in the respective region.

To sum up: In fMRI studies, the data that *in the end yield* brain images with colored blobs signalling cerebral activity, are neither neurocognitive nor neuroontological, but, as one could say, artificially brought about by a device that triggers signals according to theorems of quantum mechanics. It follows from these considerations that fMRI ‘embodies’ materially very complex properties that hinder one to treat scanners as members of the species of instruments according to Harré’s (2003) definition explained above. In addition, the setup of scanners requires from experimental subjects to adopt a very unnatural behavior.[9]

3. The concept of experimentation

It is a remarkable fact that philosophers of science would focus upon the relationship between theory and experiment in order to understand whether, and how, theories can be tested. Whereas the members of the Vienna Circle, e.g., aimed at showing that theories are amenable to verification by observations, Popper’s critical rationalism held that

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[9] Note also that the subjects in fMRI studies are compelled to rest motionless in a narrow scanner bore while signaling the solution of tasks by minimally moving nothing but some fingers. Such restrained behavior is highly ‘unnatural,’ but essential for the successful performance of neuropsychological experiments under fMRI condition. But this ‘unnatural’ pattern of behavior is fundamentally different from the ‘unnatural’ action of a magnetic field of one or more T upon protons in the brain of experimental subjects, although both − the pattern of behavior and the magnetic field-brain complex within the scanner bore − are paradigmatic for the laboratory setting as such.

theories need to be formulated in such a way that they lend themselves to falsification. The controversy was based primarily on predicate logic, for the key question was whether, and how, general scientific propositions (“all x are F”) could be deduced from single experimental observations (“some x are F”). Controversies of this kind have long prevented philosophers of science from paying due attention to other aspects of scientific research, especially to various work processes in laboratories, field research, and other places of data triggering and collecting, as well as to the role(s) of modeling in cases where direct observation is strictly impossible.

Positivists such as the members of the Vienna Circle were skeptical regarding propositions reaching beyond the limits of our perception. They claimed it would be inaccurate to assert that the temperature outside is 20º C, but accurate to assert that the thermometer displays 20º C on its visible scale. In contradistinction, contemporary realism, which is the dominant view among most scientists, claims that we can *know*, on the basis of observation(s), that things such as temperature, gravity, electrons, natural selection or neural networks *actually exist*. Contemporary realism also claims that we can corroborate *theories* beyond observation.

In spite of these and similar claims, many realists pay a minimal amount of attention to *how* experimental data relate to the world researchers are supposed to elucidate. Experimental procedures risk thus to be taken to be indispensable in principle. Hence, they are mostly considered to be *epistemologically* irrelevant, for they are said to *reveal by themselves some aspect of the natural world as it really is* without adding anything to, or modifying somehow, the aspects of the world they are revealing.

The case of fMRI is likely to show that this way of considering experimental procedures is short-sighted. Since fMRI procedures create the phenomena to be studied, one ought to dismiss the idea that such phenomena are simply there to be collected. To put some words from Ian Hacking’s remarkably apt argument: “To experiment is to create, produce, refine and stabilize phenomena. If phenomena were plentiful in nature, summer blackberries there just for the picking, it would be remarkable if experiments didn’t work. But phenomena are hard to produce in any stable way.” (Hacking 1983, 230) And since experimental results depend on the phenomena at hand, results are also not just there to be picked like summer blackberries. Or with reference to Harré (2000, 274), let us say that scientific results cannot just be “read off the world.”[10]

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[10] Many phenomena studied in scientific research, rather, are products emerging from of complex processes by which (a part of) nature is made readable by human beings within their conceptual, linguistic, and technical/instrumental frames.Without discussing Harré’s approach in detail, it follows from the main line of his arguments that experimental results are to be conceived as *interpretations* and that no interpretation is ultimately exclusive.

Harré also argues that there exists a (direct, simple) causal relation between aspects of the world and experimental apparatuses such as MRI machines (this also holds, of course, for fMRI studies, which rest on the use of MRI machines, as shown above). Hence, phenomena observed, registered, and measured in experiments may *essentially depend upon* apparatuses, whenever such apparatuses are used. This is to recapitulate that such phenomena are *actively construed.* Apparatuses are nonetheless part and parcel of the material world: they only exist in material form. Though *causality* holds *within* experiments, the relationship between experimental apparatus and world is and remains in part a *semantic* one. Apparatuses are ultimately, and in general, designed to help creating *models*. The latter are neither *true* nor *false* − they are more or less *adequate* or *representative* for the aspects of the world under examination. Such kinds of models (contrary to architectural or anatomical models) are successfully designed if and only if they permit one to control, and actively manipulate, these aspects much more significantly than one would be able to do *in nature*. Thus, phenomena yielded in experiments by means of apparatuses are intrinsically bound to the latter by which they are produced. A straightforward *causal relation to* the world *beyond the apparatuses* is no longer warranted. In contradistinction, what apparatuses *do* reveal is a single disposition or a set of such dispositions, i.e. of possibilities of nature. In other words, experimental phenomena reveal “what Nature is capable of *in conjunction with apparatus*” (Harré 1998, 369, our emphasis). Thus, transparency may be achieved rather between an experimental apparatus and nature’s disposition(s) captured by that apparatus, than between the experimental apparatus and nature’s actual states.

Harré’s approach also offers an explanation for the relative stability of experimental results. Indeed, nature’s laws causally impinge upon apparatuses themselves as part of nature, in spite of the fact that these laws cannot be determined by way of experimentation based on apparatuses.

An apparatus models nature more or less *representatively*, not directly, i.e. purely *causally*. Thus, experimenting turns out to be a way of systematically analyzing similarities and differences between a model and the aspect of the world the model is said to represent. However, apparatuses differ in the ways in which they embody analogies to the aspect(s) of nature, which they are expected to represent. In fact, the underlying relationship between apparatus and nature is intricate, for there exist apparatuses that lack even the slightest analogue in nature. The Wilson cloud chamber as a particle detector is thus a device that, as such, has no equivalent in ‘raw’ nature, although it helps to materially model some physical processes which take place in ‘raw’ nature. Likewise, submicrometre cylindrical cavities in metallic films for experimentally exploring properties of light are a device that, due to its properties, is radically non-existent in 'raw nature,' although it permits to study, and thus to model, the behavior of light in nature (see Ebbesen et al. 1998).

Hence, any apparatus fulfilling the criterion set by Harré's definition is to be seen as a material model of some structure or process occurring in nature. It "reproduces an *instance* of a natural *regularity* that exists in the real world" (Harré 2010, p. 35). Above all, an apparatus is not just taken, or derived immediately, from nature, since it is something which is designed, has been constructed from scratch, and therefore has to have additional properties. It not only has to be economical, but also purified and standardized in order to allow reliable replications. This presupposes the availability of technical means industrially supplied[11].

To sum up, two important points obtain from these considerations:

(a) Since the apparatus partakes of the material world and is causally subjected to manipulations, it should also be considered as something that affects the material world. Thus, the constructive character of apparatus-bound experiments yields experimental results that are inextricably bound to the technical arrangement at stake. This holds for fMRI as well, as this technique can be interpreted as an apparatus (not an instrument) in Harré's sense.

(b) The question as to how far we may back-infer from apparatuses to nature itself remains dependent upon a subtle balance between abstraction and verisimilitude. And this entails that the 'art of the experimenter' turns out to be a decisive factor in scientific research making more or less extensive use of apparatuses (Harré 2010, 36). To put it differently, "modeling is a scientific technique that requires a good deal of intuition and insight to be really effective" (Harré ibid, 36). It is never an affair that rests on some easy matter of *facts*.

Furthermore, Harré distinguishes two types of apparatuses:

First, working models of natural processes: There exist working models of natural processes *within* the material systems for which they count as models. Example: model organisms deliberately designed by genetic means such as a variety of rats exhibiting specific phenotypical traits, e.g. outstanding memory abilities or the propensity for fear. Although bred in a laboratory, such organisms could in principle have developed in nature without human intervention. A model organism *qua* apparatus of this sort is the material model of a piece of nature in 'domesticated' form. It is simpler, so to speak purer, more regular and thus more easily manipulable. In one word, it's easier to experiment with. Although ontologically different from that part of nature under scrutiny, but similar to all other types of apparatus, model organisms

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[11] This is a serious point as it presupposes a certain technological development of a society in order to provide technical devices such as MRT scanners.

rest on the simplified version of a set of phenomenona. In this case, experimenters do not aim at explaining the effects produced by the environment on the model organism *qua* apparatus, since they operate by transferring a piece of nature into the lab. This allows one to draw sometimes strong back-inferences from the experimental results to nature outside the laboratory (although back-inferences depend on how relations of similarity and difference are weighted by research aims).

Apparatus as apparatus-world-complex: An apparatus of this type *creates* phenomenona that *would not, and cannot, occur in nature, it literally produces artefacts*. As it is not transcendent to the world, but has to be made epistemically operant in order to solve e.g. some strong theoretical paradox (such as the particle-wave-dualism in quantum mechanics). A lot of experimentally induced phenomena result from such apparatus-world-complexes (AWC). They turn out to be hybrids of human design and nature. This was, paradigmatically, the case in Humphry Davy's isolation of sodium. As is well known, sodium does not exist in isolated form in nature. When dealing with "some chemical agencies of electricity", he discovered that applying electricity to various chemical compounds, such as sulphate of sodium and phosphate of sodium (among several other similar compounds) (Davy 1807, 18), pure sodium obtained by decomposition *within the borders* of the apparatus, i.e. in the AWC (Davy ibid., 12). To describe Davy's experiments in other terms, the "powerful electrical machine" designed by a certain Mr Nairne (Davy ibid., 31) was set up so that it constituted a model of a fragment of nature where, due to manipulations, decomposition of chemical compounds containing sodium atoms occurred. However, without this specific AWC, without this piece of experimentally 'domesticated' nature, where laws of nature did neither fail nor even slightly change, the "powerful machine" that had created a micro-universe where dispositions of natural matter could manifest themselves previously unheard of and unobserved, pure sodium would not have been isolated. The decomposition of sodium compounds was artificial, i.e. experimentally and artfully induced in, through, by, and thanks to Davy's AWC.

Back-inferences to nature are often difficult to draw in AWCs, for their ontological status as compared to the ontology of nature 'pure and simple' is unclear. Indeed, the true contribution of an apparatus to the production of phenomenona is not transparent from the outset (cf. again Davy's extensive reports on his experiments on the chemical agencies of electricity). Therefore, AWCs cannot be conceived of as instances that unmediatedly actualize properties of nature, that is, the principle of actualism has to be dropped. Instead, we can only speak of potentialities of nature that are made available by AWCs, or of affordances, to refer to

Harré’s terms.[12] Indeed, each affordance is relative to what humans intend to do with it − it “would not have existed without human action to bring it into being“ (Harré 2010, 37).

4. Functional magnetic resonance (fMRI) scanners as AWCs[13]

Let us go back to the issue of fMRI. It follows from the critical reconstruction of Harré’s approach that he conceives of experiments as instances that necessarily remain related to nature (rather than being just merely symbolized within the scientific discourse − according to some postmodernist approaches), while rejecting at the same time the traditional claim of transparency. To put it in simpler words: experimental apparatuses do not reveal states in the world *as these states are in and by themselves*. As indicated above, Harré argues for the non-eliminable, constructive character of experimental apparatuses; at the same time, however, he emphasizes that there is a world ‘out there’ to which apparatuses necessarily relate. Neither the world itself nor apparatuses by themselves reveal the phenomena considered to be relevant for the elaboration of scientific results, since both indissolubly melt into some AWC.

Concerning fMRI scanners, we claim that the most popular and common experimental devices of cognitive neuroscience are members of the AWC-type. The AWCs are intelligently designed and carefully manufactured machines that create, as one could say, pieces of ‘domesticated’ tissues ready to be used as material models of real, organic, living tissue to which they refer. Nowhere in nature do we encounter differences in blood magnetization due to a magnetic field whose force is thousands of times stronger than magnetic fields to be observed on earth’s surface. As AWCs, fMRI scanners (in conjunction with MRI scanners) model the anatomy of the brain as well as

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[12] Harré refers to James Gibson’s idea of affordance.

[13] The italian physiologist Angelo Mosso (1846-1910) is given credit for having devised the first instruments to non-invasively measure the redistribution of cerebral blood in response to cognitive tasks. Therefore, he is often seen as a father of functional magnetic resonance imaging (Sandone et al., 2014). Originally, Mosso had devised a plethysmograph to register alternations in cerebral blood flow from the dura mater in patients with skull defects. He related these alternations to different states of vigilance in the subjects or to cognitive tasks such as listening to their names or to a striking clock (Zago et al., 2009). In order to do similar studies in healthy subjects, Mosso devised a “human circulation balance.” Subjects lay on a wooden table that was balanced on a pivotal point. In a sophisticated experimental procedure, Mosso aimed at demonstrating that cognitive and affective tasks were leading to increased blood flow to the brain, thereby changing the equilibrum in which the lying subject had been set towards head side. Interestingly, Mosso’s device would be different from fMRI as it would have to count as an *instrument sensu* Harré rather than an *apparatus* (such as fMRI) (for the instrument vs. apparatus distinction, see above). In both Mosso’s plethymosgraph and his circulation balance there is a direct causal connection between states in the world (changes in cerebral blood flow) and changes in the instrument (amplitude or tilt of balance, respectively).

cerebral functions by means of highly sophisticated techniques of data production, where the relationship to natural phenomenona (the physiology in nature's brains) is opaque and by material necessity linked to the structure of the machinery. Thus, the assertion according to which neuroscientific data are "extracted from the physical world by technical measuring devices such as [...] functional MRI scanners" (Metzinger, 2004, 591) is totally misconceived if based on a realist interpretation of fMRI data, to say the least, and at worst simply wrong.

Due to their design, MRI scanners make good candidates for Bohrian apparatus-world-complexes. As we have argued above, back inferences from AWCs to the natural world beyond human intervention are inherently problematic, as their status with respect to nature remains opaque. Of course, brains in laboratories causally affect fMRI data. These data, however, do not allow us to directly conclude what brains in nature actually do, as the technique of MRI scanners produces phenomena not to be found in nature. Thus, the relationship between fMRI data and natural brains is not a causal one. It has to be judged on the basis of *adequacy*, i. e. of whether the lab situation of a magnetic field of e.g. 3 T provides an appropriate model for brains active outside the scanner in a natural magnetic field of 35 microtesla.

The best way to make sense of the epistemological status of Bohrian apparatuses (such as MRI and fMRI scanners) is to assume that they actualize a *potentiality* of the world, not an *actuality*. Thus, the fMRI scanner may help to systematically manipulate parts of the world (i.e. brains) for good or for bad, but they seem hardly apt to straightforwardly reveal by themselves, if considered to be self-controlled agencies, anything about the *essence* of the mind (i.e. about one part of the world as it *is*).

5. Conclusion

When apparatuses (in Harré's sense) such as MRI, fMRI, and similarly conceived equipments are at stake, their functioning and their output(s) entail some far-reaching consequence, as the present analytic reconstruction is meant to show. The relation holding between the observing, measuring, experimenting subjects, on the one hand, and the target objects, on the other hand, reveals itself to be epistemically significantly different from the relation holding between the said subjects and their instruments vis-à-vis the target objects given (so to speak) without some intervention caused by the means of observation and measurement. The distance between two points in space is not altered when being measured by a folding rule; human heartbeat is in itself not altered by the stethoscope. However, neither colliding subatomic particles in helium chambers nor activated brain states are (literally) seen when examined on displays, films, and other means. Which is to say that the verbs to see, to observe, to measure are semantically and epistemically flexible and need to be specified according to the context of research procedures and equipments.

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