Foundations of Science

The simulated body. A preliminary investigation into the relationship between Neuroscientific studies, Phenomenology and Virtual Reality

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Corresponding Author:	DAMIANO CANTONE, Ph.D Università degli Studi di Roma La Sapienza Dipartimento di Psicologia Roma, Lazio ITALY
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Università degli Studi di Roma La Sapienza Dipartimento di Psicologia
Corresponding Author's Secondary Institution:	
First Author:	DAMIANO CANTONE, Ph.D
First Author Secondary Information:	
Order of Authors:	DAMIANO CANTONE, Ph.D
Order of Authors Secondary Information:	
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Suggested Reviewers:	Marcello Barison, professor senior researcher, Libera Universita di Bolzano Marcello.Barison@unibz.it Phenomenology Expertise
	Silvia Capodivacca, phd Lecturer, Università degli Studi di Udine: Universita degli Studi di Udine silvia.capodivacca@uniud.it Phenomenology Expertise
	Andrea Colombo, Phd fellow, UNIRI: Sveuciliste u Rijeci cgiordan@hotmail.it Phenomenology Expertise
	Giovanni Leghissa, professor full professor, Universita degli Studi di Torino giovanni.leghissa@unito.it Phenomenology Expertise
	Silvano Tagliagambe, professor full professor, Università degli Studi di Sassari Dipartimento di Neuroscienze e Scienze

	Materno-Infantili: Universita degli Studi di Sassari sil.tagliagambe@gmail.com Phenomenology Expertise

The simulated body. A preliminary investigation into the relationship between Neuroscientific studies, Phenomenology and Virtual Reality

Damiano Cantone

Department of Psychology and Social Neuroscience - University "La Sapienza" of Rome

damiano.cantone@uniroma1.it

ORCID NUMBER 0000-0003-3604-5537

Abstract

The author of this paper discusses the theme of the "simulated body", that is the sense of "being there" in a body that is not one's own, or that does not exist in the way one perceives it. He addresses this issue by comparing Immersive Virtual Reality technology, the phenomenological approach, and Gerald Edelman's theory of Neural Darwinism. Virtual Reality has been used to throw light on some phenomena that cannot be studied experimentally in real life, and the results of its simulations enrich the phenomenological discourse on the lived body. Virtual "Reality" seems to replicate - at least in part - the simulation mechanisms of our mind, thus developments in the field of philosophy of mind.

Key words: body, Virtual Reality, simulation, presence, phenomenology.

Media Environments

If, during the 1990s, science fiction about artificial Intelligence feared the replacement of human beings with machines as intelligent, if not more so, as the living persons, and equipped with some form of self-consciousness, the one that was about Virtual Reality imagined instead the possibility of a replacement of reality *tout court* through a simulation managed by a machine. Neither scenario has been realized, but themes that were once left to science fiction have now become all-pervasive elements of our experience. Social media, Metaverse, IOT, voice assistants are an integral part of our daily experience. Access to the world is *mediated* by instruments of all kinds that change the relationship between us and the environment. As a result, as we will see below, instruments also fall within the group of entities that help determine the cognitive aspects of the agents that use them, as well as the environment and the brain-body system.

No complex technology is needed to do this: if I look in the mirror, I am able to recognize myself, and to identify myself with the reflected image. This is a cognitive function not only very refined, but one that *would not exist* if there were no reflective surfaces in the world capable of triggering it: in order to recognize yourself in the mirror, therefore, you must first expose yourself to its effects and be modified by it (Parisi, 2020). Likewise, digital technologies, in continuity and in a more radical way than classical artifacts, *modulate the relationship* between the organism and the environment. Their impact is indeed so massive that they have become an environment themselves. This, in turn, as in the case of the mirror, is reflected on us, on the way we perceive ourselves, on our sense of being there, and more in general on our cognitive abilities. In this regard, we are going to examine some exemplary cases related to Virtual Reality, in its more refined and effective immersive forms, which are perfectly able to integrate with our body not only in an organic sense, but also in a cognitive and proprioceptive sense. Before addressing the most salient features of Virtual Reality in the redefinition of the ideas of body, being there, and self-awareness in digital environments, it is useful to clarify the theoretical framework of reference, from both the perspective of phenomenology and most recent developments in neuroscience.

The primacy of the Body

The role of the body has been of increasing importance in phenomenological theory, from its Husserlian conceptualization to the current debates. In Husserl, the Body (*Leib*)[1] is foremost a place of intentional consciousness. Openness to the outside world always starts from our point of view, it is necessarily prospective. Intentional consciousness, though, is not the whole of consciousness: there is also the element of feeling, i.e. the passive sensation experienced through the body; however, this material element only acquires meaning if it submits to the representational power of consciousness through perception, thought, and acts of evaluation or feeling. The psyche is therefore closely connected to the ‘subjective body’, to a "stream with no beginning or end" (Husserl, 1989, p. 98) that

[1] In German, *Leib* refers to the body as it is lived, whereas *Körper* to the body as it can be measured. To preserve the phenomenological nuance that comes with the *Körper-Leib* distinction, we follow the English translator of Husserl’s *Ideas II*, who uses “body” for *Körper* and “Body” for *Leib*. We also make our own the English translations of the *Körper-Leib* distinction which include the twin concepts “physical/material body” (*Körper*) versus “lived/animated body” (*Leib*) and “objective body” (*Körper*) versus “subjective body” (*Leib*).

enliven the *Leib*, i.e. the 'lived/animated body'. In this sense, the problem of the mind-body relationship in the phenomenology of origins is twofold: a) the relationship between consciousness and material body, i.e. the body that is given to consciousness; b) the relationship between consciousness and lived body, i.e. the body that we directly experience from within. The famous example of the touching hands and the description of the tactile sensations that alternate in the hand that is touching and in the touched one, which are contained in the chapter significatively titled *The Constitution of Material Nature* in the second volume of *Ideas* (Husserl, 1989, p. 73), illustrates what phenomenology means by "lived body". Furthermore, it is also the starting point for Maurice Merleau-Ponty to overcome the idea of body still understood as mere material corporeity and arrive at a conception of body as *flesh*. Even for Merleau-Ponty, 'one's own body' (*corps propre*) is the presupposition of any expressive and rational operation, but such a perspective remains a prisoner of the body-world dualism, i.e. the distinction between percipient and perceived. The notion of flesh allows the French philosopher to overcome the rigid distinction between a being who thinks and one who is thought in favor of an intertwining (chiasm) between mind and body, I and the world. The flesh is an element that unites everything is living, a sort of invisible fabric that connects the ego to all the things of the world: the ego is united to the things of the world, becoming one with the world and making it flesh (Merleau-Ponty, 2000). However, there remains a difference between my flesh (*corps propre*) and that of the world: the latter is sensitive and not sentient, while my Body is the "Nullpunkt of all the dimensions in the world" (Merleau-Ponty, 2000, p. 249), the measure of everything that happens. Merleau-Ponty is the starting point for the most recent developments in phenomenology, whose authors refer to the strand that goes by the name of 'Embodied Cognition': quite disparate orientations refer to this approach, they do however share the same criticism of classical cognitivism, which is considered too linked to the Cartesian dualism that separates mind and body.

At the heart of this perspective is the idea that cognition emerges in the interaction between a living organism and its surroundings and, as a result, the mind is literally "embodied". Cognition is the result of the constant interaction between brain, body and environment, where none of these components play a primary role, but all of them are equivalent in every respect. Among the constructs that emerged from such a perspective, we can briefly mention the "Enactivism" proposed by Alva Noë, according to which consciousness and cognition are not fully intelligible without an adequate understanding of the role played by the body and the environment (Noë, 2010). Or the more radical active externalism suggested by Andy Clark and David Chalmers (Clark & Chalmers, 1998), who believe that cognitive processes should also be extended to what happens outside our body ('Theory of the Extended Mind'). The natural environment and the cultural and technological context in which we move have an active part in our mental activities, but they are not the only ones: since many processes (such as calculation, color discrimination, etc.) carried out by elements external to us would be defined as "cognitive" if they were accomplished by our mind, then we must conclude that they *are* cognitive. A further proposal that builds on Merleau-Ponty's work on 'one's own body' is that of 'Postphenomenology', whose prominent exponents Don Ihde and Peter-Paul Verbeek argue that the transformation of the environment accomplished by technology has determined an always mediated relationship between us and the Husserlian 'life-world'. Our perception is mediated by instruments (like glasses, thermometers, etc.) as is our communication, and ultimately our access to the environment. What we therefore need to do is conduct a phenomenological analysis of the relations between us (and the technological artifacts that connect us to the world) and the real-world (Ihde, 2002). For Ihde, we must consider the body, on the basis of classical phenomenology, as being active and perceiving, i.e. as the point from which I experience the world around me; but - he adds - there is a second body, "what could be called, out of context, the cultural or socially constructed body. It is the body of the condemned in Foucault, the body upon which is written or signified the various possible meanings of politics, culture, the socius" (Ihde, 2002, pp. 70-71). In this second body, technology and the power relations that are in play have a constitutive role. In this sense, there is no "neutrality of technology" (like in the classic argument according to which guns don't kill people. People kill people): body two, determined by its technologically mediated embodiment in body one, is a battlefield of forces and powers that struggle incessantly to redefine it.

A similar path has followed the research on the relationship operated in the field of neuroscience, which after a long phase when it focused its interest on the study of the functioning of the brain and the mind, has come to consider the processes that characterize the cognitive activities of the human being as a result of an indissoluble interaction between the mind, the Body and the environment. The one who has allowed a decisive paradigm shift with respect to the conception of the functioning of cognitive activity has certainly been Gerald Edelman, through his conception of "Reentry Mapping".

According to Gerald Edelman, one of the main functions of the nervous system is to be one of the most important "recognition systems" through the *neuronal group selection*. Edelman's "Neural Darwinism" hypothesis (Edelman, 1987) has its roots in the theory of Darwinian evolution applied to the development of brain neuronal structures. At first, during the brain development phase that begins in the embryo, the creation of neural groups derives from genetic information and from a series of random processes that an individual undergoes in his or her development process. At this stage, the *primary repertoire* is formed, i.e. the fundamental map of the groups of neurons in the areas of the brain. Later, the experiences of an individual's life will strengthen some neural connections, and weaken others. In this way, the neural anatomical networks defined as *secondary repertoire* – the adaptive result at the neuronal level of the brain with respect to the environment – are formed. Then the *re-entry process*, i.e. the relationship between the two networks, takes place. The networks are connected in a bidirectional and recurrent way, and constitute the higher psychological processes. One of the re-entry processes is the *perceptual categorization*. A neuronal map receives signals, in addition to other maps also from the outside world, and thus enables the animal's sensorimotor behavior. These relationships between the different maps (sensory, associative, and motor) take place on a higher order structure called the *global map*. This is a dynamic structure that varies according to the behavior of the animal and is able to correlate, through the re-entry process, sensory data with motor data, in order to activate the perceptive categorization of "objects". Thus, a *scene* is created in which the internal psychic processes and the external sensory stimuli are closely connected. With the term 'scene', Edelman means as follows: "a spatiotemporally ordered set of categorizations of familiar and nonfamiliar events, some with and some without necessary physical or causal connections to others in the same scene" (Edelman, 1992, p. 118). These categorizations are acquired also from a chronological perspective, in the sense that new pieces of information are compared with those already possessed by the living being, as a result of learning process. This means that it's necessary the arise of a conceptual memory system, able to categorize responses of the brain to the stimuli. Memory for Edelman is therefore an active process of categorizing re-entry processes on the basis of previous categorizations. It was the development of the ability to create scenes, according to Edelman, that led to the appearance of *primary consciousness*, which is a sort of "Remembered Present" (in his opinion, that primary consciousness has been developed for at least 300 million years and is present in reptiles, birds, and mammals). Edelman uses the metaphor of the "Remembered Present" because the scene that one has before his or her mind at a given time is built on the basis of perceptual categorizations developed in the past and, moreover, depends on the processing of sensory stimuli that have a slight delay compared to the reality present in the eyes of the mind. This scene gives us a sense of "being there", and of the world around us. Only on the basis of this primary consciousness, human beings can develop a *higher-order consciousness* that enables personal identity and self-consciousness; such consciousness depends on the development of language and culture, together with the ability of human beings to generate a model of the present, the past and the future. Please note that, in this perspective, an individual does not pre-exist the environment, indeed it can be said that the sense of the self and the outside arise from processes that are strongly related to each other. Along the same line Nicolelis – the first neuroscientist who managed to connect directly a human brain with a machine – proposes a theory that he himself calls "Relativistic Brain": our brain represents the most complex simulation machine in existence, and its essence consists in continuously interpreting and "staging" the external reality. Indeed, the brain systematically imagines and represents the external world and constructs and maintains the body identity and its uniqueness. Or, as the authors of *The Relativistic Brain* put it, their theory "proposes that the existence of a brain analog computational component, and its recursive interaction with digital elements, represented by the neural networks, is what allows us to anticipate, abstract, and adapt quickly to events in the external world" (Nicolelis & Cicurel, 2015, p. 84). In fact, our mind is an integrated system of interactions between neural networks and physical and environmental stimuli that can never be replicated by any computational machine, no matter how complex it is.

Virtual reality: how it works

The theoretical framework outlined in the previous paragraph finds an interesting practical translation in the experiments of social neuroscience related to "Immersive Virtual Reality" (IVR). Among the new digital technologies, IVR is the one that most manages to propose a synthesis between the aspect of interaction with the environment and the simulation activity of our mind. For "Immersive Virtual Reality" we consider essentially a combination of hardware and software devices that can offer the user a realistic simulation of an integrated multisensory experience, giving them the illusion of being physically (and being able to move freely) in a three-dimensional environment, and of being capable to interact with objects and agents (people, animals, imaginary beings) placed there (Waterworth & Riva, 2014). There are various types of virtual reality (immersive, non-invasive and social virtual environments), but in this essay we will take into consideration only immersive virtual reality. In general, a VR technology is immersive when it is able to sensorially separate the user from the physical world and replace its sensory flow with the simulated scenario generated by the computer. To enable communication and interaction between users, on the one hand, virtual reality systems use avatars, which are customized graphical representations of individuals, directly controlled by the users themselves in real time. Incarnated virtual agents, on the other hand, are graphic representations of individuals controlled by the computer itself by using an artificial intelligence program.

Commonly, to simulate an immersive virtual reality experience, you use helmets. These have the advantage of excluding the surrounding physical world from the user’s field of view. They generally embody two displays integrated in a stand that does not let the external light filter. Each display is placed in front of the corresponding eye of the user. The helmet carries a mechanism to register continually the movement of the user's head. A computer, processing this data, generates a simulation consistent with the head's movements and sends the resulting images to the displays.

Recently, they have also tested systems called CAVE (Cave Automatic Virtual Environment), composed of a room whose walls consist of screens. They project two overlapping and staggered images of a distance equivalent to the retinal disparity on the walls. This allows the user not to wear a helmet, but to move freely in the environment, interacting with virtual objects. Besides, more than one person can be in the room at the same time.

The experiments in virtual reality

It is known that one of the most important neural maps present in our brain is that of our body. Its classical representation is that of the sensory *homunculus* based on Penfield's studies of the sensory zones of the cerebral cortex, which show that our mind possesses a rather distorted image of our body, in which some parts, as hands, mouth, and eyes are much larger than they really are (Penfield & Rasmussen, 1950). Although recently this theory has been greatly implemented (Rizzolatti & Sinigalia, 2006), it is to it that neuroscientist Ramachandran referred in the treatment of phantom limb syndrome suffered by some of his patients. His hypothesis was that the mind of patients who had lost a limb continued to project an image of the body in which this limb was still present: however, since the re-entry information from the body and the environment were different from expectations, their mind generated a sharp pain (or cramps) projecting it to the place where the limb should have been. Ramachandran (Ramachandran & Rogers-Ramachandran, 1996) had the idea of building a hollow box in which a mirror had been inserted ('mirror box'): he then asked his patients to insert their healthy arm in the box while bringing the phantom arm closer, and to look in a mirror from a precise angle, thus generating the illusion of "seeing" both arms. The patient was then asked to move both arms: he had the illusion of being master of his own limb again, and the pain disappeared or eased.

This experiment, in its simplicity, has oriented a lot of research in neuroscience and cognitive sciences aimed at demonstrating the possibility of manipulating the sense of body identification and the perception of self. Two years later, along the same pattern, Botvinick and Cohen developed the famous "Rubber Hand Illusion" experiment (Botvinick & Cohen, 1998), through which they made healthy subjects have the illusion that one of their hands had been replaced with a rubber hand.

With the advent of virtual reality tools, this goal has become increasingly realistic. In 2007, a group of Swedish researchers (Petkova & Ehrsson, 2008) proposed an experiment that used virtual reality to make feel one's body from the first person's perspective as if it were another person's. In the first part of the experiment, Petkova and Ehrsson, in order to put the participant through a synchronised visual and tactile stimulation, equipped him with a virtual reality helmet (Head Mounted Display – HMD). Such display was connected to the Close-Circuit TeleVision (CCTV) cameras that had been mounted on a life-sized mannequin in a position that recorded any event from the dummy's perspective. When the participant looked at his own body, he actually looked at that of the dummy, and when someone touched the abdomen of the mannequin, the human subject felt the corresponding sensation on his abdomen. Even when the experimenter threatened to cut the abdomen of the mannequin with a knife, the anxiety and stress levels of the human subject increased considerably, while he remained normal when the knife touched his real skin. In the second part of the experiment, the cameras were mounted on another person: in a scene similar to that evoked by Husserl, when the two subjects turned towards each other to shake hands, the one wearing the helmet felt the body of the person wearing the cameras as his own. In practice, feeling the other's hand as his own, he placed himself in the (imaginary) body that should have been behind this hand, and observed his real body as if it did not belong to him. There had been a complete exchange of body for which, as the researchers report: "In a full-blown body-swap experience, one would expect to be able to perceive being localized in another human's body during the performance of everyday actions". (Ehrsson, 2008, p. 7).

In recent years, intuitions about the potential of Virtual Reality in shaping our body image, the sense of self and the sense of 'being there' have known a growing diffusion. In particular, the use of Virtual Reality has proven particularly effective in the treatment of eating disorders. It has recently been discovered that eating disorders such as bulimia and anorexia are linked to a distorted integration of information coming from the senses into our minds. In practice, they cannot integrate into a uniform and coherent perception, defined as "body matrix" (Blanke, 2012), which includes conceptual information related to the body (the meaning I attribute to my body), perceptive information (the shape and size of my body), and experiential information (autobiographical events related to the experience of the body). In this sense, the techniques that are based on the 'bodily illusions' recreated by Virtual Reality have proved very effective. In a recent experiment carried out by Riva and his team (Riva, 2019), patients were asked to choose, from 9 different types of body-avatars ranging from very thin to obese, first the one they felt to be more similar to their own, then the one that most approached the body they wanted to have. Later, in a Virtual Reality environment, they could "embody" their new bodies both in an egocentric (first-person) and an allocentric (third-person) perspective. People suffering from eating disorders were much more involved in the illusion, and at the end of the treatment showed a sensitive "realignment" of their body image. In another experiment of the same type (Serino, 2020), they came to the conclusion that when you have an illusory experience of having a larger or smaller body than your own (the authors speak of virtual *Gulliver's Travels*), you also perceive the environment in a manner that is consistent with your body size. Our body therefore seems to act as a unit of measurement of external objects, scaling the objects of the perceptive world in coherence with its dimensions.

Conclusions

What immersive Virtual Reality is able to simulate to the best of the human experience is definitely the sense of being there, the feeling of 'being inside' the recreated environment, while forgetting about the real one. On the one hand, our mind actuates a radical suspension of disbelief and assumes for real stimuli that derive from the simulation. On the other hand, immersion in a simulated reality does not imply a total suspension of the normal logical-causal links but rather the acceptance of rules, codes and signals proper to the created narrative worlds. Such rules, codes and signals are different from those of the real world, although it is always starting from the "true world" that a narrative world is built and proposed. Carroll and Choi speak in this sense of "realistic heuristic principle" of completion (Carroll & Choi, 2005) the fact that - until proven otherwise - the fictional world will function like the real one, following the same rules. Even if Carroll and Choi are referring to cinema, it can be said that Virtual Reality best verifies their hypothesis: it will be all the more effective, the more it is able to simulate all aspects of the real experience of the human subject, who uses his or her cognitive abilities to act in an environment through his or her body. The more successful the simulation, the greater the sense of being there.

Based on Edelman's findings, we know that our mind acts through the creation of a model of our body and environment, i.e. through the creation of a scene that allows us to know what objects are around us, identify their properties, and determine how we can use them. In such an environment, one's mind plans an action with or towards such objects and implements it. Finally, it verifies the effectiveness of this action through the process of re-entry. Such a description provides the most robust hypothesis of why Immersive Virtual Reality is so effective: it does not simply simulate a realistic environment, it simulates the very mechanism of our mental simulation.

To survive in a given environment, a living being needs reliable simulations that correctly "predict" the surrounding environment. The mind, therefore, makes continuous probabilistic predictions of the possibilities that certain events occur, while others do not. The mind uses past experiences to simulate oncoming events. For this, the value of the forecast will be progressively updated according to new events, in order to minimize the possibility of error. To give an example (Regis, 2019), a fish that spends all its existence in water, based on its previous experience will consider highly probable to be in the water even tomorrow: if it were to be on dry land, the event would be catastrophic because absolutely unpredictable, and would force it to simulate an environment that would not meet its expectations at all.
The considerations we have made so far highlight a primacy of acting over being, namely the fact that our perception of 'being there', our self-consciousness, is linked to the ability to act in space, as Merleau-Ponty and Gibson had already intuited.

Virtual Reality is such a promising field of investigation, even from a philosophical point of view, because it has strong analogies with the functioning of our mind. By deceiving our senses in a realistic and plausible way, in fact, it makes it so that our mind is forced to restructure its fundamental cognitive coordinates, without distorting them. Mind and Virtual Reality share a common goal: to simulate reality in order to predict in advance not only how the outside world will look like, but also how we should behave, and act on it. The better the simulation, the more effective our action on the environment, and with less effort. And as we have seen from previous experiments, this process also reverberates throughout the sense of self and being there, as well as across the image of our own body: this means that it also involves relational and emotional aspects. In this regard, numerous experiments have been carried out to increase levels of prosociality or to reduce bias related to prejudices. For example, it has been noted that for light-skinned people to have a virtual reality experience in which they "wear" a black avatar greatly reduces prejudices and negative emotions towards dark-skinned people.

The criticism of virtual reality revolves mainly on the fact that it is not able to produce a sufficiently radical simulation of real experience. Ihde, for example, believes that virtual reality still reads the human body from a Cartesian perspective, in terms of reduction of perception to the visual "in this Cartesian epistemological sense, the old evil genius trick could (and does) reemerge; could I be fooled into thinking that virtual reality is the same as real reality?" (Ihde, 2002, p. 127):

While pretending to integrate our being immersed in an environment in a complete multisensory system, in fact the sense that dominates by far is sight, whereas touch and hearing are in a very subordinate position. Smell and taste are practically absent, if not in rare experiments. However, as

Parisi rightly points out (Parisi, 2020), in the case of Virtual Reality, to focus on the fact that it is a clearly visual predominance experience is not as much important as to emphasize the decisive role that the sense of being there and the sense of self in relation to one's own body play in such technology. Since the purpose of our mind is not so much *to be* in the environment as *to act* in it, it is important to observe how VR affects at the same time the body image of a person (the subjective representation that everyone has of their own body) and the body scheme (the cognitive representation of the position and extent of the body in space and the hierarchical organization of its individual parts, aimed primarily at the organization of action in space). Body image and body scheme designate the way our mind represents our body to itself, but since, as we have seen, body and environment contribute to shaping the mind, by acting on these two elements the Virtual Reality is able to modify the cognitive processes of an individual.

All these elements lead us to conclude that Virtual Reality, especially if its limitations are overcome by technological implementations, is going to be an increasingly important tool of psychological and social investigation. From a philosophical point of view, the comparison with VR experiments is of the greatest interest, especially starting from a phenomenological and post-phenomenological approach, because it forces us to rethink key notions such as those of the body, of being there, and of self by highlighting elements of continuity and discontinuity with respect to their traditional discussion.

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References

- Blanke, O. (2012). Multisensory brain mechanisms of bodily self-consciousness. *Nature Reviews Neuroscience*, 13, 556–571. doi: 10.1038/nrn3292.
- Botvinick, M., Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature*, 391**,** 756. https://doi.org/10.1038/35784
- Carroll, N., Choi, J. (2005). *Philosophy Of Film And Motion Pictures: An Anthology*. Blackwell Publishing.
- Clark, A., Chalmers, D. (1998). The Extended Mind. *Analysis*, 58(1), 7-19.
- Edelman, G. (1987). *Neural Darwinism: The Theory of Neuronal Group Selection*. Basic Books.
- Edelman, G. (1992). *Bright Air, Brilliant Fire: On The Matter Of The Mind*. Basic Books.
- Ehrsson, H.K. (2008). Chapter 8 - Multisensory processes in body ownership, in K. Sathian, V.S. Ramachandran (Eds.), *Multisensory Perception*. Academic Press. doi.org/10.1016/B978-0-12-812492-5.00008-5.

- Husserl, E. (1989). *Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy. Second Book. Studies in the phenomenology of constitution* (R. Rojewicz, & A. Schuwer, Trans.). Kluwer. (Original work published 1913)
- Ihde, D. (2002). *Bodies in Technology*, University of Minnesota Press.
- Merleau-Ponty, M. (2000). *The Visible and the Invisible* (A. Lingis, Trans.). Northwestern University Press. (Original work published 1964)
- Nicolelis, M., Cicurel, R. (2015). *The Relativistic Brain: How it works and why it cannot be simulated by a Turing machine*. CreateSpace Independent Publishing Platform.
- Noë, A. (2010). *Out of Our Heads: Why You Are Not Your Brain, and Other Lessons from the Biology of Consciousness.* Hill & Wang.
- Parisi, F. (2020). La sintonia sensomotoria nella realtà virtuale. *Reti, saperi, linguaggi*, 1, January-June. doi: 10.12832/98420.
- Penfield, W., Rasmussen, T. (1950). *The cerebral cortex of man*. Macmillan.
- Petkova, V.I., Ehrsson, H.K. (2008). If I Were You: Perceptual Illusion of Body Swapping. *PLoS ONE*, 3(12), e3832. https://doi.org/10.1371/journal.pone.0003832.
- Ramachandran, V. S., Rogers-Ramachandran, D. (1996). Synaesthesia in phantom limbs induced with mirrors. *Proceedings: Biological Sciences*, 263, 377–386. doi.org/10.1098/rspb.1996.0058.
- Regis, M. (2019). *Introduzione alla statistica bayesiana*. Università degli studi di Torino e Istituto Nazionale di Fisica Nucleare.
- Riva, G., Giaggioli, A. (2019). *Realtà virtuali Gli aspetti psicologici delle tecnologie simulative e il loro impatto sull'esperienza umana*. Giunti.
- Rizzolatti, G., Sinigaglia, C. (2006). *So quel che fai. Il cervello che agisce e i neuroni specchio*. Raffaello Cortina.
- Serino, S., Scarpina, F., Chirico, A., *et al.* (2020). Gulliver's virtual travels: active embodiment in extreme body sizes for modulating our body representations. *Cognitive Processing*, 21, 509–520. https://doi.org/10.1007/s10339-020-00977-5.
- Waterworth, J. A., Riva, G. (2014). *Feeling present in the physical world and in computer-mediated environments*. Macmillan.