"Invasive" and "Non-invasive" Technologies in Neuroscience Communication

ARTICLE (RÉVISION PAR LES PAIRS / PEER-REVIEWED)

Maxence Gaillard[1]

Reçu/Received: 27 Jul 2015 *Publié/Published:* 10 Oct 2017
Éditeurs/Editors: Charles Dupras, Vanessa Chenel, Aliya Affdal & Stephen Clarke
Évaluateurs externes/Peer-Reviewers: John Aspler & Anonymous

Résumé

Cet article analyse une distinction faite fréquemment dans les situations de communication en neurosciences : l'emploi des termes "invasif" ou " non-invasif" pour qualifier les techniques d'observation du cerveau. Un jugement de valeur implicite ou explicite accompagnant ces termes, l'adjectif de « non-invasif » a pu être utilisé à des fins de promotion du progrès technique, en particulier à propos des nouvelles techniques d'imagerie apparues ces dernières décennies. Nous étudions ici les interactions entre experts scientifiques et la sphère politique. L'analyse porte sur plusieurs rapports d'expertise concernant les neurosciences, issus de différents comités en France. Nous montrons que la signification des termes « invasif » et « non-invasif » varie selon le contexte, c'est-à-dire en fonction de la nature du discours, des techniques en comparaison ou des parties engagées dans la discussion. La définition de ce qui est à concevoir comme invasif ou non-invasif devient un enjeu stratégique et peut ainsi changer selon les méthodes privilégiées par les experts participants à ces comités ou conseils.

Mots clés

communication scientifique, responsabilité scientifique, technologie d'imagerie cérébrale, représentation du corps, neuroéthique

Abstract

This paper analyzes a common distinction in neuroscience communication: the labels "invasive" and "non-invasive" attributed to brain-observation technologies. Because an implicit or explicit value judgment accompanies the term "non-invasive," it has been used to promote technological progress, especially new brain-imaging techniques that have appeared in recent decades. This study's material comes from interactions between some expert scientists and the political sphere. Expert reports on neuroscience from different advisory bodies in the French public sector have been collected and analyzed for use of the distinction between invasive and non-invasive. The paper shows that the meaning of these widely used labels varies according to the context, e.g., status of discourse, technologies compared, or stakeholders engaged in the discussion. The definition of what is understood as invasive or non-invasive becomes a strategic issue and can thus vary according to the methodologies favoured by experts participating in national advisory boards or councils.

Keywords

scientific communication, scientific responsibility, brain imaging technologies, body representation, neuroethics

Affiliations des auteurs / Author Affiliations
[1] International research fellow, Japan Society for the Promotion of Science, Rikkyo University, Tokyo, Japan

Correspondance / Correspondence
Gaillard Maxence, maxe.gaillard@gmail.com

Remerciements
Cet article a bénéficié des échanges avec le public lors d'un séminaire de la GT41 (Corps, techniques et société) au congrès de l'AFS (Association française de sociologie). La conférence de Montréal en Neuroéthique pour jeunes chercheurs organisée par Veljko Dubljević, Victoria Saigle et Eric Racine m'a donné l'opportunité d'écrire ce manuscrit et ils doivent être remerciés, ainsi que le comité scientifique de cette conférence pour leurs nombreux commentaires pertinents.

Conflit d'intérêts
Aucun déclaré

Acknowledgements
This paper benefited first from the exchanges with the audience at a workshop of the GT41 (Corps, techniques et société) at a congress of the AFS (Association française de sociologie). The Montréal Neuroethics Conference for Young Researchers organized by Veljko Dubljević, Victoria Saigle and Eric Racine gave me the opportunity to write down these thoughts and they should be thanked for that, as well as the scientific committee of this Conference for numerous useful comments.

Conflicts of Interest
None to declare

Introduction

The present philosophical analysis focuses on a common linguistic practice in neuroscience: the labelling of brain-observation technologies as "invasive" and "non-invasive." In the context of communication, scientists cannot always rely on technical terms in their research fields. Explanation often requires blurring of boundaries between technical wording and common language. "Technical wording" generally refers to concepts that are concise, well-defined, and shared in the scientific community, whereas "common" usage is likely to be fluctuant and left to personal intuitions.

On certain occasions, scientists can use metaphors to explain scientific results or describe scientific activity, and indeed, "invasiveness" can be seen at least as an extension of the term's meaning because the word "invasion" primarily denotes a belligerent intervention by a country transgressing another country's boundaries. Some observers have insisted on the dangerous aspects of mobilizing military language in scientific contexts, considering, for instance, the frequent appeal to military vocabulary in the biological sciences: (i) describing delivery of a nanodrug as a "destructive bomb reaching its target" would lead, in the long run, to misconceptions prejudicing the treatment [1] or (ii) stigmatizing "invasive species" would lead to biased management of ecosystems [2]. Metaphors or common language in science have a fundamental ambiguity: on one hand, historians of science have used the fertility of metaphors and displacements of language to produce knowledge [3], and on the other hand, some of their potentially misleading aspects have been noted. For instance, an appeal to an intuitive concept can become an obstacle to a truly scientific explanation [4].

Speaking of "invasive technology" in a medical or scientific domain presents the advantage of replacing the nonobvious cost-benefit analysis of medical and technological judgment with a concrete term. Language can change, so does the meaning of words, and it is now common to refer to "invasiveness" for medical purposes; dictionaries frequently indicate the term's medical extension. Putting aside questions of philosophy of language and the precise nature of the expression, such extension of reference can nonetheless be problematic. Even in the medical context, there are two different meanings: "invasive" can be said of a cancer, a tumor, or a tissue expanding outside its supposed "right" or normal territory and growing into areas where it is not welcome, and "invasive" can also be said of an instrument penetrating the body. What this association suggests, along with the word's previous military background, is that the term has some negative connotation, and this should be enough to justify that specific attention be paid to it as a label. Lack of clarity in distinguishing between invasive and non-invasive, as we will see below, is another reason to question the use of these terms.

The problem of interaction between common language and scientific reality is likely to occur in any communication situation. It goes without saying that this is a classical bioethics topic in the doctor-patient relationship. For instance, the precise wording of an informed consent form is often worth discussing and is often discussed [5]. The naming of "incidental findings" has been an object of debate for a while [6]. Another recurrent question is how to use statistics or medical images in communicating with a patient since statistics or images appear more objective than words but can also be easily misunderstood. This is also a general concern for science communication and diffusion of research: summarizing some complex research processes in a few words is full of pitfalls. To date, most neuroscience communication studies have relied on media analyses [7-8]. Media (e.g., TV, press, and Internet) are indeed major communication vectors between scientists and the public [9-10]. However, varieties of "the public" are numerous, and scientists themselves often must adapt their attitudes and wordings to the communication target, e.g., their peers (in highly specialized publications), scientists from more or less distant research fields (in general scientific publications), and students (in textbooks). A prerequisite of any reflection about communication is sensitivity to the context of exchange. For that reason, we focus here on a very specific subset of communication cases.

Among the diverse targets mentioned above, political leaders involved in budget decisions or strategic research orientations are especially worth convincing of research's interest and capacity. Dedicated venues for exchange between science and politics, for example, commissions or advisory bodies, have been established for this purpose [11]. These venues are not confined to the presentation of scientific methodologies and their results; they also assess the value of research and comment on findings, prospects for future technological developments, and so on. The following analysis is based on sources from this intermediary zone of discourse, where interaction between science and policy occurs. In this arena, researchers, physicians, and politicians interact in many ways and pursue many goals (e.g., convincing, proposing, and assessing). The configuration thus offers a variation in standpoints and in discourse status with great interest, the landscape being reduced to a small set of actors and committees.

Expert reports on neuroscience from different advisory bodies in the French public sector between 2009 and 2014 were collected during visits or from official websites. The reports were scanned for use of the "invasive/non-invasive" distinction[1] and the context of the distinction was analyzed. Although the main documents relevant to our topic were collected and analyzed, at the end of this process, there were too few quotations to pretend to apply any quantitative analysis. Some recurrent patterns occurred nonetheless; these patterns are presented in this paper. The point is rather to explore why this distinction is disseminated, how it can be used, and what can be learned from that use. As it is a non-systematic review, only some interesting configurations are quoted here. Criteria for including a specific citation are the following: the citation illustrates a typical use of the distinction, and this use is different from other ones mentioned in the paper. While this review relies only on written sources, committees often organize interviews with experts; consequently, some materials quoted here are transcripts of oral presentations. The nature of sources, their authors and the context of use of the "invasive/non-invasive" distinction for each citation mentioned, are presented throughout the paper.

A phenomenological intuition

The two labels – invasive and non-invasive – seem to refer simply to a basic intuition: does a physical object penetrate the body or not? Let us consider magnetic resonance imaging (MRI), i.e., recording radiofrequency signals emitted by water molecules under the influence of an intense magnetic field. Magnets generating the magnetic field are placed all around the head and the body, and the experimenter neither touches any internal organ of the subject nor opens the skin. Such brain-imaging

[1] Note that these terms operate in French as in English, but this cannot be said of a difficult to translate label, such as "incidental findings."

technology is likely referred to as "non-invasive" because nothing visible is inserted into the skull. In contrast, let us consider intracranial electrophysiology, i.e., recording electric currents in deep structures of the brain using electrodes introduced through a surgical procedure. This technique unequivocally receives the "invasive" label.

This invasive/non-invasive distinction is often claimed as a major reason for preferring one experimental strategy over another. Research on healthy human volunteers mostly uses MRI (or another "non-invasive" technology), while intracranial electrodes are saved for animal studies. Invasive technology in human research is only used when clinical necessity argues for it. As a recent report[2] states,

> The MRI technique, conceptualized in 1946, is a non-invasive radiologic technique without known secondary effects, based on the physical phenomenon of nuclear magnetic resonance. [12, p.21]
>
> Electrophysiology is an important technique inserting microscopic electrodes into the brain in order to record neuronal activity. Therefore, this is an invasive methodology, principally conducted on primates and rarely on humans, except in pathological cases. [12, p.122]

The invasive/non-invasive distinction falls under a phenomenological spontaneous intuition: whether or not something enters the body. This obvious distinction is shared between scientists and their non-expert audience, and is not supposed to be problematic. What follows is an attempt to go beyond the initial intuition of the distinction's clarity and explore its potential meanings.

Widespread distinction in lack of scientific criteria

The first thing to be noticed about this invasive/non-invasive distinction is that it has no conceptual or theoretical basis. One should not look for a criterion of (non)invasiveness in a scientific theory or in a classification of techniques. Neither does it reflect a precise standard established by the scientific community according to shared rules and methodologies. A distinction such as ionizing/non-ionizing radiation does, for instance, there is a physical definition of ionization, and the level of radiation produced by a certain technology can be categorized as ionizing or non-ionizing with regards to a living tissue exposed to it.

There might be some underlying theories: what are the background conceptions allowing easy characterization of any technique as invasive or non-invasive? Is there an implicit model of action and causality implied? The general progress of technology enables rapid improvement in scientific observation. Through imaging instruments, one can see inside the living body in an unprecedented way [13]. In research set-ups, scientific observation has been classically distinguished from experimentation [14-15]. During an observation, the instrument does not interact with the information source, nor does it influence the observed object. A telescope does not act on a star, nor does the eye (in fact, the star could already be dead at the time of observation). In contrast, a scalpel is designed to cut the skin and flesh, to push matter away and allow a surgeon to see inside the body.

Such a familiar distinction could be based on an elementary causality model traceable to the 17th century. In the Cartesian view, the physical world is composed of particles of matter interacting only by contact [16]. In the 18th and 19th centuries, such a conception permeated most scientific and philosophical views of nature. Yet, the success of the Newtonian theory based on "action at a distance" shows the erroneous nature of this model. Mechanical contact is not required for causality

[2] The *Centre d'Analyse Stratégique* (Center for Strategic Analysis, now called *France Stratégie*) is an advisory body in charge of general economic and social questions, reporting to the French Prime minister. Several notes on neurolaw and on neuroscience's contribution to public policy have been published.

because distant objects can also interact with each other. The prevailing philosophical view of Cartesian mechanistic explanation long hindered the progress of Newtonian theory, even in Newton's own mind; he felt obliged to appeal to "ether" as an intermediary notion bridging the gap between forces and matter [17]. Some psychologists hold the Cartesian conception for "naïve physics" implemented in the human mind [18]. Our own experience shows that inert objects are affected by mechanical causes (to move a pencil, it is more efficient to grasp or push it than to call its name).[3] In an alleged Cartesian model, a technology could be said invasive if and only if a contact occurs with the experimental subject.

However, what would be the value of such a label once the validity of the "action at a distance" model is acknowledged, as in modern physics? MRI observes the inner body through an intense magnetic field. In a way, there is an action of the magnetic field on each water molecule of the brain, the molecules being aligned with the imposed force and spinning in tune with the machine settings. Causality's true nature and whether natural laws discovered by science are just regularities of the human mind are great philosophical debates [19-20]. Our point is more precise: the conceptual distinction between invasive and non-invasive partially belongs to common sense and cannot be resolved through an instrument's physics. There are more than natural sciences as far as the body's representations are engaged. That is why this distinction is worth studying in its sociological and political contexts.

Non-invasive *versus* invasive technologies

The most general and phenomenologically obvious use of this distinction is binary. A technology is said to be invasive or non-invasive. The introductory quotation could illustrate this claim. Because an implicit or explicit value judgment accompanies the term "invasion," a negative value is likely to be associated with technologies labelled in this way. In this context and all things being equal, it is better to develop non-invasive than invasive technologies. Indeed, it is difficult to find a scientist who proudly claims to be using invasive techniques. Instead, the term has been forged in a context of the glorification of technological progress. During the last few decades, new brain-imaging techniques have appeared, such as MRI or position emission tomography (PET), which are said to be "non-invasive" compared to long-used "invasive" animal studies or surgical procedures.

Although some technologies seem obviously non-invasive and are promoted for human research, the previous section has shown that invasiveness is not a natural category. Consequently, much variation can occur in this categorization. See, for instance, the following two statements:

> For clinical or experimental investigation in human, as for *in vivo* study of mammals, the safety of non-invasive methods is essential. Therefore, methods based on X-rays (radiology, scanner X), gamma-rays (SPECT), ultrasound, nuclear magnetic resonance (RMN and functional MNR) and positron emission tomography (PET) are used. [21, p.72][4]

[3] "If there is a connection between commonsense physical reasoning and scientific reasoning, it may be reflected best in the difficulty that ordinary adults, and at least some scientists, experience in conceiving of physical phenomena to which the continuity and solidity constraints do not apply. Although systematic evidence is lacking, it would seem to be more difficult to develop clear and consistent intuitions about a world lacking continuously persisting, impenetrable bodies than to develop intuitions about a world lacking gravity or inertia. Continuity and solidity appear to be deeply embedded in human conceptions of the physical world and human ways of tracing physical bodies through time." [18]

[4] This quotation is from a strategic report of the French *ITMO* (*Institut thématique multiorganismes*) devoted to neuroscience. An *ITMO* is a transverse science management structure aiming at national unification of research conducted in a specific area (here, the nervous system and its disorders).

> This brain imaging technique [functional MRI (fMRI)] presents several advantages. Firstly, fMRI does not involve an exogenous contrast agent but an endogenous sign[5] of cerebral activity. It is thus a non-invasive technique (contrary to PET-scan for instance) that allows a dynamic measurement of cerebral activity. [12, p.126]

In the first quotation, all brain-imaging technologies, from scanner to MRI, are considered non-invasive, while in the second, only fMRI deserves the “non-invasive” label and even PET is considered invasive. How can one account for such differences?

Among the various experimental neuroscience strategies, there is competition, especially in raising money. Establishing an experimental research centre with all its technological equipment is costly. As scientific research becomes increasingly technology-loaded, technological choices represent heavy investments. These choices are often delicate, as both scientific and strategic or economic reasons overlap. In any communication situation, promotion of technology (i.e., of a specific technological research tool) becomes an important objective in the minds of researchers, in particular, directors, managers, and principal investigators [22]. The latest technology on the market often bears the burden of proof: against experimental traditions, laboratory routines, and existing equipment, convincing sponsors and colleagues that a new technology is worth the investment can be difficult. Here is a good reason to prefer positive terms in the presentation of new technologies. One can thus insist on non-invasive new technologies and claim strong support for their development.

A more precise debate also exists in functional neuroimaging between PET and fMRI proponents. Both instruments measure oxygen dynamics in the cerebral blood flow, which is precious information for human cognitive studies *in vivo*. Before fMRI, PET appeared when the first functional imaging studies in cognitive neuroscience were conducted in the 1980s. Subsequently, major neuroscience centres were equipped with this technology. FMRI appeared a little later and progressively overtook PET during the 1990s. Currently, most functional neuroimaging studies use fMRI methodology. Yet, researchers who have chosen PET strategy still have much to say about fMRI’s limits (see for instance [23]). Furthermore, at its beginning, fMRI had to show that it could do as well as PET; otherwise, no one would have turned to the new instrument. Furthermore, there is no such thing as good or bad experimentation *per se*: Scientists always compare technologies and experimental strategies (referring, for example, to the existing “gold standard”). PET can be termed “invasive” because it requires a needle stick to inject into the subject’s arm a radioactive solution as a tracer, whereas fMRI does not.

These contextual elements account for the difference in categorizations in the above quotations. Each text is indeed specific in its purpose and writing process. The *ITMO* report (first quotation) is a common ground document: many scientists from various disciplines are engaged in its writing. Researchers are coming to agreement in the formulation of scientific orientations to be pursued in general. From this committee’s perspective, all technologies are valued as non-invasive. In contrast, the CAS report chapter (second quotation) is authored by a scientific advisor of the council. He is also a cognitive scientist and a very active proponent of the fMRI method, and he values here fMRI more than PET, associating the positive adjective “non-invasive” only with fMRI.

In this context of comparison between different technologies, another use of the distinction is possible.

Gradation: more and less invasive technologies

In numerous occurrences, the distinction between invasive and non-invasive is not oppositional but a matter of degree. In this case, invasiveness is considered a scale along which technologies can be

[5] The author refers here to the blood oxygen level dependent (BOLD) phenomenon in functional MRI: a natural property of desoxyhemoglobin allows increase of the magnetic resonance signal.

classified. Contrary to the opposition of invasive/non-invasive, a gradation-type expression does not fit the spontaneous binary model (observation *vs.* action; contact *vs.* distance). What does it mean for a technology to be more or less invasive? Does something penetrate the skin or not? Does something enter the brain or not?

> According to experts, brain-machine interface aims at analyzing and restoring lost functions. Better prosthetic devices, which are less invasive, are developed. [24, p.35] (SR)[6] Recently, human research has been conducted through a less invasive approach, electrodes being implanted in the surface of the cortex of a patient. [25, p.143] (physician)
>
> There are today numerous manners of treating the nervous system, and the number of these possibilities is growing, whether it involves chemicals or more or less invasive procedures such as brain imaging, magnetic transcranial stimulation, implants or neuroprostheses. [25, p.83] (SR)
>
> When a surgeon wants to operate on a patient and wants to know his language areas, one often proceeds to a pharmacological test, namely the Wada test. One injects a barbiturate in a carotid in order to anesthetize a brain hemisphere, observes whether the patient loses language, and identifies language lateralization. For a decade, clinical teams have been exploring less invasively, appealing to fMRI as a guide for surgery. [25, p.97] (neurologist)

First, one can notice again that the invasiveness metaphor is likely to appear in the competitive context between technologies, even if in a different manner. Second, the statements just quoted do sometimes fit a phenomenological model of the body as a territory to protect. A surface electrode in the cortex can accurately be declared less invasive than a deep-brain electrode. On this basis, people can intuitively agree on what is to be designated as more or less invasive: everybody can see the apparent effects of technology on the body.

However, such a conception can lead to paradoxical assertions. Indeed, even some surgical procedures can be labelled non-invasive:

> There is a strong [societal] demand for innovation, especially technological innovation, and the successes of the non-invasive surgery (laser eye surgery for instance), the Internet, home automation and the mobile phone attest to this trend. [26, p.12][7]
>
> This project aims at the acquisition of equipment generating ultrasound in order to destroy – thanks to heat and without opening the skull – limited targets like brain tumors or to stimulate non-invasively some brain structures. [24, p.49] (SR)

While some technologies are described as “non-invasive,” their action on the body is recognized at the same time. The skull and the skin are phenomenologically safe, but the brain can be reached. Non-invasive surgery is efficient, because of a physical *effect* on the body. In this case, the model of observation is definitely away: even a non-invasive instrument can be an intervention tool. “Action at a distance” is clearly possible and is even a prerequisite for a “non-invasive” cure. In this respect, the property of non-invasiveness is no longer a criterion for identifying harmless technology. An

---

[6] *OPECST* (*Office Parlementaire d’Evaluation des Choix Scientifiques et Technologiques*): the parliamentary office in charge of assessment of scientific and technological choices in France. Excerpts come from text written by state representatives (SR) themselves or from public interviews of scientists. Some state representatives might also have been physicians or academics in previous careers.

[7] The *SNRI* (*Stratégie Nationale de Recherche et d’Innovation*) Report was a ministry-conducted initiative. Researchers from various fields were gathered in working groups to elaborate a proposal for a national research strategy.

instrument can indeed act on the body's internal structures and destroy them from the outside. Should "non-invasive" no longer be considered laudatory?

From fear of invasion to objective risk analysis

Another option would be the following: as a positive term, "non-invasive" would designate the general fact that a technology is harmless. In this case, "invasive" would refer to everything that harms a patient or an experimental subject and everything painful or something that has a significant bodily impact. Under these circumstances, harm comes not only from small injury to the skin. Radioactivity is an essential feature of many brain-imaging instruments. Some devices produce ionizing radiation to visualize the body's inner parts; some use radioactive tracers to record internal activity. However, sticking a needle in a patient for a couple of minutes is less dangerous than strong exposure to radioactive rays. For instance, consider PET, which is sometimes classified as "invasive" and sometimes as "non-invasive." It is surely not the needle in the arm of the subject that represents a risk; at most, that is a discomfort during the experimental procedure, as is confinement in PET or MRI machines and the noise of their operation. However, injection of a radioactive tracer is problematic. There are limits imposed on research: healthy volunteers shall not be exposed to certain doses of legally defined radiation. When considering research on healthy human participants, it may not be worth taking any risk, and the statement "PET is more invasive than fMRI" could make sense.

In the clinical context, cost-benefit analyses appear totally different: a small dose of radiation is, of course, better than an erroneous diagnosis, and a surgical intervention is generally better than a tumor's continued growth. Nonetheless, during public presentations held before the previously mentioned Parliamentary Office, some shocking pictures of invasive technologies strongly affected the public. A lay audience might have difficulty understanding why such technologies are still applied to patients. The presentation and promotion of non-invasive technologies in the same panel is even more misleading. One hypothesis is that confusion could emerge as a side effect of communication hype. After emphatic promotion of some new technology's non-invasive property, researchers and physicians are frequently criticized for their continued, general use of invasive technologies and methodologies. Indeed, some researchers attempt to protect themselves from criticism. Expert speakers must present their work very carefully and firmly insist on the medical benefits of invasive procedures. A possible strategy is to debunk the myth of non-invasive-thus-safe technology:

> Some neuroimaging technologies are presented as non-invasive, and yet their safety and reliability are still an issue. [24, p.79] (SR)

Biologists or clinical researchers working at the neuronal level with invasive methods can sometimes be very critical of their neuroimaging colleagues in cognitive neuroscience using PET or fMRI, accusing off-record their scientific methodologies of shortcuts and weakness. Even so, documents looking for unanimity are stepping back regarding the invasive/non-invasive distinction and argue against its relevance:

> The theoretical and experimental separation of invasive and non-invasive human BMI research is not useful for the field or for future applications. The aim of the European effort should be to develop and test both invasive and non-invasive, commercially available and affordable BMIs that are tailored to specific applications. BMIs for direct brain communication and for motor restoration should have priority. [27, p.48][8]

This last excerpt chooses willingly to overcome the distinction, in favour of general promotion of neuroscience. The many ways of articulating neuroscience and policy can be broadly classified along

[8] This document was written by some members of the European Brain Council, a gathering of European scientific societies sharing interest in neuroscience and related research areas and clinical disciplines.

two main lines: self-organization of science through institutions or direct exchange from particular scientists to politicians. A situation where scientists exchange directly with politicians might favour competition between scientists. Experts are prompted for use of the invasive/non-invasive distinction in order to promote "non-invasive" technologies. The definition of what is to be understood as invasive or non-invasive becomes a strategic issue, and thus, can vary according to the methodologies used by experts participating in advisory boards or councils. In contrast, self-organization might favour agreement among experts before reaching the political level. In the report mentioned above, a consensus is reached within the neuroscience community before going public, and the strategy includes a decision not to open the Pandora's box of technology comparison. The strategy is aimed at smoothing opposition between different scientific methodologies and strategic choices. Furthermore, the authors are condemning a communication strategy hazardous in the long run for the promotion of neurotechnologies, as the public can switch from non-invasive lauding to invasive blaming. Such a move would illustrate a classic case of a hyping strategy turning against its originator [28].

Conclusion

The distinction between "invasive" and "non-invasive" technologies is not uncommon in the neuroscience and policy literature. The main lesson of our analysis is that the distinction's boundaries can vary greatly according to context; failing to define a unique model of the invasive property that could account for a unique invasiveness criterion. Here, we have interpreted and discussed several uses of "invasiveness" by referring to the context of discourse. The meaning of the distinction is often correlated with the strategy of actors to explain or promote their activity.

The fact that the phenomenological distinction is somewhat obscure might not be a problem per se because context often disambiguates meaning. However, this ambiguity might be a problem in science *communication*. Researchers are not only laboratory specialists; some have to defend and promote their choices to various audiences, such as politicians and funders. The resulting intermediary language corresponds neither to pure technical scientific lectures (often deprived of data and technical content) nor to absolutely disinterested pedagogical presentations. Even if concepts are not scientifically based (the invasive/non-invasive distinction does not allow identification of a natural family of instruments or techniques), the two notions are encountered in such literature.

Looking for the right word is part of improvement in research communication and its ethics. When scientific concepts are available, such as ionization, there is no need to look for other words. At the same time, it might be possible to tackle risk analysis directly: which technology is more dangerous and why? Is an intuitive distinction that does not fit with a precise canon really welcome? In a kind of paternalist tone, emphasis on non-invasiveness can be anticipated to spare a patient or a volunteer experimental participant from irrational fears ("look, nothing is going to hurt you"). However, it is common knowledge that radiation can cause cancer in the long run despite its risk not originating from a visible, immediate breach of the skin. People are even more inclined to fear "contamination" or "exposure" *because* they believe in the potential effects of radiation or electromagnetic waves, whether this fear is grounded in reason or not (see, for instance, the phenomenon of electromagnetic hypersensitivity). This is particularly true of the brain, an organ without sensory receptors, which cannot be felt by patients or subjects themselves. Referring to invasiveness or non-invasiveness of technology in this context might not help. The minimal prescriptive result would be to avoid using such an emotionally or negatively loaded term as "invasive." This discussion should further encourage exploration of relations between scientific concepts and common language.

References

1. Bensaude-Vincent B, Loeve S. Metaphors in nanomedicine: the case of targeted drug delivery. NanoEthics. 2014;8(1):1-17.
2. Tassin J, Kull C. Pour une autre représentation métaphorique des invasions biologiques. Natures Sciences Sociétés. 2012;20(4):404-414.

3. Fox-Keller E. Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines. Cambridge: Harvard University Press; 2002.
4. Bachelard G. La formation de l'esprit scientifique. Paris: Vrin; 1938.
5. Jefford M, Moore R. Improvement of informed consent and the quality of consent documents. The Lancet Oncology. 2008;9(5):485-493.
6. Christenhusz G, Devriendt K, Dierickx K. Secondary variants – in defense of a more fitting term in the incidental findings debate. European Journal of Human Genetics. 2013;21,1331-1334.
7. Racine E, Waldman S, Rosenberg J, Illes J. Contemporary neuroscience in the media. Social Science & Medicine. 2010;71(4):725-733.
8. Gonon F, Konsman JP, Cohen D, Boraud T. Why most biomedical findings echoed by newspapers turn out to be false: the case of attention deficit hyperactivity disorder. Plos One. 2012;7(9).
9. European Commission. Special Eurobarometer 340 - Science and Technology. Bruxelles: European Commission (Wave 73.1 – TNS Opinion & Social); 2010.
10. National Science Board. Chapter 7 - science and technology: public attitudes and understanding. Science and Engineering Indicators 2014. Arlington: National Science Foundation (NSB 14-01); 2014.
11. Guston D. Between Politics and Science: Assuring the Integrity and Productivity of Research. Cambridge: Cambridge University Press; 2000.
12. Centre d'Analyse Stratégique. Le cerveau et la loi : analyse de l'émergence du neurodroit. Document de travail coordonné par Olivier Oullier (N°2012-07). Paris: CAS; 2012.
13. Kevles B. Naked to the Bone: Medical Imaging in the Twentieth Century. New Brunswick: Rutgers University Press; 1997.
14. Bernard C. Introduction à l'étude de la médecine expérimentale. Paris: Baillère; 1865.
15. Shapere D. The concept of observation in science and philosophy. Philosophy of Science. 1982;49(4):485-525.
16. Descartes R. Les principes de la philosophie. Paris: Henry Le Gras; 1647.
17. Bachelard G. Le nouvel esprit scientifique. Paris: Alcan; 1934.
18. Spelke E, Breinlinger K, Macomber J, Jacobson K. Origins of knowledge. Psychological Review. 1992;99(4):605-632.
19. Hume D. A Treatise of Human Nature. London: John Noon; 1739.
20. Kant I. Kritik der reinen Vernunft. Riga: Johann Friedrich Hartknoch; 1781.
21. Institut Thématique Multi-Organismes Neurosciences, Sciences cognitives, Neurologie, Psychiatrie. Orientations stratégiques. Paris: Aviesan; 2010.
22. Joly PB. On the economics of techno-scientific promises. In Akrich M, Barthe Y, Muniesa F, Mustar P (eds.) Débordements. Mélanges offerts à Michel Callon. Paris: Presse des Mines; 2010, 203-222.
23. Fox P. The coupling controversy. NeuroImage. 2012;62(2):594-601.
24. Office parlementaire d'évaluation des choix scientifiques et technologiques. L'impact et les enjeux des nouvelles technologies d'exploration et de thérapie du cerveau. Rapport par MM. Claeys et Vialatte, députés. Paris: Assemblée Nationales et Sénat; 2012.
25. Office parlementaire d'évaluation des choix scientifiques et technologiques. L'impact et les enjeux des nouvelles technologies d'exploration et de thérapie du cerveau. Annexes. Paris: Assemblée Nationales et Sénat; 2012.
26. Ministère de l'Enseignement Supérieur et de la Recherche. 2009. Stratégie Nationale de Recherche et d'Innovation, Rapport général. Paris: MESR; 2009.
27. Di Luca M, Baker M, Corradetti R, Kettenmann H, Mendlewicz J, Olesen J, Ragan I, Westphal M. Consensus European document on brain research. European Journal of Neuroscience. 2011;33(1):768-818.
28. Nightingale P, Martin P. The myth of the biotech revolution. Trends in Biotechnology. 2004;22(11):564-569.