ARTÍCULOS
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Challenging the experimentalist dogma: Empirical incommensurability in early neuroscience*

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Abstract: This article examines the "experimentalist dogma" in Pablo Melogno's analysis of empirical incommensurability during the chemical revolution. Melogno argues that preserving experimental methods indicates no significant perceptual differences between Joseph Priestley and Antoine Lavoisier. To refine this view, we propose a taxonomy of empirical incommensurability and apply it to the neuronist revolution, focusing on the late 19th–early 20th-century controversy between Camillo Golgi and Santiago Ramón y Cajal. We challenge the experimentalist dogma by analyzing debates on dendritic spines and cerebellar stellate cells, showing that shared experimental practices do not ensure perceptual similarity. Instead, we argue that, even under identical experimental conditions, perceptual differences between Golgi and Cajal stem from their commitments to incompatible conceptual schemes.

Keywords: Incommensurability, perceptual change, neuron, Camillo Golgi, Santiago Ramón y Cajal

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Cuestionando el dogma experimentalista: inconmensurabilidad empírica en la neurociencia temprana

Resumen. En este artículo, examinamos el "dogma experimentalista" en el análisis de Pablo Melogno sobre la inconmensurabilidad empírica durante la revolución química. Melogno sostiene que la conservación de los métodos experimentales indica la ausencia de diferencias perceptuales significativas entre Joseph Priestley y Antoine Lavoisier. Para refinar esta perspectiva, proponemos una taxonomía de la inconmensurabilidad empírica y la aplicamos a la revolución neuronista, centrándonos en la controversia de finales del siglo XIX y principios del XX entre Camillo Golgi y Santiago Ramón y Cajal. A través del análisis de debates sobre las espinas dendríticas y las células estrelladas del cerebelo, cuestionamos el dogma experimentalista, mostrando que la continuidad de las prácticas experimentales no garantiza la similitud perceptual. Sostenemos que, aun bajo condiciones experimentales idénticas, las diferencias perceptuales entre Golgi y Cajal se explican mejor por sus compromisos con esquemas conceptuales incompatibles.

Palabras clave: Inconmensurabilidad, cambio perceptual, neurona, Camillo Golgi, Santiago Ramón y Cajal

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1. Introduction

According to *The Structure of Scientific Revolutions* (Kuhn, 1970; *Structure* from now on), incommensurability refers to the impossibility of making definitive comparisons between successive paradigms, or between competing schools, due to the lack of objective or neutral parameters of comparison. Thomas Kuhn provides several depictions of the phenomenon of incommensurability. A fundamental condition is the absence of a common and objective empirical basis between successive paradigms, or competing schools, which would function as the ultimate authority for comparisons.

Kuhn (1970) resorts to the idea of a "gestalt" switch when speaking of this type of empirical incommensurability. That notion was previously introduced by Norwood Hanson (1958), influenced by both Ludwig Wittgenstein's philosophy of psychology (Wittgenstein, 2001) and Gestalt psychology (Kohler, 1947). The idea of gestalt change offered a plausible and vivid picture of how it was possible for the empirical basis of competing scientific theories to be, in many cases, influenced by the very theories they were intended to test. Hypothesis testing often involves the training of scientists' perception, i.e., a "learning to see" guided by paradigmatic concepts.

At least when he presents his ideas in a general and abstract way, Kuhn characterizes the change brought about by a scientific revolution as a gestalt change that modifies the perceptions of scientists. However, in his metatheoretical analyses, it is not easy to find episodes in which scientists' perceptions have been directly affected. In the "Epilogue: 1969" of the *Structure,* Kuhn (1970) makes it clear that his statements about changes in scientists' ways of seeing must be interpreted metaphorically in the absence of more adequate ways of describing this phenomenon.

> We do not see electric currents at all, but rather the needle of an ammeter or galvanometer. Yet in the preceding pages, particularly in Section X, I have repeatedly acted as though we did perceive theoretical entities like currents, electrons, and fields, as though we learned to do so from examination of exemplars, and as though in these cases too it would be wrong to replace talk of seeing with talk of criteria and interpretation. The metaphor that transfers 'seeing' to contexts like these is scarcely a sufficient basis for such claims. In the long run it will need to be eliminated in favor of a more literal mode of discourse. (Kuhn, 1970, pp. 196-197)

For this reason, there is some debate among Kuhn scholars about the scope of this metaphor, whether it can be interpreted literally, or whether there are revisions of this idea in Kuhn's later works (Hoyningen-Huene, 1993; Diez, 2012).

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This point has been widely debated in one of Kuhn's favorite cases, the revolution in chemistry (Falguera, 2004; Hoyningen-Huene, 2008; Caamaño, 2009). Notably, Pablo Melogno (2021) has argued that the discovery of oxygen is not an adequate exemplar of change at the perceptual level. On the contrary, he contends that the idea of perceptual change is useless for understanding the kind of incommensurability that occurs between competing paradigms in the chemical revolution. Although Melogno's argument introduces a reasonable distinction between differences in perception and differences in the conceptual interpretation of perception, the conclusion that Priestley and Lavoisier saw the same thing rests on an unspoken principle according to which given two laboratory observations, similar experimental designs of those observations entail similar perceptual content. We will refer to this underlying principle as the "experimentalist dogma."

The aim of this article is to show why this principle may be dogmatic and incorrect. In Section 2, we present Melogno's proposal. In Section 3, we introduce a scheme —a sketch of taxonomy— of the different varieties of empirical incommensurability and discuss some relations between them. In Section 4, we examine an early episode of the neuroscientific revolution, i.e., the neuronist revolution in neuroanatomy (Shepherd, 2015), in order to illustrate how our scheme may be useful or illuminating in its application to the history of science. In the proposed case study, the experimentalist dogma does not offer the best explanation of the peculiar form of empirical incommensurability that seems to be at play, thus suggesting its inadequacy.

2. The experimentalist dogma

Melogno (2021) argues that Kuhn's (1970) notion of perceptual incommensurability is ineffective for reconstructing the chemical revolution. No change in perception, according to Melogno, played a central role in the discovery of oxygen. Melogno argues that the idea Priestley and Lavoisier did not have different perceptual experiences follows from the methodological continuity between experimental practices before and after the revolutionary process. Incommensurability, Melogno suggests, should rather be situated at the conceptual level.

Melogno questions two aspects of the thesis of empirical incommensurability that some attribute to Kuhn. First, he rejects a perceptualist dogma, which holds that scientific revolutions require perceptual change. Second, he opposes a form of conceptualist dogma, which is traceable –in philosophy of science, at least– to Hanson (1958), which claims that perceptual content is determined and internally structured by its conceptual interpretation.

Melogno's distinction between experimental practices, perceptual experiences, and conceptual interpretation proves fruitful for studying the case of the neuronist revolution in neuroanatomy, an early episode in the initial revolution of modern neuroscience. However, we argue that the same case study compels us to question a third experimentalist dogma, inspired by Ian Hacking (1983, 1988, 1992; Sullivan, 2021) and presumably endorsed by Melogno (2021). According to this third dogma, perceptual content is, to a large extent, determined by the experimental practices involved in obtaining those results. This position is expressed in passages such as the following:

> If two scientists perform the same experiment starting from the same raw material, with the same apparatuses and measuring scales, we can conclude that they receive very similar stimuli. If they also obtain the same results, we can also affirm that they formed the same perception from the same stimulus and that they use different conceptual frameworks to refer to the same results. (Melogno, 2021, p. 76; our translation).

Our goal here is not to discuss Melogno's specific conclusions regarding the chemical revolution. Instead, we intend to refine his analysis of empirical incommensurability, and in particular discuss this experimentalist dogma, in a more general way. To this end, we will introduce a taxonomic scheme for the varieties of empirical incommensurability and consider some of their relations.

3. Empirical Incommensurability: A Taxonomy

Without claiming to be exhaustive, in this section we will present a taxonomy of the different forms of empirical incommensurability. Some of the varieties distinguished here are found in Kuhn's own work, others have been explored by different authors (cf. Lorenzano and Nudler, 2012; Ginnobili, 2014).

We argue that, in laboratory contexts, two successive scientific observations are empirically commensurable if (i) the experimental intervention, (ii) the perceptual content and (iii) the conceptual interpretation of that content are relevantly similar in both.

According to the conceptualist dogma, denounced by Melogno (2021), in laboratory contexts, if two observations have conceptual interpretations that differ in a relevant way (i.e., do not satisfy condition (iii)), then the perceptual content may differ in a relevant way, violating condition (ii), even if condition (i) (commensurability of the intervention) is met.

According to the experimentalist dogma, presupposed by Melogno (2021), in laboratory contexts, if two observations meet the condition of commensurability of intervention, then we can be sure that they meet the condition of similarity of perceptual content. If there is any form of incommensurability, it must be sought at the level of conceptual interpretation.

We will follow this thread of commensurability failures that can occur at the level of the empirical basis to delineate our taxonomic scheme. If, in the context of an episode of scientific change, any of these conditions is not met for two successive observations, we can speak of empirical incommensurability or, rather, of various types of empirical incommensurability. Some of these types are problematic for the experimentalist dogma, while others are relatively harmless to it. Of course, that they are innocuous to the experimentalist thesis does not mean that they are causally irrelevant factors in scientific change, but rather that they are compatible with the idea that observation has a "life of its own" in the laboratory that is relatively independent of the vagaries of theory. In what follows, we will present the different types of incommensurability that make up our scheme: *incommensurability of the intervention, perceptual incommensurability, and conceptual incommensurability* which, in turn, subdivides into semantic incommensurability of the empirical kind, semantic incommensurability of the theoretical kind, and incommensurability of interpretation.

3.1. Incommensurability of the intervention

The commensurability of the experimental intervention requires both (a) similarity of the target system and (b) similarity of the experimental design.

First, commensurable observations must have similar target systems; ideally, they should satisfy an extensional identity requirement, i.e., they should be observations of *the same thing*, i.e., of the same system in the world. Reasonably, we require less than extensional identity. How much similarity is necessary or how much difference is compatible with satisfying requirement (a) are ultimately matters of degree. Two theories —paradigms or schools— may be empirically incommensurable, either because they focus on different systems or because they focus selectively on different aspects, properties, or regions of the same system, and not necessarily because they possess conceptually incommensurable underlying theories —either partially or wholly—. For example, if two researchers look under the light microscope at Purkinje cells of the cerebellum, stained with the same staining method, but one does so in adults and the other in embryos of the same species, do they count as observations of the same thing? Can there be a dispute about whether these scientists study the same system? The answer depends on how many common properties these scientists identify in the target system as relevant to the scientific inquiry.[1]

1 Did Aristotle and Galileo see the same thing when they observed pendulums? This is how the question is presented by Kuhn in The Structure: "Since remote antiquity most people have seen one or another heavy body swinging back and forth on a string or

Second, commensurable observational results must be the product of similar experimental designs and repertoires. This means that satisfaction of the experimental intervention similarity condition can fail in at least two ways. If, in laboratory contexts, a pair of observations does not satisfy the target system similarity condition, then they are not observations of the same thing, and even if they share experimental design, this can be expected to affect both the similarity of perceptual content and their theoretical interpretation.

If a pair of observations meet the target system similarity condition but differ in a relevant way in their experimental repertoires, it is to be expected that this will also affect the similarity of both the perceptual content and its theoretical interpretation.

3.2. Perceptual incommensurability

Perceptual incommensurability has probably been the most discussed in philosophy. Plausibly, this is because perceptual incommensurability implies a questioning of some principles of modern empiricism. On the one hand, it questions the close association between experience and certainty, and on the other, it questions the idea that theoretical concepts acquire meaning from experience (and not vice versa). Furthermore, the discourse in terms of gestalt changes was used by Hanson, Kuhn, and other authors in a metaphorical way to speak of conceptual changes in the categorization of objects. That is, this form of incommensurability was used to speak metaphorically of empirical incommensurability (in general) and semantic incommensurability (in general).

This form of incommensurability is the most difficult to study, particularly in relation to episodes in the history of science, since experience, as such, is in the realm of the subjective. The most influential presentation of this form of incommensurability in the field of philosophy of science, although not under this name, was developed by Hanson (1958). He made use of the reversible perspective figures of Gestalt to give plausibility to the idea that differences at the conceptual level may imply differences at the level of the very configuration of experience.

Because of its subjective nature, perceptual incommensurability is usually inferred indirectly from the manifestation of one of the other types of incommensurability.

chain until it finally comes to rest. To the Aristotelians, who believed that a heavy body is moved by its own nature from a higher position to a state of natural rest at a lower one, the swinging body was simply falling with difficulty. Constrained by the chain, it could achieve rest at its low point only after a tortuous motion and a considerable time. Galileo, on the other hand, looking at the swinging body, saw a pendulum, a body that almost succeeded in repeating the same motion over and over again ad infinitum. And having seen that much, Galileo observed other properties of the pendulum as well and constructed many of the most significant and original parts of his new dynamics around them." (Kuhn, 1970, pp. 118-119) Kuhn's idea is that the change in "the way of seeing" the pendulum led Galileo to track different properties to describe the motion of the system. For example, instead of paying attention to the weight of the pendulum object, he determined the period of oscillation.

Melogno's work on the revolution in chemistry aims to infer perceptual commensurability from the similarity in the type of experimental interventions performed. In the tradition of Hanson and Kuhn, perceptual incommensurability is inferred indirectly from differences in the level of conceptual interpretation.

3.3. Conceptual incommensurability

Conceptual incommensurability can be analyzed, in turn, in three subtypes, which we will call (a) semantic incommensurability of the empirical kind, (b) semantic incommensurability of the theoretical kind, and (c) incommensurability of interpretation.

Two theories (paradigms/schools) exhibit empirical semantic incommensurability if the underlying theories on which they rely to categorize their "empirical basis" are themselves incommensurable. Conversely, they exhibit theoretical semantic incommensurability if the theoretical concepts and the principles or laws that link them are incommensurable. In the middle of the 20th century, several authors, more or less independently, proposed an idea (which we consider a true metatheoretical discovery). The starting point consisted of separating the theoretical/non-theoretical distinction from the observational/non-observational distinction in order to think of the way that independent testing of theories works in the context of theory-ladenness of observation (a thesis that had been growing in acceptance). Despite variations in the different approaches, the central idea consisted of distinguishing, among the fundamental concepts of a theory, those that made it possible to safeguard the independence of the test because they could be applied from theories other than the one under scrutiny (Hempel, 1970, 1973; Lewis, 1970; Hesse, 1967, 1969; Sneed, 1971). The "empirical basis" of a theory T (now in quotation marks because it would not necessarily consist of observational concepts) would be constituted by the T-non-theoretical concepts, i.e., those that can be determined independently of the theory T.

Thus, even if the theory-ladenness of observation were real, this would not imply that the testing of theories is circular. For the "empirical basis" of a theory could be laden with other theories. In this sense, the distinction would put a limit to the thesis of radical semantic holism since there would be a sense in which concepts do not depend semantically on every theory in which they appear—there is a sense in which T-non-theoretical concepts do not semantically depend on the theory T (since they have criteria of determination independent of T).

Going back to the issues that concern this paper, these distinctions allow us to think of a form of empirical incommensurability that had not been clearly considered by Kuhn, which is also a form of semantic incommensurability. Two theories would be empirically incommensurable in this sense if they do not share the underlying theories from which their T-non-theoretical concepts derive.

This thesis can be sophisticated in different ways. On the one hand, this form of semantic empirical incommensurability is not necessarily an all-or-nothing question. For example, Charles Darwin's theory of natural selection and William Paley's natural theology, incommensurable in almost every conceivable respect, attribute functions similarly (and, in that sense, can be said to appeal to the same underlying theories that enable functional attribution). However, Darwin modified these underlying theories because, in the providential framework of natural theology, functional attributions, in many cases, depended on the plan of creation. Whole organisms and their parts could have functions related to the maintenance of the overall system. Since such functions could not arise by natural selection, Darwin eliminated from functional biology any function that did not benefit the organism or the group to which it belonged (Ginnobili, 2014, 2022; Caponi, 2011). Faced with the semantic empirical incommensurability question between these two theories, the answer is not an all-or-nothing one. The theories in question appeal to the same theory with some important modifications. Another sense in which semantic empirical incommensurability can be complexified is by considering that T-theoreticity is a heterogeneous phenomenon. In Sneed's (1971) proposal, in which a concept is T-theoretic if all of its application criteria depend on the theory T, and T-non-theoretic if not, T-theoreticity relates to theory-testing. But there are other possible related distinctions, which are neither coextensive nor intensionally equivalent to Sneedian T-theoreticity, which considers the role of concepts with respect to explanation—and is thus sometimes called T-explicativity (Ginnobili & Carman, 2016; Roffé et al., 2023; Díez et al., 2024). Moreover, it can be argued that the meaning of concepts is hardly reduced to their criteria of determination (Díez, 2002). If the meaning of theoretical concepts is more complex, then other semantic dependencies must be considered (Ginnobili & Barberis, in press). For the issue at hand, dealing with these distinctions in detail is unnecessary. María Caamaño discussed the chemical revolution in this sense based on the structuralist distinction (Caamaño, 2009, 2011), defending that the chemical revolution is a case of partial theoretical incommensurability and empirical commensurability. It would also be interesting to compare her approach with Melogno's, which is based on experimental commensurability, to establish relations between both types of incommensurability, but this exceeds the limits of our work.

Finally, we come to the incommensurability of interpretation. This is perhaps the most classical form of incommensurability, since it does not entail the theory-ladenness of observation. A good way to present this form of incommensurability is by comparing it to perceptual incommensurability. Here, it is not a matter of the differences in how the object is seen but of how the same experiences are interpreted. Of course, this implies assuming that the experiences are the same. For example, consider the debate on whether the spots on the Moon seen through a telescope are craters or effects of the Earth's atmosphere; is this discussion at the

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level of interpretation of the same observational data, or does it involve a change in the observers' own experience? Given the subjective nature of experience, the question is not easy to answer. It is not implausible that there are cases where there are differences at the level of interpretation without differences at the perceptual level. While these differences in interpretation may be symptomatic of more important or profound theoretical differences, they may not be. The difference with empirical semantic incommensurability is that what is at stake is not a different categorization of a phenomenon based on theoretical or non-theoretical concepts of the theory, although, as we shall see, the acceptance of a certain theory may influence interpretation.

It could be argued that if differences at the level of experimental design involve different theoretical presuppositions, then there is no real distinction between conceptual and experimental incommensurability. However, in the case of conceptual incommensurability, the underlying theories provide concepts that are part of the fundamental laws of the theory, while in experimental incommensurability, the underlying assumptions function as auxiliary hypotheses when carrying out a specific test of the theory in question. When we speak of experimental incommensurability, we are thinking in any case of presuppositions of experimental design that do not form an essential semantic link with the theories in question.

Since in this paper we discuss the experimentalist dogma, we are interested in characterizing cases with which this dogma is incompatible. In the following, we claim that two successive observations are empirically incommensurable in a narrow sense if they have commensurable interventions and do not satisfy the condition of similarity of perceptual content. If they have commensurable interventions, share perceptual content, and differ only in their conceptual interpretation, they are empirically incommensurable in a broader sense since they are compatible with the cases highlighted by Melogno, in which scientists see the same thing, have the same perception, but interpret it conceptually in different ways. Finally, if two observations do not satisfy any of the conditions of commensurability of the intervention, and this affects the observational content, they are empirically incommensurable in an innocuous sense since they do not represent a threat to the experimentalist dogma.

4. The neuronist revolution

In this section, we apply our taxonomy of varieties of empirical incommensurability to the case of the neuronist revolution. By "neuronist revolution" we mean the process of discovery of the neuron, a revolution in the anatomy and physiology of the nervous system that took place between the end of the 19th and the beginning of the 20th century, with multiple protagonists in different European countries. We focus on the micrographic and histological controversies between Camillo Golgi and Santiago Ramón y Cajal.

By 1860, it was clear to continental histologists that nerve tissue contained cell bodies, on the one hand, and nerve fibers, on the other, but the relationship between cells and fibers was unknown. Nerve cells, in general, have a branched structure. Some of these branches arise from the cell body and travel long distances, becoming entangled along the way with branches coming from other cells. Guido Cimino (1999) describes this stage of research on the microscopic structure of the nervous system in the following terms:

> Progress was closely connected to innovations in the instruments and techniques of microscopic observation. Not only were the microscopes increasingly powerful and technically refined, but techniques for 'preparing' the material for observation were becoming more and more advanced (techniques of fixation, hardening, inclusion, sectioning and coloration). Among these techniques, the methods employed for coloration or impregnation acquired a great importance, thanks partly to progress in the chemical industry that produced the coloring agents, and partly to the awareness that various tissues, and therefore various types of cells, reacted differently to different substances and stained differently. (Cimino, 1999, p.434)

The technical problem consisted, then, of developing a technique for staining nerve tissue that would make it possible to visualize, under the microscope, its component elements clearly and distinctly, that is, to represent the nerve cell in its entire extension, up to the termination of its most distant branches, and separately, distinguishing the individual cell against the background of the cell forest (DeFelipe & Jones, 1992; Mazzarello, 2010; Fiorentini, 2011). The initial breakthrough came from the invention, by the Italian histologist Camillo Golgi, of the method of staining nerve tissue based on silver nitrate, the *reazzione nera* or black reaction. Several historians of science call it a "revolutionary method" (Cimino, 1999; Shepherd, 2015; Bentivoglio et al., 2019). Through mechanisms still unknown, the method allows one to selectively visualize, in black color, the cell bodies, dendrites and axons of a few cells per piece, on an amber background.

From a physiological perspective, according to Golgi, the different "provinces" of the nervous system share the structure of a single diffuse, continuous, and complex network formed by the intertwining of the axons of the different cells. As a whole, this nervous network was the true organ of perception, thought, and action. This idea appears fully developed in his *Sulla fina anatomia*:

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> In all the strata of the gray substance of the central nervous organs, there exists a fine and complicated diffuse nervous network, in the formation of which these occur:
>
> (a) The fibrillae emanating from the nervous prolongations of the cells of the first type (motor, or psycho-motor).
>
> (b) The nervous prolongations of the cells of the second type, in totality, decomposing complexly (sensory, or psycho-sensory).
>
> (c) The nervous fibrillae emanating from those nervous fibres which pass on to put themselves in direct relation with the gangliar cells of the first type (fibres of the first category).
>
> (d) Many nervous fibres in totality, that is to say, those which, identically with the nervous prolongation of the cells of the second type, decomposing into very slender filaments, and thus losing their proper individuality, pass on to be gradually confounded in the network in question. (Golgi 1885; translated in Shepherd 2016, pp. 97-98).

Golgi's method had a mixed reception in the international community. It remained relatively dormant until 1888, when the second experimental breakthrough occurred with the Spanish anatomist Santiago Ramón y Cajal's micrographic studies of nervous tissue (Cajal, 1888). Cajal improved Golgi's method in several ways. He invented a double impregnation procedure, which improved the specimens' sharpness and the results' replicability (DeFelipe & Jones, 1992). Unlike Golgi, Cajal applied the technique mainly on embryonic nerve tissue. In embryos, axons are not yet coated with myelin so that they can be better impregnated and visualized to completion.

Cajal never believed in the existence of a diffuse, continuous, and complex network of axons. His micrographic drawings, which are true works of art as well as scientific documents, demonstrate visually that each nerve cell constitutes a "completely autonomous canton" (Cajal, 1888; our translation) from the anatomical, physiological, and developmental point of view, like individual trees that together compose a dense forest. Cajal accepted countless of Golgi's anatomical discoveries, but on crucial issues their opinions diverged markedly. First, while Cajal accepted that axon collaterals are real, it was not clear to him that they would eventually lose their individuality in a diffuse network. He could never observe anastomoses, continuity of tissue, between nerve cell axon endings, in any brain region, in any species, at any stage of development. By parsimony, it is necessary to conclude that axons can perform their nerve transmission function even while terminating freely, without forming a network. Secondly, and for the same reasons, dendrites can perform a nerve function, even if, as Golgi discovered, they terminate freely. The outline and main anatomical components of the nerve cell are thus delineated: a cell body from which both the dendrites and the axon arise, in different configurations, both with nervous function.

Microscopic observation of the manner in which the terminations of axons were placed in relation to the dendrites or cell body of their neighboring cells, e.g., the way in which the tufts of the stellate cells of the cerebellum envelop, like a basket, the body of the Purkinje cells (cf. Section 4), suggested to Cajal (1891) a physiological generalization about the direction of nerve impulse communication between parts of the same cell and between neighboring cells, namely, the law of dynamic polarization. According to the law of dynamic polarization, then, the nerve impulse always goes from the dendrite, which functions as the input mechanism, to the termination of the axon, which functions as the output; from there, the impulse is transmitted to the dendrite or cell body of the next neuron (Cajal, 1891). The law introduces a non-anatomical concept: the direction of nerve impulse conduction in relation to the parts of the cell. There are only two permissible directions for interneuronal conduction: axodendritic (from the axon of one neuron to the dendrite of another) and axosomatic (from the axon of one neuron to the soma, or cell body, of another). There is no place in the theory for dendro-dendritic (as von Gerlach argued), somato-dendritic, or axo-axonic (as Golgi argued) conduction.

4.1. Dendritic spines

An interesting case to test our taxonomy of empirical incommensurability types is the controversy between Golgi and Cajal over dendritic spines' existence (and function). Bentivoglio et al. (2019) discuss the case of dendritic spines in Golgi and argue that, upon reexamination of Golgi's preparations, the spines are visible, not without difficulty, despite Golgi's denial of their existence both in micrographic drawing and in his linguistic descriptions. The authors present unpublished images of neurons, mainly from the hippocampus, neocortex, and cerebellum, comparing them with some of Golgi's drawings. Spines are especially evident in the dendrites of some cortical pyramidal neurons impregnated with Golgi's stain, although Golgi, possibly concerned about artifacts, did not identify them (see Bentivoglio et al., 2019, p. 10).

The authors note that Golgi (1885) did not describe dendritic spines in his 1885 compendium and only acknowledged their existence later in his drawings of Purkinje cells in 1901, although without further comment (DeFelipe, 2015). In his Nobel acceptance speech, Golgi stated that he was not convinced that the small protrusions on dendrites were genuine characteristics of dendrites, as he had observed similar protrusions on glial cells and axons.

In his initial observations, Golgi was extremely concerned about artifacts and found multiple precipitates in his preparations, with no clear way to distinguish

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whether these metallic precipitates were inside or on the cell surface (Jacobson, 1993). This position was initially shared by Koelliker (1896), who, however, eventually accepted the existence of dendritic spines.

Koelliker substantiated his position on the artifactual character of dendritic spines with the following reasons: (1) dendrites appeared smooth in dissected neurons of macerated central nervous system tissue, including Purkinje cells and spinal motor neurons; (2) spines showed great variability in number and size in Golgi preparations; (3) spine-like protrusions were found in glial cells and axons in these same preparations. Koelliker's conclusion was that the variability in their appearance and lack of clear function indicated that they were artifacts (Jacobson, 1993).

Cajal, on the other hand, was the first to describe and name the spines in 1888, based on the impregnation of the cerebellum of birds with Golgi's method. In his first paper of 1888 on the cerebellar cortex, Cajal described some irregularities of the surface of the dendrites of the Purkinje cells, and mentioned them, according to Jacobson, without further comment. This is not quite true, for in a footnote to that first article, Cajal says:

> At first we believed that these eminences were the result of a tumultuous precipitation of silver; but the constancy of their existence and their presence, even in preparations in which the reaction appears with great delicacy in the other elements, inclines us to estimate them as a normal disposition. (Cajal, 1888, p. 309; our translation; see Figure 1).

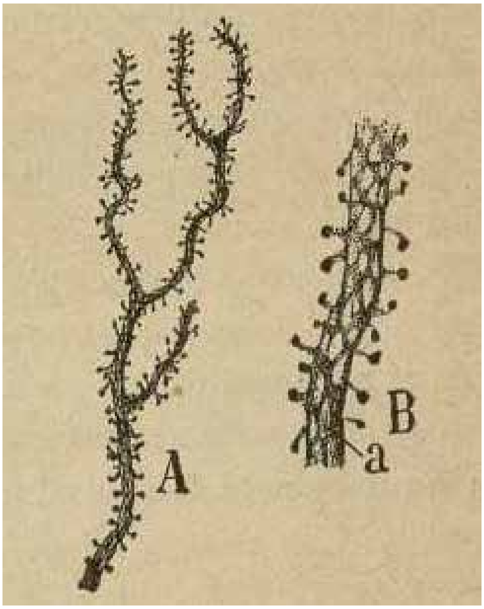

Figure 1. Original drawings by Cajal, showing dendritic spines of a cerebellar Purkinje cell (Cajal, 1899, p. 55).

Historical analysis of this controversy suggests that it is just a case of incommensurability of interpretation, or empirical incommensurability in the broad (not narrow) sense, for it is quite plausible that both Golgi and Cajal perceived the spines through the microscope but then interpreted them incompatibly in the light of their different theoretical commitments, namely Golgi's reticularism, and Cajal's neuronism. It is reasonable to think that, as in the case of the revolution in chemistry, both scientists perceived the same thing, i.e., that their perceptions had the same observational content so that the incommensurability is at the conceptual or interpretative level. Or at least, more weakly, we can affirm that there is no reason to believe this is a case of perceptual incommensurability.

Cajal performed controls to rule out artifacts, verifying the distribution of spines in different neuronal areas and also using methylene blue staining. For Cajal, the authenticity of the spines was supported by the fact that: (1) they were visible with different staining methods (i.e., they were robustly detectable); (2) they were consistently found in the same dendritic regions and not in others; and (3) they had a specific morphology, suggesting that they were not metallic precipitates (Jacobson, 1993).

It could be thought that the difference in the way in which dendrites are conceptualized has to do with the fact that Golgi impregnation is especially effective in brain tissue of young animals, or embryos, where the dendritic spines are more evident, an aspect also highlighted by Cajal (García-López et al., 2010). If so, we could imagine that this is, in fact, a case of innocuous incommensurability (type 1) since the spines are more visible in embryos than in adult individuals. That is, it could be argued that differences in the target system explain the eventual differences at the level of representation. However, it is more reasonable to think that, in this case, the difference in interpretation could be due to the different theories accepted by Golgi and Cajal. Cajal's dynamic polarization law, which allowed only axo-dendritic or axo-somatic interneuronal connections, could include dendritic spines and assign them a nerve conduction function, whereas Golgi's reticularist model could not (Barberis, 2018). In Golgi's theoretical model, nerve cells contributed to forming a diffuse nerve network consisting exclusively of axons or axonal collaterals. His theory attributed nutritive functions to dendrites, in relation to blood vessels and glial cells, and excluded dendrites from the conductive role. Thus, Golgi's identification of dendrites as artifacts is best explained by considering that they did not appear to play any role in his physiological hypothesis.

Proponents of reticular theories initially considered spines as artifacts, but later, when their authenticity was no longer in doubt, explained that the spines were sites of cytoplasmic continuity between dendrites, as a form of dendro-dendritic connection (Bethe, 1903; Held, 1929). This passage indicates that there was a change of interpretation within the reticular paradigm, with respect to spines, from considering them as artifacts at the beginning to sites of dendro-dendritic connection.

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In summary, the case of dendrites is best understood as a case where acceptance of theories led to different interpretations of experience. Regarding empirical incommensurability in the narrow sense, there is no reason to believe that there were differences at the level of perception. That is, considering Corgi's reticular and Cajal's neuronal theories, with respect to the case of dendrites, there are incommensurable observations with respect to interpretation (in this case because of the accepted theories), but would be perceptually and experimentally commensurable.

4.2. The case of the nerve extensions of the stellate cells of the cerebellum

The most interesting case for discussing the experimental dogma assumed by Melogno is the following. In his atlas *Sulla fina anatomia degli organi centrali del sistema nervoso,* Golgi (1885) classified nerve cells into two main types: large type I (motor) cells and smaller type II (sensory) cells. This classification was based on whether the cells' axon was continued by a myelinated fiber from the white matter (type I) or whether it remained in the immediate vicinity of the cell without leaving its province (type II). Golgi thought that type I cells were motor because they connected a given region to distant regions via white matter tracts, and type II cells were sensory because their influence never left a delimited region. In studying the cortical cells of the cerebellum that Cajal later termed "basket cells," Golgi proposed that their axons branched within an anastomotic plexus of collaterals in the granular layer. According to this interpretation, the axons emerged from this plexus to enter the white matter, which led Golgi to classify them as type II cells.

However, in 1888, in his first study of the cerebellar cortex, Cajal observed something different: the axons of the basket cells did not lose their individuality as they branched but ended around the cell bodies of the Purkinje cells. This allowed him to infer that these cells did not connect directly with the white matter but did so indirectly through the axons of the Purkinje cells. This discovery was crucial for Cajal to develop the law of dynamic polarization, which implied a flow of activity from cell to cell. This principle allowed him to describe in detail the intrinsic circuits of almost all nervous system regions, thus revolutionizing the understanding of their functional organization.

During the 1906 Nobel Prize award ceremony, Golgi used his speech to express his objections to the "neuronal doctrine" proposed by Cajal (Sotelo, 2011). In particular, he used his studies on the cerebellum to refute his colleague's conclusions about the organization and circuitry of this structure. Referring to basket cells, Golgi stated:

> Similarly, I cannot accept as a good argument in support of the theory ("Neuron doctrine") the statement… that says that the processes of the cells of the

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> molecular layer of the cerebellum terminate by forming endings on the bodies of the cells of Purkinje, for I have verified that the...bundles of fibrils coming from the nerve process of the small cells of the molecular layer, and which ought to form the alleged ending on the surface of the cells of Purkinje, can be seen to continue by an infinite number of subdivisions into the nerve network. (Golgi, 1967, p. 192).

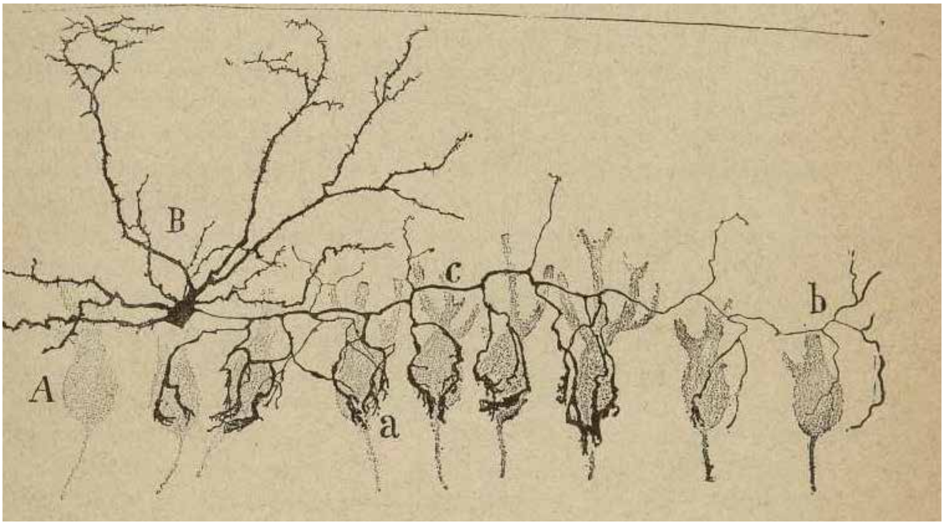

Figure 2. Ramón y Cajal's drawing of the cells of the cerebellum of a rat, showing the tufted or basket-shaped axon terminations around the soma of the giant Purjinke cells (in light pencil). (Cajal, 1899, p. 69)

Beyond this concrete example, in that same conference, he insisted on the rejection of the neuronal doctrine stating:

> I must declare that when the neuron theory made, by almost unanimous approval, its triumphant entrance on the scientific scene, I found myself unable to follow the current of opinion, because I was confronted by one concrete anatomical fact; this was the existence of the formation which I have called the diffuse nerve network. (Golgi, 1967, p. 193).

These exchanges suggest a perceptual incommensurability with similar experimental designs, since both Golgi and Cajal, observing the same nervous system region and using the same experimental technique, nevertheless represent incompatible observational contents. The best explanation for this perceptual divergence seems to lie in their theoretical assumptions. That is, not only is it a case of perceptual incommensurability, but it seems to fit Hanson's proposal, according to which the acceptance of theories can lead to different configurations of perception.

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According to Golgi, the central nervous system was considered a gigantic network of chaotic communication and not a federation of nervous organs with clear and distinct functional locations (Mazzarello, 2007).

However, Mazzarello (2007) argues that the diffuse nerve network, in which the axonal extensions of nerve cells were fused (or intimately intertwined) into a diffuse network along which the nerve impulse propagated, was actually an illusory network created by superposition and intertwining of the various axons, from which erroneous microscopic images were generated in Golgi's mind. Recall that the sections impregnated with Golgi's method are quite thick (some exceed $150^{\mu m}$). If so, then one might think that the perceptual divergence between Golgi and Cajal could be explained as a case of innocuous empirical incommensurability (type 2), for although the target systems are similar, there is a crucial difference in the experimental protocol (see Raviola and Mazzarello, 2010, p. 345).

However, it should be recognized that Golgi himself questions this "methodological" interpretation of his differences with Cajal, since he himself was interested in highlighting Cajal's lack of originality in relation to silver nitrate staining.

> Regarding the way of applying the rapid method which Ramón y Cajal explicitly declares his ("ma manière de appliquer la méthode rapide"), as I find that he suggests a mixture of the solutions of bichromate and osmic acid, with proportions identical to those indicated by me (1:4, see pp. 503 and 504 of my *Studies on fine anatomy*, etc.), I cannot but ask what the speciality of the method in question consists in (...) That other authors (...) attribute to him the method of hardening by direct immersion of the fresh pieces in the osmium-bichromic mixture, is something that can easily be explained: it is a simple omission from my description; but that Ramón y Cajal now attributes to himself the method, which he has at other times acknowledged as mine, is certainly something of less easy explanation. Naturally, I cannot suppose that he would make the specialty of his method consist in the insignificant increase of 1 g. in the dose of bichromate; but if this were so, I should declare the statement contained in the above sentence erroneous, since for the good success of the reaction such an increase is certainly not necessary. (Golgi, 1891, p. 459; our translation).

Another argument for doubting that this is a genuine case of perceptual incommensurability, i.e., not caused by differences in experimental design, is found in the work of Raviola and Mazzarello (2010). They point out that, upon close inspection of the drawings published by Golgi during the decade after the invention of his method, it can be observed that the diffuse nerve network that he postulated is notably absent.

In a drawing of the cerebellar cortex, made in collaboration with Fusari (Fig. 5, corresponding to Table XI of Golgi, 1883, 1885), the recurrent collaterals of Purkinje cell axons ascend toward the deep boundary of the molecular layer, but do not integrate into the plexus formed by the axons of the basket cells (see Raviola and Mazzarello, 2010, p. 76). Within the molecular layer, axonal branches follow a tangential course in the deep region, generating perpendicular collaterals that descend and terminate in the granular layer. In the drawing of the granular layer of the Golgi cerebellar cortex, approximately 140 free endings of axonal branches can be counted in an area of 105 μm². Excluding intersections, apparent fusion between axon branches is observed in only three cases. However, these supposed anastomoses could simply be noise or artifacts in the drawing, as Golgi does not emphasize their importance in the text.

Quite different is the conclusion we can draw from the three drawings of the cerebellar cortex that illustrate Golgi's Nobel lecture (Golgi, 1906). These drawings radically differ from those published in the 1870s: the granular layer is occupied by a sinuous, branching, anastomosing process, which is continued by the baskets surrounding the soma of the Purkinje cells (figs. 3-5).

In his early drawings, we observe that the free terminations are sparse and the individual arborizations vary significantly. Conversely, the axonal branches in Figures 3, 4, and 5 are interconnected or at least extensively intertwined with each other in the granular layer. It is reasonable to conclude that, at least in one of the figures, the granular layer was not drawn with camera lucida and its thickness does not reflect what was observed through the optical microscope.

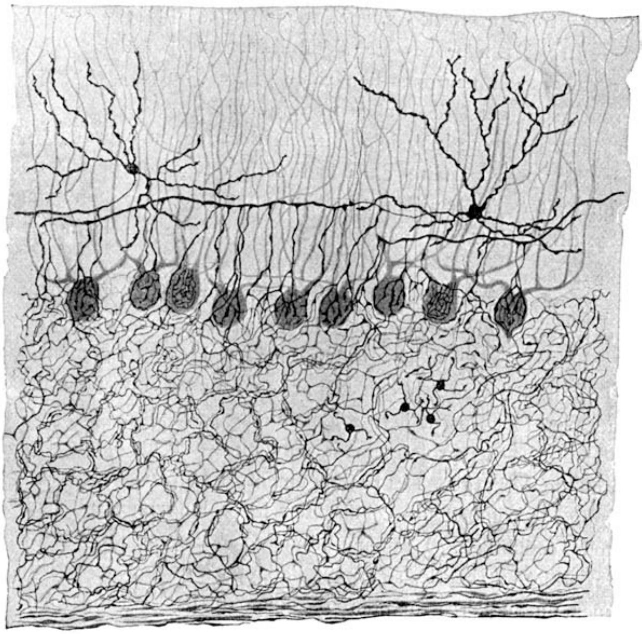

Figure 3. Cerebellar cortex in the drawing made by Golgi in his Nobel Lecture. Taken from Golgi (1967, p. 191).

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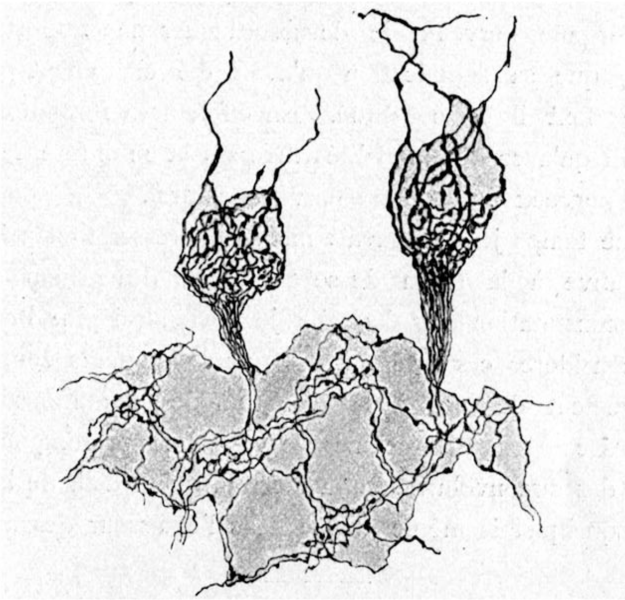

Figure 4. In this drawing, the branches of the axonal arborizations of the basket cells are extensively anastomosed (or intertwined) as they surround the Purkinje cell soma. Some of their fibrils continue into the diffuse nerve network of the granular layer. Taken from Golgi (1906).

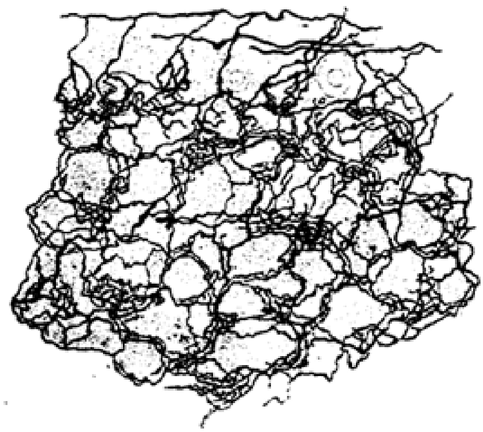

Figure 5. The diffuse nerve network in the granular layer surrounds empty spaces whose diameter is much larger than the soma of a granule cell. From Golgi (1967, p. 200).

If Raviola and Mazzarello (2010) were correct, then this could be a case of incommensurability in a broad (not narrow) sense, that is, a "Melogno case", in which both Golgi and Cajal see the same thing in their micrographic work on the cerebellum, as demonstrated by their early drawings, but interpret it differently, to the point of engaging, in the late Golgi, in "a combination of fact and fiction".

Table 1 offers a way of summarizing the different varieties of empirical incommensurability presented in Section 3, and it shows how our scheme may be useful or illuminating in its application to an early episode of the neuroscientific revolution, as developed in this section. While there are arguments that either Golgi is "fabricating" the observation of the diffuse network in the molecular layer or that it is a genuine observation but caused by a peculiarity of his experimental protocol, there is also a prima facie plausible argument that it is a case of incommensurability in the narrow sense, in which the experimentalist dogma that the observational content of a scientific representation is determined by the similarity of the target system and the similarity of the experimental protocol is misguiding.

Type of Incommensurability	Exemplar	Commensurability of the intervention		Perceptual commensurability	Commensurability of conceptual interpretation
		Similarity of the target system	Similarity of experimental protocol		
Incommensurability in a broad sense	Dendritic spines	Yes	Yes	Yes	No
Incommensurability in the innocuous sense (1)		Yes	No	No	No
Incommensurability in the innocuous sense (2)		No	Yes	No	No
Incommensurability in a narrow sense	Stellate cells of the cerebellum	Yes	Yes	No	No

Table 1. Taxonomic scheme applied to the neuron revolution

5. Conclusion

In this article we scrutinize what can be called an "experimentalist dogma" presupposed in Pablo Melogno's analysis of empirical incommensurability in the chemical revolution. According to this dogma, perceptual content is largely determined by the experimental practices involved in obtaining those results. Given two laboratory observations, similar experimental designs of those observations entail similar perceptual content.

We have argued that Melogno's distinction between perceptual incommensurability and incommensurability, of conceptual interpretation (of the same perceptual content) is important as a starting point for a taxonomy of types of empirical incommensurability but ultimately insufficient. Some of these types refer to

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cases of empirical incommensurability in a narrow sense; others refer to cases of empirical incommensurability in a broad sense since they do not involve perceptual change; finally, other cases of incommensurability are best explained by differences in experimental design, or the target system, and so represent forms of incommensurability that are innocuous to the experimentalist dogma.

Second, we have shown how this taxonomic scheme is useful for analyzing the various phenomena of empirical incommensurability implicated in the neuronist revolution. Thus, the controversy between Golgi and Cajal (among other histologists at the turn of the century) about dendritic spines illustrates a case of incommensurability in a broad sense. Regarding the case of the nerve endings of the stellate cells of the cerebellum, the question is far from being so simple. At least, the experimentalist dogma does not offer the best explanation of the peculiar form of empirical incommensurability that seems to be at play, thus suggesting its inadequacy. Golgi and Cajal saw different things while observing similar target systems (the cerebellum) with similar experimental techniques (silver staining). The best explanation for this perceptual divergence lies in the conceptual or theoretical differences that, in this case, shape the observational content.

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