ISSN 2039-4667; E-ISSN 2239-2629
Vol. 9 (2018), n. 2, pp. 109-126

RICERCHE

# Michael Gazzaniga's Neuro-cognitive Antireductionism and the Challenge of Neo-mechanistic Reduction

Diego Azevedo Leite[α]

Ricevuto: 1 febbraio 2018; accettato: 25 giugno 2018

**Abstract** Michael Gazzaniga, a prominent cognitive neuroscientist, has argued against reductionist accounts of cognition. Instead, Gazzaniga defends a form of non-reductive physicalism: epistemological neuro-cognitive non-reductionism and ontological monist physicalism. His position is motivated by the theses that: (1) cognitive phenomena can be realized by multiple neural systems; (2) many outcomes of these systems are unpredictable; and (3) multi-level explanations are required. Epistemological neuro-cognitive non-reductionism is presented as the most appropriate stance to account for the way in which phenomena should be explained in cognitive neuroscience. In this paper, I argue, however, that a recent form of (ontological and epistemological) neuro-cognitive reductionism, namely neo-mechanistic reductionism accounts for the arguments presented by Gazzaniga. Thus, the theory offers a more consistent and well-articulated view of the relationship between cognitive and neural phenomena that is specifically compatible with the explanatory strategies and aims of contemporary cognitive neuroscience.
KEYWORDS: Neo-mechanistic Philosophy; Michael Gazzaniga; Non-reductionism; Reductionism; Philosophy of Cognitive Neuroscience

**Riassunto** *L'antiriduzionismo neurocognitivo di Michael Gazzaniga e la sfida della riduzione neomeccanicista* – Uno dei più importanti neuroscienziati dei nostri tempi, Michael Gazzaniga, si è schierato contro una concezione riduzionista della cognizione. Al contrario Gazzaniga difende una forma di fisicalismo non-riduzionistico che risulta dalla combinazione, sul piano epistemologico, di un anti-riduzionismo cognitivo e, sul piano ontologico, di un monismo fisicalista. La sua posizione è motivata dalla tesi per cui (1) i fenomeni cognitivi possono essere realizzati da molteplici sistemi neurali; (2) molti esiti di tali sistemi non si possono prevedere; (3) e sono pertanto necessarie spiegazioni a livelli plurimi. La concezione presentata come più adeguata per dare conto sul piano epistemologico di come i fenomeni dovrebbero essere spiegati all'interno delle neuroscienze cognitive è una forma di anti-riduzionismo neuro-cognitivo. In questo articolo si sostiene tuttavia che una recente forma di riduzionismo neuro-cognitivo (epistemologico ed ontologico) può dare conto degli argomenti presentati da Gazzaniga. Si tratta di una teoria che offre una interpretazione maggiormente coerente ed articolata della relazione fra fenomeni cognitivi e neurali e che offre un modello di spiegazione compatibile con gli scopi esplicativi delle neuroscienze cognitive contemporanee.
PAROLE CHIAVE: Filosofia neomeccanicista; Michael Gazzaniga; Nonriduzionismo; Riduzionismo; Filosofia della neuroscienza cognitiva

[α]Dipartimento di Psicologia e Scienze Cognitive, Università degli Studi di Trento, Corso Bettini, 84 - 38068 Rovereto (I)

E-mail: diego.azevedo.leite@gmail.com (✉)

Creative Commons - Attribuzione - 4.0 Internazionale

MICHAEL GAZZANIGA IS ONE OF the most distinguished researchers in the contemporary field of cognitive neuroscience.[1] Some authors even consider him to be the "father" of this research area.[2] Thanks to his numerous theoretical and empirical contributions to the field over a span of more than fifty years, he has had an enormous influence on many significant debates, e.g. the effects of split-brain surgery on cognitive phenomena such as visual consciousness and language;[3] the relationships between the human brain and moral beliefs, and between neuroscience and ethics;[4] the relation between neuroscience, free will and law;[5] the possible evolution of certain brain structures;[6] and how the brain generates social beliefs.[7] His theories are representative of many fundamental ideas in these areas of research.

Gazzaniga's important impact on the field is also due to the fact that he is one of the few contemporary cognitive neuroscientists who tries to explicitly and directly address the debate on the so-called mind-body problem (or neuro-cognitive relation),[8] a problem which tacitly underlies all discussion in cognitive neuroscience, since at the most fundamental theoretical level this discipline interrogates the relationship between neural systems and cognition.[9] Indeed, this line of research is described as a «combined study of mind and brain»[10] whose ultimate aim is «to provide a brain-based account of cognition».[11] A discussion of Gazzaniga's perspective is not only important for understanding his particular position on this issue, but also for more broadly examining the conception of the relationship between brain and cognition implicit in the very structure of the neuro-cognitive research informed by his views.

In order to understand, characterize and explain cognition, a number of authors consider reductive approaches attractive. From an ontological point of view, these approaches usually imply a simpler and more integrated (unitary) conception of the entities and the processes that science and philosophy investigate.[12] From an epistemological point of view, reductive approaches usually also help to advance scientific integration, avoiding gaps between scientific domains and theories.[13]

However, other authors consider reductive approaches problematic especially because of their implications for the way in which cognitive phenomena are characterized and for preserving the autonomy of psychological theories in the face of neuroscientific theories.[14] In fact, it is extremely difficult to pursue the reductionist ambition to integrate or even to link traditional psychological concepts and explanations with neurophysiological concepts and explanations.

Gazzaniga belongs to a group of authors who expressly embrace an epistemological neuro-cognitive non-reductionist position. He suggests a version of a neuro-cognitive non-reductive explanation. This solution is purported to overcome problems with the neuro-cognitive epistemological reductionist view and to offer, at the same time, a plausible ontological and epistemological account of the relationship between cognition and the brain that is appropriate for the ultimate explanatory aims of cognitive neuroscience. In this paper, I will examine Gazzaniga's view and show that even though he attempts to construct an epistemological non-reductive account of cognition, his view is completely compatible with a particular kind of contemporary ontological and epistemological reductionist position.

I will discuss Gazzaniga's position on reducibility, as well as the reasons why he considers epistemological non-reductionism to be the most suitable approach to explanations of (human) neuro-cognitive phenomena. The author understands epistemological neuro-cognitive reductionism as intertheoretical relations of derivation when identity relations between terms are constructed. He claims that epistemological reduction so considered is problematic for three reasons: (1) cognitive phenomena are realized by multiple systems; (2) the outcomes of neuro-cognitive systems are unpredictable; and (3) multilevel explanations are indispensable. On this basis, I will show that Gazzaniga's defense of the epistemological non-reductionist view is problematic and is actually compatible with a particular kind of contemporary ontological and epistemological neuro-cognitive reductionism. Gazzaniga believes that epistemological neuro-cognitive non-reductionism is the only position that can account for all three of these aspects. However, I argue that multiple realizability, unpredictability, and multi-level explanations, as framed by Gazzaniga, can be accommodated by the neo-mechanistic neuro-cognitive reductionist approach, which is also compatible with the explanatory strategies and ultimate aims of contemporary cognitive neuroscience.

## Gazzaniga's defense of non-reductionism

According to Gazzaniga, evidence from neurologically impaired patients, especially split-brain patients, and recent neuroimaging data show that the human brain is organized into local circuits, specialized for specific functions, known as modules.[15] These circuits run simultaneously in parallel, are distributed all over the brain and process different inputs through various kinds of automatic computation. These different systems contain millions of networks that are connected to and affect each other. It is these different systems that implement cognitive processes.[16] Cognitive processes are thus understood as information processes implemented by neural systems; more specifically, as information processes realized by automatic computations.

The same applies to those mental phenomena we can consciously access, e.g. perceptions, beliefs, desires, intentions etc., which are "enabled" individually by a number of local neural systems and subsystems.[17] Although consciousness appears to be unified, it is generated by these vastly separate systems. Somehow these systems are able to integrate and unify the information they process and get it to the level of consciousness. This happens when the brain "considers" the information they provide to be most important at a specific moment. Thus, Gazzaniga's view essentially seems to be that whatever experience a person happens to be conscious of at a particular moment, this is the one that became dominant and got «the prize of conscious recognition».[18] The genesis of beliefs is also explained as the result of a brain process. More specifically, beliefs are said to be produced by a special module in the left hemisphere, called *the interpreter*. The function of this mechanism consists in processing all the inputs of other systems in the brain in order to "interpret" them, i.e. to create a personal, consistent narrative of our past (the prior actions of our nervous system). This system looks for patterns: it is driven to «seek explanations or causes for events» and «hypothesize about the structure of the world».[19] It is the "interpretation" of the information made available by this brain module that actually creates human beliefs: «[...] there is a system in the left hemisphere of the brain [...], which produces beliefs [...]».[20]

The view that thinking is a form of information processing based on computations (on symbolic or sub-symbolic representations) provides an idea of how a purely physical system might bring about specific "cognitive processes" (e.g. playing chess, recognizing faces, and reproducing basic English sentences). Still, it is not quite clear how all these systems, which compute information automatically, integrate all this information to get to the level of a unified conscious cognitive state. Above all, it is not clear how exactly we should understand the relationship between physical (neural) and human cognitive phenomena in this perspective, especially when one considers some particular features of human cognitive phenomena.[21]

One way to deal with the problem of how these phenomena are related would be to endorse some kind of ontological neuro-cognitive reductionism and maintain that all aspects of our human mental life can be reduced to physicochemical neural processes. As Gazzaniga acknowledges, many neuroscientists endorse an ontological reductionist position of this kind. In their opinion, future advances in understanding how the brain works will «reveal all one needs to know about how the brain enables the mind».[22] However, even though Gazzaniga agrees with these basic tenets, i.e. that we are nothing but biological machines living in a physical world,[23] he does not consider it necessary to subscribe to an epistemological neuro-cognitive reductionist account. Ultimately, he attempts to defend a kind of ontological monist physicalism, but at the same time an epistemological non-reductionist position, i.e. roughly, he believes that explanations of human cognitive phenomena have some autonomy regarding explanations for neural activity.

Gazzaniga's view on epistemological neuro-cognitive reductionism is not entirely clear nor is it articulated in detail.[24] However, he often describes this kind of reductionism using terms such as "derivation" or "prediction".[25] Given his most frequent and clear characterizations of epistemological reduction and his counter-arguments against this reductionist position, the most plausible interpretation is that Gazzaniga implicitly relies on the traditional and influential theory of scientific reduction developed by Ernest Nagel.[26] In this view, reductions are achieved by a deduction (or derivation) of a law or theory ($T_2$) from a more fundamental law or theory ($T_1$). The deduction provides a deductive-nomological explanation, whereby $T_1$ explains the phenomena explained by $T_2$. In Nagel's view, there are two kinds of theoretical scientific reduction: between theories in the same domain of explanation and between theories in different domains. The first is called "homogeneous" and the second "heterogeneous" reduction. When theories in play cover the same domains (are homogeneous), the reduction can be achieved relatively easily because both theories are dealing with the same terms. However, when theories in play cover what appears to be different domains (are heterogeneous – as in the case of neuroscience and psychology/cognitive science) and use different terms, then the reduction is more difficult to achieve. To realize a proper heterogeneous reduction following this theory, it is necessary to establish "bridge principles" that make the reductive links between the terms possible. Nagel does not specify the exact nature of these principles, which could be characterized in terms of conditionals, bi-conditionals or identities. It is indeed in terms of identities (e.g. certain mental states and certain neural states are identical, that is, they refer to the same thing)[27] that Gazzaniga understands the reduction relation. As he maintains: «I do not think that brain-state theorists, those neural reductionists who hold that every mental state is identical to some as-yet-undiscovered neural state, will ever be able to demonstrate it».[28]

Gazzaniga identifies, however, three main difficulties involved in such epistemological reductions of cognitive to neural theories. The first difficulty is due to the argument from multiple realizability.[29] This argument was initially formulated by Hilary Putnam[30] and later accepted and developed by, among others, Fodor.[31] It is a well-known argument that is most commonly put forward against the traditional psycho-neural type identity theory, but which also applies to Nagel's traditional intertheoretical reductionist approach construed by means of using type identity relations as bridge laws. The argument holds that the same types of cognitive phenomena can be realized by different types of physical neural systems. In this way, the human cognitive state of "being in pain", for instance, is not necessarily identical to, let us say, a specific type of connection between specific types of neurons in the human brain, because it could be the case that this type of mental state could be realized in the brains of organisms that do not have this specific type of neural connection and yet the mental state of being in pain would remain the same (e.g. the brain of an octopus could realize the same pain the human brain does).[32] Therefore, types of cognitive phenomena cannot be identical to types of neural phenomena and cannot be ontologically reduced to them in this way.

Accordingly, in Gazzaniga's view, systems in the brain are «flexible and largely independent».[33] They can be changed or replaced, with the sole requirement that they be compatible with the general architecture of the whole greater system of which they form a part. For example, if a region in this brain is damaged, it could be replaced by an artificial component, as long as the new subsystem retains the same functional role as the original component (having the same causal role, producing the same effect) and is compatible with the entire structure of the brain. And this substitution could also be made if the artificial part were in some respects different from the original subsystem, i.e. the original neurons and their respective connections. In this way, a mental function related to a specific behavior can be implemented or realized in many different forms and thus – on the basis of the argument of the multiple realizability – they cannot be considered as reducible through identities to some specific neural processes. This ontological point is not incompatible with ontological monist physicalism (it just leads to token-token neuro-cognitive physical ontological relations), but it has important epistemological implications for the relations between neural and cognitive theories. Given the multiple realizability of human cognitive phenomena and the impossibility of constructing bridges between neural and cognitive concepts, it is also not possible to achieve an intertheoretical reduction along these lines. Thus, the multiple realizability of human cognitive phenomena leads to epistemological human neuro-cognitive non-reductionism.

The second difficulty for the epistemological neuro-cognitive reductionist, in Gazzaniga's view, is the fact that the brain is a dynamical complex system whose effects can never be completely determined or predicted. This kind of system is defined as something composed by many different subsystems that interact. This interaction is so complex that it produces genuinely new properties and thereby states which are «greater than the sum of their parts»[34]and cannot be reduced to the operations of the component parts. According to Gazzaniga, it is a «basic principle in experimental science» that «no measurement is infinitely precise», and there will «always [be] imprecision», therefore any measure will always include a «degree of uncertainty in the value».[35] For Gazzaniga, such measurements are indeed impossible "in principle": «Uncertainty is present because no matter what measuring device is used, it has a finite precision and, therefore, imprecision, which can never be eliminated completely, even as a theoretical idea».[36] And since the initial conditions of a system cannot be measured with complete accuracy, i.e. the initial measurement will always have a degree of uncertainty, the results derived from that measurement will also be uncertain.

If we now apply this reasoning to the relation between neural and cognitive phenomena, we need to conclude, following Gazzaniga's reasoning, that it is impossible to predict cognitive states and processes just by looking at physicochemical neural interactions and laws. Systems with great complexity in their organization sometimes interact in a completely different form than simpler systems (e.g. with nonlinear causal interactions, such as positive and negative feedback loops). These complex interactions produce new properties that behave in accordance with laws that are radically different from those related to the components of the complex system and which cannot be deduced or derived from the laws associated with those components. This is the reason why complex systems are unpredictable, and therefore, according to Gazzaniga, irreducible.[37]

With this account of the nature of human cognitive phenomena, the author does not intend to give up on the monist ontological physicalism he endorses. Even if these new properties somehow emerge in whole human neuro-cognitive systems given the complex interactions between their parts, they are not something different from, or beyond, physical nature. No mysterious new cognitive causal powers are available for these new cognitive capacities, states or properties. However, this ontological account and its epistemological implications compromise the epistemological human neuro-cognitive reduction, as characterized by Gazzaniga. For a precise derivation between laws in the two different domains (neural and cognitive) would not be possible. Such a derivation would not be possible because laws relating to the behavior of the whole system would not follow from the laws relating to the behavior of the parts taken in isolation. Given that there is no derivation of neural and cognitive laws, there is no epistemological human neuro-cognitive reduction either. For Gazzaniga, a similar problem is found in the domain of physics, since Newton's laws of classic mechanics cannot be derived from laws related to quantum mechanics.[38]

Finally, Gazzaniga suggests that explanations that span multiple levels are needed in order to explain how neuro-cognitive processes work.[39] Natural phenomena are complex and they cannot be completely explained at a single level, e.g. at some fundamental physical level. Instead, they seem to be organized in many levels that go – to consider physical and biological descriptions only – from elementary particles to atoms and molecules, from molecules to cells, and from unicellular organisms to complex multicellular organisms with complex organs, like the brain. The brain itself can be described at different levels of organization, e.g. at the level of molecules, neurons, neural connections, neural networks, neural systems, etc. At these various levels, there are, for Gazzaniga, different types of modules or systems, as well as different types at the same level. Interactions occur both intra-level i.e. among systems at the same level (for example, among neurons in the brain) and inter-level, i.e. among systems and their components (subsystems) at different levels (for example, among atoms or molecules and the whole structure of a specific neuron).

According to Gazzaniga, reality itself is organized in multiple levels and this leads to the irreducibility of scientific explanations in the various sciences: we will always have multiple sciences which are largely autonomous from each other. In contrast with the intertheoretical account of scientific reduction, he argues that theories at a higher-level of explanation cannot simply be deduced from theories at a lower-level of explanation (e.g. one cannot deduce theories based on biological laws from theories based on chemical laws). There are different levels of explanation, each with its particularities and relevance, and one level cannot be simply logically derived from another as was hypothesized by advocates of intertheoretical epistemological reductionism. This applies not only to biology or chemistry, but also to cognitive neuroscience and cognitive science. According to Gazzaniga, multi-level explanations as well as the unpredictability and multiple realizability of human cognitive phenomena are incompatible with an intertheoretical human neuro-cognitive reductionist framework.

## Gazzaniga's theory as a reductionist theory

In the previous section we considered why Gazzaniga takes epistemological neuro-cognitive non-reductionism to be a preferable account to epistemological neuro-cognitive reductionism. The former position, in his view, is consistent with: (1) the multiple realizability of human cognitive phenomena; (2) the unpredictability of cognitive phenomena produced by dynamical complex neural systems; (3) a multi-level account of scientific explanation.

The issue concerning his conclusion is, therefore, whether epistemological neuro-cognitive reduction is necessarily jeopardized by multiple realizability and the unpredictability of cognitive phenomena, and also whether it is necessarily incompatible with any kind of multi-level account of cognitive phenomena. To address these points, we need to better clarify the controversial notion of reduction. That Gazzaniga choose to base his view on a critique of the intertheoretical Nagelian theory and psycho-neural type identity theory is reasonable to the extent that these theories are still highly influential in present debates. However, many accounts of reduction have been proposed in philosophy of science and philosophy of mind especially since the late 1920s, and there are still today many intense debates about which account best describes scientific practice and the possible reduction of cognitive phenomena.[40]

Recently, a new comprehensive theory for understanding scientific practice especially in the life sciences, including cognitive neuroscience, has been proposed. The application of this theory to cognitive neuroscience provides the necessary material to counter Gazzaniga's arguments.

This new comprehensive theory is part of what can be called *neo-mechanist philosophy*,[41] a new philosophical body of fundamental theories that have been highly influential in contemporary philosophy of science and are advocated by many scholars.[42] A broadly neo-mechanist trend in philosophy of science gained more prominence approximately in the last quarter of the twentieth century. It can be divided into two major traditions.[43] The first tradition is represented most prominently by the works of Wesley Salmon[44] and Phil Dowe,[45] and makes use of the concept of mechanism primarily to discuss causation. The second tradition is represented most prominently by the works of William Bechtel and Robert Richardson, as well as Stuart Glennan, Peter Machamer, Lindley Darden and Carl Craver.[46] These authors, instead, use the notion of mechanism to describe how scientific explanations work, especially when they need to account for complex systems (e.g. in the biological sciences). In this paper, I focus solely on the second tradition, which is better suited to a discussion of how scientific explanations in cognitive science and neuroscience might best relate to each other.

This tradition, to the extent that it is concerned with the biological sciences, can be regarded as providing two major theories about biological phenomena and scientific explanations. The first theory is ontological and it clarifies what a *complex system biological mechanism* (CSB-mechanism) is: it can thus be called the *mechanistic theory of biological systems* (MTBS). The second theory is concerned with epistemology and it clarifies how explanations of CSB-mechanisms should be constructed: it can be called a *mechanistic theory of scientific explanations in the biological sciences* (MTSEBS).

Given that neo-mechanists consider cognitive neuroscience to be a biological science, there are also two versions of this theory applied to cognitive neuroscience. The first clarifies what a *complex system neuro-cognitive mechanism* (CSNC-mechanism) is: thus, it is a *mechanistic theory of neuro-cognitive systems* (MTNCS). The second clarifies how CSNC-mechanisms should be explained: thus, it is a *mechanistic theory of scientific explanations in cognitive neuroscience* (MTSECN).[47] The clearest and most detailed accounts related to cognitive neuroscience are given by William Bechtel and Carl Craver.[48]

Bechtel and Craver make indeed a great effort to show that the classical theory of scientific intertheoretical reduction proposed by Nagel is wrong because it relies on the *deductive-nomological theory of scientific explanation* (DNTSE),[49] i.e. on the idea that something can be explained only if it can be deduced from some universal laws of nature.[50] Contrarily, MTSEBS and thus MTSECN do not focus on logical deduction and universal laws, which are typically not useful for the concrete work of biologists and cognitive neuroscientists. In contrast, the starting point of these theories is the general claim that scientists working in the life sciences formulate explanations in terms of "mechanisms".

Accordingly, a mechanism, roughly put, is «a structure performing a function in virtue of its component parts, component operations, and their organization».[51] The core idea is that mechanisms are hierarchical systems that are made of components (working parts) and their operations; the working parts perform operations and interact causally with other parts of the mechanism. The general behavior of the whole system is a result of the specific organization of the components and their interactions. A mechanistic explanation should describe how the organized functioning of the mechanism is responsible for the phenomenon to be explained. According to MTNCS, neuro-cognitive complex systems, as investigated by cognitive neuroscience, must be understood as complex neural systems that process information in a particular way. Bechtel points out that cognitive neuroscientists «have appealed to systems-level understanding of the brain as providing the appropriate point of connection to the information processing accounts advanced in psychology».[52] Thus, the theory endorses ontological monist physicalism, as Gazzaniga does. Ultimately, all phenomena in reality have a physical nature, including (human) cognitive phenomena. As Craver and Tabery point out, many neo-mechanists accept the «central ideas that motivate a broadly physicalist world-picture».[53] MTSECN, on the other hand, provides the norms for the scientific explanations of such neuro-cognitive complex systems.

Bechtel confirms that «from the point of view of mental activity» this approach is reductionist, and he calls it "*mechanistic reduction*".[54] The author's mechanistic approach «emphasizes the need to identify all (or at least the major) operating parts of the mechanism responsible for the phenomenon of interest and to understand the way they are organized and how their operations are orchestrated to realize the phenomenon».[55] Accordingly, in a mechanistic neuro-cognitive epistemological reduction, properly constructed, one must first of all describe the phenomenon to be explained and then localize the mechanism responsible for producing the phenomenon. Once this is done, the process of decomposition can start: this is aimed at understanding how the components work, how their operations are performed and how they are organized in order to produce the phenomenon. Since complex biological mechanisms are composed of parts and their organization, the decomposition of a whole mechanism and its explanation can span multiple levels. A mechanistic epistemological neuro-cognitive reduction is achieved when a model of a set of mechanisms and their interactions at a lower-level can fully account for the causal processes of the whole mechanism at a higher-level, even when this whole mechanism is described with a completely different vocabulary – as long as the terms can be properly related.

One of the best examples of a concrete application of MTNCS and MTSECN to specific cognitive phenomena concerns memory, which has been traditionally an object of study in the field of psychology. Functional analyses of the memory system reveal the existence of many memory subsystems such as, e.g., short-term memory, long-term memory, phonological memory, visuo-spatial memory, semantic memory, episodic memory, etc. as well as different processes related to them, such as encoding, storage, consolidation, retention, and retrieval.[56] The identification of sub-functions of a system is the kind of work that cognitive psychologists do most of the time. In mechanistic explanations this is called functional decomposition. Due to the great complexity of the memory system it is more useful to seek explanations for each sub-function first, and then try to understand how they are related considering the mechanism of memory as a whole.

One of the best understood phenomena in the memory system is memory consolidation. Roughly put, this is the phenomenon of transforming short-term memories (which are labile and easy to disrupt) into long-term memories, which are robust and enduring and permit the organism to remember important events for a longer period of time and modify its behavior accordingly.[57] To explain this phenomenon, all the relevant regions in the brain responsible for the functions that compose the neuro-cognitive mechanism of memory consolidation, including all relevant mechanistic levels of decomposition, must be identified through the process of localization, i.e. all the particular component parts and component operations of the whole mechanism must be determined. Finally, the causal processes and causal interactions within the mechanism's functions need to also be understood, i.e. the general organization of the mechanism.

The explanation starts at the highest level of the whole mechanism. At this level, it is necessary to correctly identify the entire neural network that is responsible for memory consolidation (recent studies show that this includes the hippocampus and other particular areas in the brain).[58] Secondly, it must be established whether this large neural system is indeed all that is relevant for the explanation of the phenomenon. For this, techniques such as fMRI can be useful, since they can specify what regions in the brain are activated during the performance of a specific psychological task. However, a mechanistic explanation at this level also needs to clarify how the neural network encodes and decodes new memory episodes through information processing and computational operations and how these processes produce and affect, for instance, the different degrees of consolidation that characterize the memories under investigation.

Once this has been clarified, a second level of explanation must be provided in which the large neural system is decomposed into particular sub-neural systems localized in more specific regions. Here the goal is to understand the information processing and computational operations (e.g. spiking patterns in populations of neurons) of these smaller neural networks and how they contribute to the performance of the whole mechanism composed by such neural-nets.

Moreover, a further stage of decomposition must be reached: the processes underlying memory at an inter-cellular level. The explanation at this particular level aims at describing the components of a particular neural network and at understanding how small numbers of neurons operate (for example, how they depolarize and fire in the process of propagating action potentials, or how they are responsible for synaptic processes, neurotransmitters being released, and so on). Here it is possible to measure the spiking rates of neurons, or spiking frequency and to record neural activity in general. There is already sufficient evidence to clarify, for example, the process of long-term potentiation (LTP). The process is understood as: «the persisting enhancement in the response of a postsynaptic cell to an input from a presynaptic cell when the postsynaptic cell has readily spiked after inputs from the presynaptic cell».[59] Many authors consider this process to be central for the consolidation of memories at a purely physiological level.

Finally, the explanation can go to another lower mechanistic level: the intra-cellular and molecular level. At this level, the description is in terms of the activity of the relevant proteins, molecules and ions, such as, for instance: N-methyl-D-aspartate (NMDA), protein kinase A (PKA), cyclic adenosine monophosphate (cAMP), $\alpha$-amino-3-hydroxy-5-methyl-4-isoxazole proprionic acid (AMPA), $Ca^2$+, Na+ and K+ ions.[60] These proteins and molecules are considered to be important for the processes of LTP, i.e. components in the mechanism of LTP, which is a sub-sub-subsystem in the whole mechanism of memory consolidation and plays a role that, together with the operations happening at higher levels, allows for this phenomenon to take place. As one can see, this kind of explanation «exhibits a progression from behavioral-level characterization of memory consolidation to identification of important components in the process at progressively lower levels».[61] In the end, all levels are equally important in achieving a complete multilevel mechanistic explanation of the particular phenomenon.

According to Bickle, some scientific experiments already present evidence for establishing the connection between a molecular and cellular mechanism and a particular behavior that indicates a cognitive function, as in certain cases of memory consolidation.[62] In one scientific experiment, a mouse in which the cellular transcription factor CREB was “knocked-out” had intact short-term memory on many rodent memory tasks, but showed a great decrease in memory capacity in comparison with the control for the long-term memory versions of these tasks. In another experiment CREB was increased in a small population of neurons in a manipulated mouse. This led to an increase of memory consolidation measured by fear conditioning behavior in the modified mice. Since CREB has traditionally been considered to be implicated in the induction of LTP, ultimately it is arguably the presence of CREB that is doing the most central bottom-level causal work. In fact, CREB is part of a particular molecular mechanism that involves cAMP, PKA and CREB, which leads to LTP. Bickle claims that blocking any step of this mechanistic process «virtually eradicates memory consolidation, while enhancing steps can lead to faster and stronger consolidation».[63] Thus, it is these smaller molecular mechanisms that, taken together, explain the behavior of the whole mechanism of memory consolidation in these particular cases. This kind of explanation supports the integration of neural hierarchical compositional mechanisms at different levels. This is the reason why it is not only compatible with the scientific explanations found in the field of cognitive neuroscience but it is also the most appropriate approach for the explanatory and integrative goals of the field: i.e. to integrate neural and cognitive scientific theories and to describe (human) cognitive processes through the activities of neural systems. However, this is also a neuro-cognitive reductionist explanation, since the ‘lower-level’ mechanisms and their interactions at this lower-level can always account for the causal interactions of “higher-level” mechanisms. Lower-level neuro-cognitive mechanistic models can completely account for the causal explanation described (in different terms) by neuro-cognitive mechanistic models at a higher-level. Thus, there is a mechanistic epistemological neuro-cognitive reduction.

This neuro-cognitive mechanistic ontological and epistemological reductive framework is able to respond to all the three explanatory requirements that Gazzaniga points out. Firstly, mechanistic epistemological neuro-cognitive reduction provides an answer for the multiple realizability of cognitive phenomena, as framed by Gazzaniga.[64] More particularly, the mechanistic theory applied to cognitive neuroscience avoids the general problem of multiple realizability of cognitive phenomena because it neutralizes the argument, as provided by the author. In Bechtel’s view, evidence from neuroscience (comparative studies with brain-damaged animals, PET and fMRI) shows that there are many relevant similarities in brain areas across species; he argues that if mental states were described in terms as fine-grained as those used to describe neural states (e.g. if we hypothesize that a specific neural mechanism produces a specific state of pain, rather than pain in general), the multiple realizability of cognitive phenomena becomes less plausible.[65] A single neuro-cognitive mechanism responsible for producing a specific cognitive state (e.g. a human pain state, or a dog pain state), with all its particularities, can be localized; hence, local reductions through (heuristic) identity relations (involving more equivalently grained states) are plausible. In other words, as Bechtel points out, if one uses the same standards of typing for cognitive and neural phenomena, in terms of fine and coarse grain, then «types might range across species and enable scientists to claim that the same type of mechanism in different species produces the same type of [cognitive] phenomena».[66] In this sense, it may be possible to establish reductive identity relations: «Type identity claims are core to the practice of mechanistic explanation in biology [and cognitive neuroscience] and are not jeopardized by the philosophical claims of multiple realization».[67] Since cognitive functions and processes can thus be identified with functions and processes of neural mechanisms, there can be epistemological neuro-cognitive reduction between cognitive theories and models of cognitive systems and neuroscientific theories and models of neural mechanisms. This is an argument in contrast with Gazzaniga's view that neuro-cognitive type identities cannot be established at all. Since in some particular cases, for some particular neuro-cognitive processes, identities are arguably plausible, as in some particular cases of memory consolidation,[68] Gazzaniga's point is misleading. Thus, Bechtel's approach remains more plausible than Gazzaniga's, even if the general issue of multiple realizability is still quite controversial.

The second argument raised by Gazzaniga against neuro-cognitive epistemological reductionism is concerned with the idea that this kind of reduction necessarily implies predictability.[69] In his line of reasoning, if one has all the relevant knowledge of the elements in the deduction of a certain behavior, s/he must be able to anticipate (predict) all the aspects of this behavior; in the same way that Newton's classical laws of mechanics and his universal law of gravitation or Einstein's theory of general relativity can, with a high level of precision, predict the motion of the planets. However, since the theory of mechanistic neuro-cognitive epistemological reduction does not require logical deduction from fundamental to less fundamental laws and their related properties, nor the kind of high level predictability that results from this, it is compatible with a high degree of indetermination. In other words, with respect to mechanistic theory it is irrelevant if at a certain time an event or a set of events occur that cannot be deduced or predicted with great accuracy by these related theories on the basis of the initial state of the system due to the inaccuracy of measures taken at the start or given the complexity of the relations between its parts. What really matters for a mechanistic epistemological neuro-cognitive reduction is whether it is possible to describe these properties in causal, functional, computational, neural or any other mechanistic physical language – and then to identify these mechanisms and their components as far as possible (i.e. at least the most relevant ones that contribute causally to a given effect), ultimately producing a scientific theory to account for them at a lower-level. This does not mean that the mechanistic theory gives up on predictability once and for all. It simply accounts for the fact that the more dynamical and complex a system is, the less its outcomes will be predictable. As the examples of particular kinds of memory consolidation given by Bickle show,[70] descriptions of the behavior produced by the lower-level molecular mechanisms are responsible for the explanation of the causal effects of the whole higher-level mechanism, even though there is no deduction or laws involved.

Concerning the last argument developed by Gazzaniga, it is not even clear that Nagel's theory cannot account for multiple levels of scientific explanation. Nagel intended to develop a theory to integrate scientific activity and, thus, relate all the domains of science having physics as its basis. However, Nagel had a very particular notion of reduction in mind. He was concerned with theories in a given scientific domain and across scientific domains. Theories in his view were constructed as a set of laws and statements about reality. Nagel does not assert in his major work that classic physics should literally reductively explain biological phenomena or psychological phenomena. Even though he argued for scientific reduction across all of the sciences, his view appears to still be compatible with an account of multiple levels of natural phenomena and scientific domains, as long as these levels are properly related. But leaving aside this issue with respect to Nagel, the mechanistic theory applied to cognitive neuroscience is built on the idea that we need to rely on different hierarchical "levels of explanation".[71] According to Machamer, Darden and Craver, the main interest of neo-mechanists is a multilevel explanation since the life sciences have *per se* a multilevel character. «It is the integration of different levels into productive relations that renders the phenomenon intelligible and thereby explains it».[72] However, when lower-levels can account for the causal processes of higher-levels in a given neuro-cognitive complex mechanism, mechanistic scientific explanations in cognitive neuroscience become epistemologically reductive, even though higher-level explanations are still accepted as adequate descriptions of the phenomena in a different language.

Therefore, Gazzaniga's view is entirely compatible with a particular form of neuro-cognitive ontological and epistemological reductionism, namely neo-mechanistic neuro-cognitive reductionism. Gazzaniga's view concerning neuro-cognitive phenomena and related explanations is thus misleading. Because of this, MTNCS and MTSECN provide a more consistent and coherent view for the contemporary field of cognitive neuroscience, given that these theories are compatible with the explanatory strategies and ultimate explanatory aims of this scientific domain.

## Concluding remarks

Gazzaniga deserves credit for many advances in our understanding of how particular brain mechanisms operate; more importantly, he is one of the most significant pioneers in the field of cognitive neuroscience, and a leading scientist interested in research about the neuro-cognitive relation. In his attempt to construct a more systematic theory about the relationship between human brain and cognition based on his achievements and more generally on some of the achievements of cognitive neuroscience, he comes to the broad conclusion that any epistemological reductionist account concerning explanations of human cognition must be rejected. In his view, epistemological neuro-cognitive reductionism is incompatible with the multiple realizability and unpredictability of human cognitive phenomena and also with the idea that explanations in neuro-cognitive sciences are intrinsically multi-level.

However, to argue for epistemological neuro-cognitive non-reductionism on these general grounds turns out to be misleading. As I show in this paper, recent neo-mechanistic theories are able to account for these arguments, as framed by Gazzaniga, and still offer a robust form of ontological and epistemological neuro-cognitive reduction. Thus, this form of reduction is perfectly in line with Gazzaniga's view on human cognition. More importantly, this theory has the additional advantage of providing the most accurate description so far of the kind of scientific explanations constructed in contemporary cognitive neuroscience, thereby offering foundational support for its explanatory aims. Therefore, Gazzaniga's claim that understanding the relation between neurological and cognitive processes in human cognition means relying on a non-reductive explanation is untenable. On the contrary, the approach that appears to be most compatible with the explanatory aims and strategies of contemporary cognitive neuroscience is the neo-mechanist ontological and epistemological neuro-cognitive reductionist account.

It is important to emphasize that this analysis does not intend to provide a defense of MTCNS and MTSECN. Indeed, these theories have many limitations that could not be addressed in this paper.[73] The point of the present work is solely to argue that, given the general ontological monist physicalist framework that Gazzaniga accepts and the arguments against epistemological (human) neuro-cognitive reductionism that he provides, his positions on the epistemological irreducibility of human cognitive phenomena do not hold up. Accordingly, this paper attempts to offer a genuine contribution to debates concerning the plausibility of fundamental theories of cognition and neuro-cognitive integration in cognitive neuroscience.

## Notes

[1] For instance, Gazzaniga established the *Cognitive Neuroscience Institute*, founded the *Journal of Cognitive Neuroscience* and cofounded the *Cognitive Neuroscience Society*. He is also first author of the

popular textbook, *Cognitive Neuroscience: the Biology of the Mind*.

[2] See P.A. REUTER-LORENZ, K. BAYNES, G.R. MANGUN, E.A. PHELPS (eds.), *The Cognitive Neuroscience of Mind: A Tribute to Michael S. Gazzaniga*, MIT Press, Cambridge: (MA) 2010.

[3] See M.S. GAZZANIGA, *The Bisected Brain*, Appleton Century Crofts, New York 1970; M.S. GAZZANIGA, *Tales from Both Sides of the Brain: A Life in Neuroscience*, Ecco, New York 2015; M.S. GAZZANIGA, J.E. LEDOUX, *The Integrated Mind*, Plenum Press, New York 1978.

[4] See M.S. GAZZANIGA, *The Ethical Brain*, Dana Press, New York 2005.

[5] See M.S. GAZZANIGA, *Who's in Charge? Free Will and the Science of the Brain*, Ecco, New York 2012-II edition.

[6] See M.S. GAZZANIGA, *Mind Matters: How Mind and Brain Interact to Create our Conscious Lives*, Houghton Mifflin, Boston 1988; M.S. GAZZANIGA, *Nature's Mind: The Biological Roots of Thinking, Emotions, Sexuality, Language and Intelligence*, Basic Books, New York 1992; M.S. GAZZANIGA, *The Mind's Past*, University of California Press, Berkeley (CA) 2000; M.S. GAZZANIGA, *Human: The Science Behind What Makes Us Unique*, Ecco, New York 2008.

[7] See M.S. GAZZANIGA, *Social Brain: Discovering the Networks of the Mind*, Basic Books, New York 1985.

[8] I use here "cognition" and "cognitive" as synonymous of "mind" and "mental", as it is common in the specialized literature. Moreover, I am interested here particularly in the human adult normally functioning cognition.

[9] See B.J. BAARS, N.M. GAGE, *Fundamentals of Cognitive Neuroscience*, Elsevier, Oxford (UK) 2013; M.S. GAZZANIGA, R.B. IVRY, G.R. MANGUN, *Cognitive Neuroscience: The Biology of the Mind*, Norton, New York 2014 - IV edition; K.N. OCHSNER, S.M. KOSSLYN (eds.), *The Oxford Handbook of Cognitive Neuroscience.* Volume I, Oxford University Press, Oxford (UK) 2014; J. WARD, *The Student's Guide to Cognitive Neuroscience*, Psychology Press, New York 2015 – III edition.

[10] B.J. BAARS, N.M. GAGE, *Fundamentals of Cognitive Neuroscience*, cit., p. 3.

[11] J. WARD, *The Student's Guide to Cognitive Neuroscience*, cit., p. xi, see also pp. 1-2.

[12] See J. KIM, *Mind in a Physical World: An Essay on the Mind-Body Problem and Mental Causation*, MIT Press, Cambridge (MA) 1998; J. KIM, *Physicalism, or Something Near Enough*, Princeton University Press, Princeton 2005; D. PAPINEAU, *The Rise of Physicalism*, in: C. GILLETT, B. LOEWER (eds.), *Physicalism and Its Discontents*, Cambridge University Press, Cambridge 2001, pp. 3-36; D. PAPINEAU, *Naturalism*, in: E.N. ZALTA (ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2016 Edition), URL: https://plato.stanford.edu/ archives/win2016/entries/naturalism/; D. STOLJAR, *Physicalism*, Routledge, London/NewYork 2010; D. STOLJAR, *Physicalism*, in: E.N. ZALTA (ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2015 Edition), URL: http://plato.stanford.edu/archives/ spr2015/entries/physicalism/.

[13] See e.g. J. BICKLE, *Philosophy and Neuroscience: A Ruthlessly Reductive Account*, Kluwer Academic Press, Norwell (MA) 2003; J. BICKLE, *Reducing Mind to Molecular Pathways: Explicating the Reductionism Implicit in Current Cellular and Molecular Neuroscience*, in: «Synthese», vol. CLI, n. 3, 2006, pp. 411-434; J. BICKLE, *A Brief History of Neuroscience's Actual Influences on Mind-Brain Reductionism*, in: S. GOZZANO, C.S. HILL (eds.), *New Perspectives on Type Identity: The Mental and the Physical*, Cambridge University Press, Cambridge (UK) 2012, pp. 88-110; P.S. CHURCHLAND, *Can Neurobiology Teach Us Anything about Consciousness?*, in: «Proceedings and Addresses of the American Philosophical Association», vol. LXVII, n. 4, 1994, pp. 23-40; F. CRICK, *The Astonishing Hypothesis*, Scribner's, New York 1994; J.G. KEMMENY, P. OPPENHEIM, *On Reduction*, in: «Philosophical Studies», vol. VII, n. 1-2, 1956, pp. 6-19; E. NAGEL, *The Structure of Science. Problems in the Logic of Explanation*, Harcourt, Brace & World, New York 1961; P. OPPENHEIM, H. PUTNAM, *The Unity of Science as a Working Hypothesis*, in: G. MAXWELL, H. FEIGL, M. SCRIVEN (eds.), *Concepts, Theories, and the Mind-Body Problem*, Minnesota University Press, Minneapolis 1958, pp. 3-36.

[14] See K. AIZAWA, C. GILLETT, *The Autonomy of Psychology in the Age of Neuroscience*, in: P.M. ILLARI, F. RUSSO, J. WILLIAMSON (eds.), *Causality in the Sciences*, Oxford University Press, New York 2011, pp. 202-223; J.A. FODOR, *Special Sciences*, in: «Synthese», vol. XXVIII, n. 2, 1974, pp. 97-115; J.A. FODOR, *Special Sciences: Still Autonomous After All These Years*, in: «Philosophical Perspectives», vol. XI, 1997, pp. 149-163; H. PUTNAM, *The Nature of Mental States* (1967), in: H. PUTNAM, *Mind Language and Reality: Philosophical Papers*, Volume II, Cambridge University Press, Cambridge (UK) 1975, pp. 429-440; D. WEISKOPF, *The Func-*

*tional Unity of Special Science Kinds*, in: «British Journal for Philosophy of Science», vol. LXII, n. 2, 2011, pp. 233-258.

[15] See M.S. GAZZANIGA, *Who's in Charge?*, cit., p. 33. See also M.S. GAZZANIGA, *Social Brain*, cit., p. x; M.S. GAZZANIGA, *Tales from Both Sides of the Brain*, cit., p. 338 and 340.

[16] See M.S. GAZZANIGA, *Who's in Charge?*, cit., pp. 40-41; M.S. GAZZANIGA, *Social Brain*, cit., p. 18; M.S. GAZZANIGA, *Tales from Both Sides of the Brain*, cit., p. 337.

[17] For the distinction between phenomenal and access consciousness see N. BLOCK, *On a Confusion about the Function of Consciousness*, in: «Behavioral and Brain Sciences», vol. XVIII, n. 2, 1995, pp. 227-247.

[18] M.S. GAZZANIGA, *Who's in Charge?*, cit., p. 66.

[19] *Ivi*, pp. 84-85. See also M.S. GAZZANIGA, *Tales from Both Sides of the Brain*, cit., p. 150ff.

[20] M.S. GAZZANIGA, *The Ethical Brain*, cit., p. xviii.

[21] See F. ADAMS, K. AIZAWA, *The Bounds of Cognition*, Wiley-Blackwell, Malden (MA) 2010; D. CHALMERS, *Facing up to the Problem of Consciousness*, in: «Journal of Consciousness Studies», vol. II, n. 3, 1995, pp. 200-219; J.A. FODOR, *LOT 2: The Language of Thought Revisited*, Oxford University Press, Oxford 2008; F. JACKSON, *Epiphenomenal Qualia*, in: «Philosophical Quarterly», vol. XXXII, n. 127, 1982, pp. 127-136; F. JACKSON, *What Mary Didn't Know*, in: «Journal of Philosophy», vol. LXXXIII, n. 5, 1986, pp. 291-295; J. LEVINE, *Materialism and Qualia: The Explanatory Gap*, in: «Pacific Philosophical Quarterly», vol. LXIV, n. 4, 1983, pp. 354-361; T. NAGEL, *What is it Like to be a Bat?*, in: «Philosophical Review», vol. LXXXIII, n. 4, 1974, pp. 435-456.

[22] M.S. GAZZANIGA, *Who's in Charge?*, cit., p. 4.

[23] See *ivi*, p. 7

[24] Sometimes he frames reduction in general as defending the thesis that «a complex system is nothing but the sum of its parts» (e.g. M.S. GAZZANIGA, *Tales from Both Sides of the Brain*, cit., p. 335). Probably Gazzaniga means by this that epistemological reduction is the explanation of a property, function or behavior of a given whole system by means of the mere "sum" of the properties, functions or behaviors of its component parts. For instance, the total weight of a given physical object (e.g. a motorbike) is equal to the sum of the weights of its parts. Weight, however, is a property traditionally investigated in physics, it is a variable that can be completely quantified according to standard methods of measurement, and "sum" here is simply mathematical addition. When we are talking about complex biological mechanisms, such as the brain, this reasoning about reduction is problematic, since, for instance, the mathematical addition of different physiochemical processes in neurons would never explain the processes that a neural network is capable of performing. The interrelations between the most interesting and relevant processes and functions here are not those of simple mathematical addition, as in the case of summing weights. They are relations of causation between physical activities. Indeed, no author has ever advanced any detailed account of epistemological reduction in the literature along these lines.

[25] See, e.g., M.S. GAZZANIGA, *Who's in Charge?*, cit., pp. 123, 124,130, and 134. See also M.S. GAZZANIGA, *Tales from Both Sides of the Brain*, cit., p. 350.

[26] See E. NAGEL, *The Structure of Science*, cit., chap. 11. Evidently, this is not to say, at all, that Gazzaniga is a Nagelian. The reductionist account described by Gazzaniga is the account of a theory he wants to criticize. He constructs it using elements taken from Nagel's theory, even if he is not aware of this.

[27] The idea of establishing identity relations between mental and neural states is actually a traditional well-known ontological reductive program in philosophy of mind developed at the end of the 1950s, namely the classic psycho-neural type-type identity theory, whose advocates are mainly Place (see U.T. PLACE, *Is Consciousness a Brain Process?*, in: «British Journal of Psychology», vol. XLVII, n. 1, 1956, pp. 44-50), Feigl (see H. FEIGL, *The "Mental" and the "Physical"*, in: H. FEIGL, M. SCRIVEN, G. MAXWELL (eds.), *Concepts, Theories and the Mind-Body Problem*, Minnesota University Press, Minneapolis 1958, pp. 370-497) and Smart (see J. SMART, *Sensations and Brain Processes*, in: «The Philosophical Review», vol. LVIII, n. 2, 1959, pp. 141-156). The central claim which these authors agree on is that some types (or kinds, or classes) of mental states or processes are (contingently) identical with some types (or kinds, or classes) of neurophysiological states or processes.

[28] M.S. GAZZANIGA, *Who's in Charge?*, cit., p. 130. This interpretation of reduction is not the one that Nagel himself endorsed (see, e.g., R.C. RICHARDSON, *Functionalism and Reductionism*, in: «Philosophy of Science», vol. XLVI, n. 4, 1979, pp. 533-558; K. SCHAFFNER, *Ernest Nagel and Reduction*, in: «Journal of Philosophy», vol. CIX, n. 8, 2012, pp. 534-565); still, this is the one that best describes

how Gazzaniga conceives of epistemological reduction and that best explains why he considers this kind of reductionism to be an inacceptable stance for cognitive phenomena.

[29] See, *ivi*, p. 131.

[30] See H. PUTNAM, *The Nature of Mental States* (1967), in: H. PUTNAM, *Mind Language and Reality: Philosophical Papers, Volume 2*, Cambridge University Press, Cambridge 1975, pp. 429-440.

[31] See J.A. FODOR, *Special Sciences*, in: «Synthese», vol. XXVIII, n. 2, 1974, pp. 97-115.

[32] H. PUTNAM, *The Nature of Mental States*, cit., p. 436.

[33] M.S. GAZZANIGA, *Tales from Both Sides of the Brain*, cit., p. 349.

[34] M.S. GAZZANIGA, *Who's in Charge?*, cit., p. 71.

[35] *Ivi*, p. 109.

[36] *Ibidem*.

[37] Gazzaniga also conflates issues about causal scientific determinism, indeterminism and free will in this discussion (see M.S. GAZZANIGA, *Who's in Charge?*, cit., chap. 4). However, the clearest and most important part of his argument concerning epistemological neuro-cognitive non-reductionism relies on the unpredictability of cognitive phenomena given the complex interactions of neural systems. Thus, his discussions about causal determinism do not concern us here.

[38] See M.S. GAZZANIGA, *Who's in Charge?*, cit., p. 125: «The balls in my living room are made up of atoms that behave as described by quantum mechanics, and when those microscopic atoms come together to form macroscopic balls, a new behavior emerges and that behavior is what Newton observed and described. [...] you can't predict [derive] Newton's laws from observing the behavior of atoms, nor the behavior of atoms from Newton's laws».

[39] M.S. GAZZANIGA, *Tales from Both Sides of the Brain*, cit., p. 344. See also M.S. GAZZANIGA, *Who's in Charge?*, cit., p. 125.

[40] See, e.g., A. BECKERMANN, H. FLOHR, J. KIM (eds.), *Emergence or Reduction? Essays on the Prospects of Nonreductive Physicalism*, De Gruyter, Berlin 1992; R.C. RICHARDSON, S. STEPHAN, *Reductionism (Antireductionism, Reductive Explanation)*, in: M. BINDER, N. HIROKAWA, U. WINDHORST (eds.), *Encyclopedia of Neuroscience*, Heidelberg, Springer 2009, pp. 3395-3398; S. SARKAR, *Models of Reduction and Categories of Reductionism*, in: «Synthese», vol. XCI, n. 3, 1992, pp. 167-194; M. SILBERSTEIN, *Reduction, Emergence, and Explanation*, in: M. SILBERSTEIN, P. MACHAMER (eds.), *The Blackwell Guide to the Philosophy of Science*, Blackwell, Oxford 2002, pp. 80-107; R. VAN GULICK, *Reduction, Emergence and Other Recent Options on the Mind/Body Problem: A Philosophic Overview*, in: «Journal of Consciousness Studies», vol. VIII, n. 9-10, 2001, pp. 1-34; R. VAN RIEL, R. VAN GULICK, *Scientific Reduction*, in: E.N. ZALTA (ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2015 Edition), URL: http://plato.stanford.edu/archives/fall2015/entries/scientific-reduction. Some of the most frequently debated views are, for example, reduction as translation (see R. CARNAP, *The Unity of Science*, Kegan Paul, Trench, Trubner, and Co, London 1934; O. NEURATH, *Philosophical Papers, 1913-1946*, Riedel, Dordrecht 1983); reduction as intertheoretical deduction/derivation (see E. NAGEL, *The Structure of Science*, cit.); reduction as intertheoretical explanation (see J.G. KEMMENY, P. OPPENHEIM, *On Reduction*, in: «Philosophical Studies», vol. VII, n. 1-2, 1956, pp. 6-19); Schaffner's theory of reduction (see K. SCHAFFNER, *Approaches to Reduction*, in: «Philosophy of Science», vol. XXXIV, n. 2, 1967, pp. 137-147); new wave reduction (J. Bickle, *Psychoneural Reduction: The New Wave*, MIT Press, Cambridge (MA) 1998; C. HOOKER, *Towards a General Theory of Reduction. Part I: Historical and Scientific Setting*, in: «Dialogue», vol. XX, n. 1, 1981, pp. 38-59; C. HOOKER, *Towards a General Theory of Reduction. Part II: Identity in Reduction*, in: «Dialogue», vol. XX, n. 2, 1981, pp. 201-236; C. HOOKER, *Towards a General Theory of Reduction. Part III: Cross-Categorial Reduction*, in: «Dialogue», vol. XX, n. 3, 1981, pp. 496-529); ruthless molecular and cellular neuroscientific reduction (J. BICKLE, *Philosophy and Neuroscience*, cit.; J. BICKLE, *Reducing Mind to Molecular Pathways*, cit.; J. BICKLE, *Real Reduction in Real Neuroscience: Metascience, Not Philosophy of Science (and Certainly Not Metaphysics!)*, in: J. HOHWY, J. KALLESTRUP (eds.), *Being Reduced: New Essays on Reduction, Explanation, and Causation*, Oxford University Press, Oxford 2008, pp. 34-51; J. BICKLE, *A Brief History of Neuroscience's Actual Influences on Mind-Brain Reductionism*, cit.; A. SILVA, J. BICKLE, *The Science of Research and the Search for Molecular Mechanisms of Cognitive Functions*, in: J. Bickle (ed.), *The Oxford Handbook of Philosophy and Neuroscience*, Oxford University Press, Oxford/New York 2009, pp. 91-126); reductive logical behaviorism (see G. RYLE, *The Concept of Mind*, Hutchinson, London 1949); reduction as psychoneural type identity relation (see U.T. PLACE, *Is*

*Consciousness a Brain Process?*, cit.; H. FEIGL, *The "Mental" and the "Physical"*, cit.; J. SMART, *Sensations and Brain Processes*, cit.); and functional reduction (D. CHALMERS, *The Conscious Mind*, Oxford University Press, Oxford 1996; D. CHALMERS, F. JACKSON, *Conceptual Analysis and Reductive Explanation*, in: «The Philosophical Review», vol. CX, n. 3, 2001, pp. 315-360; J. KIM, *Mind in a Physical World*, cit.; J. KIM, *Physicalism, or Something Near Enough*, cit.; A. LEVY, *Materialism and Qualia*, cit.; J. LEVINE, *Three Kinds of New Mechanism*, in: «Biology & Philosophy», vol. XXVIII, n. 1, 1993, pp. 99-114). For a discussion and an overview of some of these theories, see J. BICKLE, *A Brief History of Neuroscience's Actual Influences on Mind-Brain Reductionism*, cit. One might be inclined to also include here the eliminativist approach of P.M. Churchland (see P.M. CHURCHLAND, *Eliminative Materialism and the Propositional Attitudes*, in: «The Journal of Philosophy», vol. LXXVIII, n. 2, 1981, pp. 67-90; P.M. CHURCHLAND, *Reduction, Qualia, and the Direct Introspection of Brain States*, in: «The Journal of Philosophy», vol. LXXXII, n. 1, 1985, pp. 8-28) and P.S. Churchland (see P.S. CHURCHLAND, *Neurophilosophy*, MIT Press, Cambridge (MA) 1986). However, this is a matter of dispute. For a discussion see R. VAN GULICK, *Reduction, Emergence and Other Recent Options on the Mind/Body Problem*, cit.

[41] The term "mechanism" or "mechanist philosophy" has been applied to various kinds of ideas and theories in the history of scientific and philosophical thought. However, according to the neo-mechanists, past theories did not put forward any systematically articulated account of mechanistic phenomena and explanations; these have only begun to be developed more recently by the new mechanists.

[42] See e.g. W. BECHTEL, R.C. RICHARDSON, *Discovering Complexity: Decomposition and Localization as Strategies in Scientific Research* (1993), MIT Press, Cambridge (MA) 2010; W. BECHTEL, A. ABRAHAMSEN, *Explanation: A Mechanist Alternative*, in: «Studies in History and Philosophy of Biological and Biomedical Sciences», vol. XXXIII, n. 2, 2005, pp. 421-441; W. BECHTEL, *Mental Mechanisms: Philosophical Perspectives on Cognitive Neurosciences*, Routledge, New York 2008; W. BECHTEL, *Molecules, Systems, and Behavior: Another View of Memory Consolidation*, in: J. BICKLE (ed), *The Oxford Handbook of Philosophy and Neuroscience*, Oxford University Press, Oxford/New York 2009, pp. 13-40; W. BECHTEL, *Identity, Reduction, and Conserved Mechanisms: Perspectives from Circadian Rhythm Research*, in: S. GOZZANO, C.S. HILL (eds.), *New Perspectives on Type Identity: The Mental and the Physical*, Cambridge University Press, Cambridge 2012, pp. 43-65; J. BOGEN, P. MACHAMER, *Mechanistic Information and Causal Continuity*, in: P.M. ILLARI, F. RUSSO, J. WILLIAMSON (eds.), *Causality in the Sciences*, Oxford University Press, Oxford/New York 2010, pp. 845-864; W. BOONE, G. PICCININI, *Cognitive Neuroscience Revolution*, in: «Synthese», vol. CXCIII, n. 5, 2016, pp. 1509-1534; C.F. CRAVER, *Explaining the Brain*, Oxford University Press, Oxford 2007; S. GLENNAN, *Mechanisms and the Nature of Causation*, in: «Erkenntnis», vol. XLIV, n. 1, 1996, pp. 49-71; S. GLENNAN, *Rethinking Mechanistic Explanation*, in: «Philosophy of Science», vol. LXIX, n. S3, 2002, pp. S342-S353; S. GLENNAN, *The New Mechanical Philosophy*, Oxford University Press, Oxford 2017; P. MACHAMER, L. DARDEN, C.F. CRAVER, *Thinking about Mechanisms*, in: «Philosophy of Science», vol. LXVII, n. 1, 2000, pp. 1-25; G. PICCININI, C.F. CRAVER, *Integrating Psychology and Neuroscience: Functional Analyses as Mechanism Sketches*, in: «Synthese», vol. CLXXXIII, n. 3, 2011, pp. 283-311; S. ROBINS, C.F. CRAVER, *Biological Clocks: Explaining with Models of Mechanisms*, in: J. BICKLE (ed.), *The Oxford Handbook of Philosophy and Neuroscience*, Oxford University Press, Oxford/New York 2009, pp. 41-67.

[43] See A. LEVY, *Three Kinds of New Mechanism*, cit.; S. IOANNIDIS, S. PSILLOS, *Mechanisms, Counterfactuals, and Laws*, in: S. GLENNAN, P. ILLARI (eds.), *The Routledge Handbook of Mechanisms and Mechanical Philosophy*, Routledge, London 2018, pp. 144-156.

[44] See W. SALMON, *Scientific Explanation and the Causal Structure of the World*, Princeton University Press, Princeton 1984.

[45] See P. DOWE, *Physical Causation*, Cambridge University Press, Cambridge 2000.

[46] For references see *supra*, note 42.

[47] This taxonomy is mine and I use it because it is more clear, precise and systematic than the loose taxonomies presently used in the specialized literature. See W. BECHTEL, *Mental Mechanisms*, cit.; W. BECHTEL, *Molecules, Systems, and Behavior*, cit.; C.F. CRAVER, *Explaining the Brain*, cit.

[48] Craver writes in this work about "neuroscience", however, he considers cognitive neuroscience to be part of it, and often he talks specifically about cognitive neuroscience.

[49] This theory can also be called the *covering law theory of scientific explanation* (CLTSE). See C.G. HEMPEL, P. OPPENHEIM, *Studies in the Logic of Explanation* (1948), in: C.G. HEMPEL, *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*, Free Press, New York 1965, pp. 245-290.

[50] There is a large debate in contemporary philosophy of science concerning DNTSE and the neo-mechanistic theory of scientific explanations, especially in the biological sciences, over the issue of what is the best theory of scientific explanations. It is out of the scope of this paper to deal with that issue. For more discussions on this debate see, e.g., W. BECHTEL, A. ABRAHAMSEN, *Explanation: A Mechanist Alternative*, cit.; W. BECHTEL, *Mental Mechanisms*, cit., chap. 1; C.F. CRAVER, *Explaining the Brain*, cit., chap. 2.

[51] W. BECHTEL, *Mental Mechanisms*, cit., p. 13. See also C.F. CRAVER, *Explaining the Brain*, cit., p. 5.

[52] W. BECHTEL, *Molecules, Systems, and Behavior*, cit., p. 13.

[53] C.F. CRAVER, J. TABERY, *Mechanisms in Science*, in: E.N. ZALTA (ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2017 Edition), URL: https://plato.stanford.edu/archives/spr2017/entries/science-mechanisms/, § 2.5. See also G. PICCININI, C.F. CRAVER, *Integrating Psychology and Neuroscience*, cit., p. 284: «We do endorse reductionism in the sense that every concrete thing is made out of physical components and the organized activities of a system's components explain the activities of the whole. Setting aside dualism and spooky versions of emergentism, we take these theses to be uncontroversial».

[54] W. BECHTEL, *Molecules, Systems, and Behavior*, cit., pp. 13-14 – italics in the original. See also W. BECHTEL, *Mental Mechanisms*, cit., p. 129.

[55] W. BECHTEL, *Molecules, Systems, and Behavior*, cit., p. 14. The views on scientific reduction offered by leading neo-mechanists are diverse. Craver completely rejects epistemological scientific reduction and argues for causal pluralism and the autonomy of higher level scientific explanations. On the other hand, Bechtel defends scientific reduction, but equates it with mere decomposition, which is extremely weak, to the extent that it is not even clear whether it is a kind of scientific reduction at all. In an upcoming paper I argue at length that although the ideas of the new mechanists concerning scientific reduction are highly controversial, the theory's central philosophical commitments lead towards a kind of strong neuroscientific reduction.

[56] See W. BECHTEL, *Mental Mechanisms*, cit., chap. 2; M.W. EYSENCK, M.T. KEANE, *Cognitive Psychology: A Student's Handbook*, Psychology Press, New York 2015, VII edition, chap. 6.

[57] See W. BECHTEL, *Molecules, Systems, and Behavior*, cit., p. 15; W. BECHTEL, *Mental Mechanisms*, cit., chap. 2.

[58] *Ivi*, p. 16 and 22.

[59] *Ivi*, p. 16.

[60] See *ivi*, p. 18.

[61] *Ibidem*. See also W. BECHTEL, *Mental Mechanisms*, cit., chap. 3; C.F. CRAVER, *Explaining the Brain*, cit., chap. 5.

[62] See J. BICKLE, *A Brief History of Neuroscience's Actual Influences on Mind-Brain Reductionism*, cit., p. 101.

[63] J. BICKLE, *Real Reduction in Real Neuroscience*, cit., p. 38.

[64] For the incompatibility of multiple realization with Nagel's theory of reduction construed through identities as bridge principles see the classics by Putnam (H. PUTNAM, *The Nature of Mental States*, cit.) and Fodor (J.A. FODOR, *Special Sciences*, cit.). For the compatibility between Nagel's theory constructed without identities and multiple realization see R.C. RICHARDSON, *Functionalism and Reductionism*, cit.

[65] See W. BECHTEL, *Mental Mechanisms*, cit., p. 139. See also W. BECHTEL, *Identity, Reduction, and Conserved Mechanisms*, cit., p. 44.

[66] W. BECHTEL, *Identity, Reduction, and Conserved Mechanisms*, cit., p. 45. See also W. BECHTEL, J. MUNDALE, *Multiple Realizability Revisited: Linking Cognitive and Neural States*, in: «Philosophy of Science», vol. LXVI, n. 2, 1999, pp. 175-207; W. BECHTEL, R.N. MCCAULEY, *Heuristic Identity Theory (or Back to the Future): The Mind-Body Problem against the Background of Research Strategies in Cognitive Neuroscience*, in: M. HAHN, C.S. STONESS (eds.), *Proceedings of the 21st Annual Meeting of the Cognitive Science Society*, Erlbaum, Mahwah 1999, pp. 67-72.

[67] W. BECHTEL, *Identity, Reduction, and Conserved Mechanisms*, cit., p. 62. The issue of multiple realizability of cognitive phenomena has been discussed in the literature of philosophy of mind and philosophy of psychology since the 1960s and much has been said about it. However, Gazzaniga does not address this debate in detail, and this is also why his view is easily handled by some of the leading neo-mechanists concerned with cognitive neuroscience. However, the debate on the multiple realizability

and multiple realization of cognitive phenomena is complex and still intense. Indeed, many authors have offered relevant arguments not only against this argument (see, e.g., J. Bickle, *Philosophy and Neuroscience*, cit.; J. KIM, *Multiple Realization and the Metaphysics of Reduction*, in: «Philosophy and Phenomenological Research», vol. LII, n. 1, 1992, pp. 1-26; L.A. SHAPIRO, *Multiple Realizations*, in: «Journal of Philosophy», vol. XCVII, n. 12, 2000, pp. 635-654; T.W. Polger, *Evaluating the Evidence for Multiple Realization*, in: «Synthese», vol. CLXVII, n. 3, 2009, pp. 457-472; T.W. POLGER, L.A. SHAPIRO, *The Multiple Realization Book*, Oxford University Press Oxford 2016), but also in favor of it (see, e.g., K. AIZAWA, *The Biochemistry of Memory Consolidation*, cit.; K. AIZAWA, *Neuroscience and Multiple Realization: A Reply to Bechtel and Mundale*, in: «Synthese», vol. CLXVII, n. 3, 2009, pp. 493-510; K. AIZAWA, C. GILLETT, *The Autonomy of Psychology in the Age of Neuroscience*, cit.; D.A. WEISKOPF, *The Functional Unity of Special Science Kinds*, cit.). A detailed evaluation of the leading neo-mechanists position concerning this issue is beyond the scope of the present paper and will be addressed in future work.

[68] See J. BICKLE, *Reducing Mind to Molecular Pathway*, cit.; J. BICKLE, *A Brief History of Neuroscience's Actual Influences on Mind-Brain Reductionism*, cit.

[69] See M.S. GAZZANIGA, *Who's in Charge?*, cit., pp. 122, 123, 126, 127, and 130; M.S. GAZZANIGA, *Tales from Both Sides of the Brain*, cit., pp. 335, 336, 341, 342.

[70] See J. BICKLE, *A Brief History of Neuroscience's Actual Influences on Mind-Brain Reductionism*, cit.

[71] See W. BECHTEL, A. ABRAHAMSEN, *Explanation*, cit., p. 426.

[72] P. MACHAMER, L. DARDEN, C.F. CRAVER, *Thinking about Mechanisms*, cit., p. 23.

[73] See B. VON ECKARDT, J.S. POLAND, *Mechanism and Explanation in Cognitive Neuroscience*, in: «Philosophy of Science», vol. LXXI, n. 5, 2004, pp. 972-984.