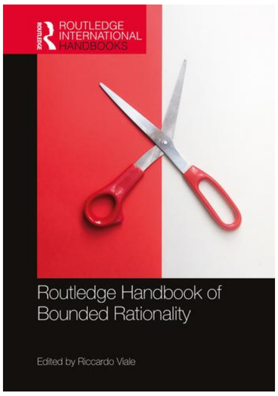

Routledge Handbook of Bounded Rationality

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Embodied bounded rationality

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23

EMBODIED BOUNDED RATIONALITY

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The root of bounded rationality in cognitive psychology and the bounds of embodied cognition

There is little doubt that one of Simon's key contributions throughout his scientific career—if not the main one—was rooting the notion of bounded rationality in cognitive psychology (Simon, 1976). He called his notion of bounded rationality in the cognitive psychology realm "cognitivism" (Haugeland, 1978), an approach, also known as the "information-processing" approach, which he contributed to affirming together with his colleague Allen Newell, starting in the mid-1950s. According to cognitivism, cognition works through the internal (i.e. mental) manipulation of representations of the external environment accomplished through referential "symbols" (e.g., Newell & Simon, 1972). Connecting Simon's theory of cognition to his theory of rationality is the notion that cognition works in a way that is *necessary and sufficient* for intelligent behavior (what is known as the "physical symbol system hypothesis," see Newell & Simon, 1976). The idea that results from integrating Simon's view of cognition with his view of bounded rationality is that rationality is a "process and product of thought" (Simon, 1978), in which the internal bounds of reason (Simon, 1955) adapt to the external bounds of the environment (Simon, 1956) in a disembodied fashion.

In this picture, in fact, there is no place for flesh and blood. Patokorpi (2008) has emphasized that there is an inner tension in Simon's thought, as, on the one hand, he was a strong advocate for a realistic approach to the bounds of rationality, while, on the other, he represented them through the "unbounded" power of digital computation and the metaphor of computers. This inner tension, which did not simply concern Simon's thought but an entire generation of cognitive scientists, would have huge consequences in the history of cognitive psychology. In the early 1990s, Newell and Simon's physical symbol system hypothesis was questioned when the "embodied robots" designed by Rodney Brooks proved able to simulate simple forms of intelligent behavior by externalizing most of cognition onto the physical properties of environments, thus dispensing with abstract symbolic processing (Brooks, 1991). This is just one instance from the recent history of cognitive science pointing to the fact that while bounded rationality remains a pivotal notion in behavioral economics and economic psychology, new theoretical views and massive experimental evidence in cognitive science have superseded cognitivism and its abstract representation of cognition (Wallace et al., 2007). Contemporary cognitive psychology emphasizes that cognition is "embodied," as it constitutively depends on body states, on the morphological traits of the human body, and on the sensory-motor system (see, e.g., Wilson, 2002). As such, it can be said to introduce another "bound" to human cognition, able to integrate the internal bounds represented by cognitive limitations and the external bounds of task environments: the human body. In this chapter, we argue that, in so far as the human body represents a new bound for human cognition, it can also have an important role in the re-conceptualization of bounded rationality. Since the new approach of embodied cognition is so recent, it is still rather plural and variegated, and as such far from a stable synthesis (for reviews on the issue of conceptual pluralism in embodied cognition, see the classic Wilson, 2002; for more recent reviews, see Gallese & Lakoff, 2005; Clark, 2008; Kiverstein & Clark, 2009). Without the claim of being exhaustive, here is a list of classic books on the idea that the body is a constitutive part of cognition: Varela, Thompson, & Rosch (1991); Clancey (1997); Clark (1997); Lakoff & Johnson (1999); Rowlands (1999); Shapiro (2004); Gallagher (2005); and Pfeifer & Bongard (2006). As a matter of terminology, although different labels have been used to identify and distinguish different views of embodiment, we will refer to them all by means of the common synthetic label "embodied cognition" (Calvo & Gomila, 2008; Shapiro, 2014).

The morphology of the human body and the sensory-motor system in cognition

Different arguments have been provided to support the idea that cognition is embodied. We will consider here two main categories of arguments: the evolutionary arguments on the one hand, and the developmental arguments on the other (Meier et al. 2012). An evolutionary argument for embodied cognition consists in emphasizing that the brain is structured by evolutionary layers, so that the new layers exploit and build upon the resources of older ones, which were mostly devoted to 'lower' cognitive activities like sensory-motor control (this has been called the "principle of neural exploitation," see Gallese 2008, or "principle of neural reuse," see Anderson, 2010). Another evolutionary argument concerns the emergence of cognitive artifacts from the morphological traits of the human body as is the case, for example, with numeric systems. It is well known that numeric systems depend on the underlying morphological traits used for counting (e.g., the 10-based numeral system uses the 10 fingers of the hands, while other numeric systems stem from the use of other bodily resources; see Gibbs, 2006). Numeric processing, as such, is not an abstract process (Cohen Kados & Walsh, 2009). In this regard, even the disembodied cognitive artifact *par excellence*, the entire apparatus of mathematics, is rooted in the human body (Lakoff & Nuñez, 2000). On the other hand, the developmental arguments for embodiment focus on childhood learning, emphasizing the role of the child's exploration of the surrounding space (and the related physical sensations) in the development of cognitive faculties and structures in adulthood (e.g., Williams, Huang, & Bargh, 2009). Further, developmental processes of imitation, based on "embodied simulation" (Gallese 2003, 2007), lie at the root of intersubjectivity (e.g., Gallese & Goldman, 1998; Iacoboni, 2009; Gallese 2014). Far from being just an alternative hypothesis on the foundations of cognition, the idea that cognition is embodied is evidenced by a number of experiments connecting body states to judgment, decision-making, problem-solving, attitude formation, etc. Experimental evidence shows that body variables decisively direct and affect decision-making (see the classic study by Damasio, 1994; for a review of related neuroeconomics evidence, see Reimann & Bechara, 2010). Further, problem-solving is non-trivially dependent on body correlates like, for instance, eye movement (e.g., Werner & Raab, 2014). Other various experimental evidence shows that people judge steepness depending on the weight of their backpacks (Bhalla & Proffitt, 1999), that environmental temperature affects social attitudes (e.g., Zhong & Leonardelli, 2008), that imagined food consumption makes people satiated (Morewedge, Huh, & Vosgerau, 2010), or that physical weight induces the perception of importance (Jostmann, Lakens & Schubert, 2009).

A more complex view of Simon's scissors

Most of the experimental findings introduced above simply do not make sense in the cognitivist paradigm. This is mainly because an entire conceptual locus, the human body, was missing in the cognitivist picture of cognition. This is mostly visible if we consider the famous metaphor that Simon used to introduce bounded rationality: the scissors metaphor. As Newell and Simon said:

> Just as a scissors cannot cut paper without two blades, a theory of thinking and problem solving cannot predict behavior unless it encompasses both an analysis of the structure of task environments and an analysis of the limits of rational adaptation to task requirements.
>
> *1972, p. 55*

The existence of two "blades," cognition and environment, is not able by itself, however, to express the richness of human cognitive activity. In other words, human cognition is underdetermined by the two *loci* of the scissors metaphor.

Before exploring the reasons and consequences of this underdetermination, it is important to say something on the connection between Simon's "bounded rationality" and Gerd Gigerenzer's "ecological rationality." As is well known, Gigerenzer was deeply inspired by Simon's scissors metaphor (e.g., Gigerenzer & Goldstein, 1996). In line with Simon, Gigerenzer's notion of ecological rationality for heuristic judgment maintains that "A heuristic is ecologically rational to the degree that it is adapted to the structure of the environment" (Gigerenzer et al., 1999, p. 13). Furthermore, although much less committed than Simon to the cognitivist approach to cognition, Gigerenzer admits that ecological rationality's program is inspired by "Simon and Newell's emphasis on creating precise computational models" (Gigerenzer et al., 1999, p. 26; see Petracca, 2017, for further points of contact between the two views). Undoubtedly, ecological rationality moves a step forward with respect to Simon's bounded rationality by emphasizing the crucial requirements of ecology for rational adaptation, but the 'cognitive' dimension of ecology remains either Simonian (e.g., when emphasizing the modularity of human intelligence, Gigerenzer, 1997) or not fully explored.

In a true ecological model of cognition, the role of the human body is pivotal (Hirose, 2002). Although one may still maintain that adaptation is between "cognition" and "environments," this is not a good reason to rule out the role of the human body as a mediating evolutionary or developmental interface. This is why we propose to enrich the traditional scissors metaphor by identifying another conceptual locus, the human body, which would metaphorically take the place of the 'pivot' of the scissors. In the next two sections, we will explore how heuristics and representations, two notions that are central in Simon's traditional view of bounded rationality, can be reconceptualized in the light of embodied cognition.

Rules of thumb: embodied heuristics

Embodied cognition can help to reconsider such a fundamental notion in bounded rationality as heuristics. This may be accomplished, at a first level of approximation, by emphasizing that a common name for heuristic is the "rule of thumb": an expression emphasizing that heuristics originate from body resources used for inferential purposes. The thumb can be considered as a true cognitive resource, either when it is institutionally established as a measuring device or when it is used on the fly as a tool to estimate approximate distance, length, etc. Less speculatively, the heuristic that better represents the *trait d'union* between ecological rationality and the embodied cognition approach is the "gaze heuristic," which is worth examining in some detail. It is important to note, incidentally, that Gigerenzer discussed this well-known heuristic in his more 'embodied' book, when he explicitly emphasized the notion of "gut feelings" (Gigerenzer, 2007). The gaze heuristic is a heuristic that is used to correct motion, on the fly, to achieve a spatial goal (see Hamlin, 2017); as such, it is used in many real-world activities like, for instance, catching a ball flying through the air, chasing prey, or landing an airplane. Contrary to the idea that individuals unconsciously perform complicate computations in this kind of task (Dawkins, 1976), the gaze heuristic shows that humans simply exploit the coupling between the visual perceptual apparatus and the invariant (because of the laws of physics, the relative invariance of human environments, etc.) properties of motor tasks. The gaze heuristic specifically reads: "Fix the gaze on the objective and adapt movement and running speed so that the angle of gaze remains constant." A wide array of motor tasks are possible through this heuristic without the need to rely on complex computations, simply by focusing on one variable: the object's angle. The gaze heuristics shows that adaptation occurs not only between cognition and environments, but it also crucially involves the structure of the perceptual and motor apparatuses.

Affordances and heuristics

The gaze heuristic is based on a fundamental principle: perceptive estimations are driven by pragmatic reasons, as perception aims to facilitate individuals' adaption to different situations (Mastrogiorgio & Petracca, 2018). The gaze mechanism is therefore a form of *ecological rationality* based on perceptual processing (Viale, 2017). However, the perception of environmental information (used by individuals to make decisions) is not a static and passive activity like taking a photograph. It involves instead the active research and manipulation of the inputs coming from eyes, head, and trunk movements. Moreover, an external object is perceived through the signals that it sends to the individual, so as to trigger neuro-motor patterns functional to this interaction. Objects 'speak' to the individual and 'tell' her/him what to do to allow interaction. This is the 'affordance' offered by the object, which the individual is invited to 'follow.' The concept of affordance, introduced by the psychologist of perception James Gibson (1950, 1979), concerns the dynamic relations that are established between an agent and a perceived object. Any perceptual stimulus coming from objects not only represents a collection of properties, but also triggers a possibility for action coupled with the sensory and motor characteristics of the perceiver. Our motor system is activated every time we observe an object that can be grasped, and get ready to perform an action congruent with the physical features of the object (Caruana & Borghi, 2016). For instance, a ball thrown in the air induces the action of picking up the ball, and this is true for any other stimulus (the irregular slope of a mountain triggers the affordance of climbing it, etc.). Evidence of this *embodied* mark of perception comes from neuroscience. By observing the effect of damage to the inferotemporal and parietal regions, it was noted that during the observation of an object the information is sorted along two different cerebral channels: a *ventral pathway*, which connects the visual to the temporal cortex and oversees semantic recognition processes, and a *dorsal pathway* in the cortex, which reaches the parietal lobe and processes the pragmatic aspects connected to visual-motor transformation and to action (Caruana & Borghi, 2016). The parietal lobe, however, presents features that are particularly interesting to explain the motor aspects involved in perception. In this region, a *dorso-dorsal pathway* can be observed, as well as a *ventro-dorsal* one, and the *intraparietal sulcus* (dividing the inferior parietal lobule from the superior one). The first pathway of visuomotor transformation is aimed to enable the action of reaching and grabbing objects. The second pathway concerns instead the storage of motor programs. The *intraparietal sulcus* is, however, the element that presents the most significant characteristics in terms of visuomotor coordination. The neuronal composition of its anterior part (AIP, *Anterior Intraparietal Area*) presents visual, visuomotor, and motor neurons that are activated, selectively, every time we observe objects that can be grasped. During the mere observation of graspable objects, this area automatically instantiates a grasping action, regardless of the actual will to grasp them. The same happens also in the area of F5 mirror neurons, to which the AIP is connected. According to Rob Ellis and Mike Tucker (2000), the affordances concerning the automatic grasping of objects occur because of the repeated co-occurrence of visual and action patterns. For example, the repeated past association that has occurred between the ball falling and the action to pick it up results in an affordance consisting in the automatic behavior to reach it, typical of the gaze heuristic. Moreover, it would not seem possible for affordances to be triggered indiscriminately, without any 'top-down' adjustment stemming from the context of outcomes and goals to be achieved. Since we are surrounded by many objects and each of them has multiple affordances (e.g., a cup may be grasped by the handle, the base, the lip, etc.), it is unlikely that our brain engages in responding to this proliferation of affordances indiscriminately (Caruana & Borghi, 2016, p. 48). Tipper and his team (2006) performed a clever experiment that seems to demonstrate that the effect of affordances is task-driven and not automatic. For example, when facing a book on a table, if the goal is grasping the book to put it on a shelf, a power grasp affordance will be triggered. If, instead, the goal is to flip through the pages, a precision grasp one will be triggered. Thus, when the ball is falling down, the grabbing affordance is activated when we find ourselves in the context of playing and the goal is to grab the ball. This may be not the case if we are taking our dog for a walk in a park and people are playing with a ball in the distance. Almost all objects have conflicting and competing affordances, and it is the context and our goals that make us select the coherent one. The context may be physical or social. For example, when the grasping distance of an object makes it too far away in an extra-personal space (physical context effect), no affordance is triggered. If instead it is within the peri-personal space of the individual (social context effect), the affordance is triggered. Our capacity to understand other people's intentions, through what is called *embodied simulation* (see below), leads us to treat them as avatars with regard to the perception of objects and their affordances, as if we want to act in their place. This effect seems to be generated by embodied simulation working as a "mind-reading" activity (Viale, 2012).

These remarks on sensory-motor aspects of perception may provide the basis for a variety of decision-making heuristics. As noted earlier, gaze heuristics can be explained according to a sensory-motor model. Other heuristics, such as the ones based on recognition like the "take-the-first" heuristic, can be explained within the same framework (Viale, 2017). If we think of recognition as the first option coming to mind when playing a team game and having to pass the ball to a teammate, it is clear that this process relies on sensory-motor memory. The repeated co-occurrence of similar situations in previous games with the same teammates (or different players occupying similar positions) in the game dynamics leads to the creation of mnemonic patterns (e.g., through the ventro-dorsal pathway for the storage of motor programs) of a sensory-motor type that trigger automatic decisions about passing the ball. The player passes the ball to the first player corresponding to the sensory-motor memory patterns. In other words, it is the affordance of the teammate in a certain position on the field that triggers the player's sensory-motor memory and that makes him/her pass the ball in a certain way.

Heuristics and embodied emotions

People often talk about decisions based on a "gut feeling." Particularly when a decision is taken under time pressure, with limited information, and when the effect of this decision has implications on one's well-being, one does not rely on complex computations but on gut feelings. Consider the required speed in financial trading decisions: there is no time for in-depth reasoning, as decisions have to be made in just a few seconds. Only intuition and gut feeling can work as decision makers. Gigerenzer (2007) presents numerous examples of decisions taken in this way. What characterizes gut-based decisions? These are decisions where the emotional component contained in choosing one option over another is expressed positively or negatively at the bodily level (Damasio, 1994). When the taxi driver takes one glance at the customer and feels a "knot in the stomach," he or she suddenly decides the customer cannot be trusted and it is not safe to take him on board.

The role of emotions is evident in many other aspects of decision making. When using the recognition heuristic, it is the emotional element of familiarity that often leads us to pick one option over another (Viale, 2017). Emotion plays an important role also in the case of "one reason-based" heuristics (Gigerenzer & Gaissmaier, 2011). Let us consider the "take-the-best" heuristic, according to which, when making a choice, an individual retrieves from memory situations, facts, and reasons, and uses the first cue in order to evaluate alternatives. The emotion related to specific episodes is important to strengthen memorization and the subsequent retrieval. Heuristics based on recognition and on "one reason" have the capacity to generate decisions that are more adaptive if compared to the algorithms of (neo)classical rationality. They allow us to deal with an environment characterized by uncertainty and complexity through rapid decisions that are simple, frugal, and effective in terms of prediction. They are therefore the center of gravity of the *ecological* dimension of *bounded rationality* (Viale, 2017). This adaptive capacity can be explained precisely by the role that emotion plays in the interaction between the individual and the environment. The mechanisms of emotion seem to refer to the functions of the *ventromedial prefrontal cortex*, which includes the *orbitofrontal cortex*. By virtue of its multiple incoming connections with sensory and enteroceptive areas and of its outgoing connections with the autonomous nervous system, the ventromedial cortex serves to read physical expressions and to assess the physiological state of the body. In this way, it reads physical sensations connected to decision-making options and automatically leads the individual toward those that are characterized by well-being and pleasure, avoiding negative ones. Another important cortical structure involved in the emotional experience is the *insula* or *Island of Reil*. Its *posterior part* functions as a primary enteroceptive cortex in its own right. It receives a variety of stimuli from gustative representation to pain, tactile sensations, disgust, visceromotor control, thermoception, etc. According to the neuroscientist Bud Craig (2011), the posterior insula processes this information and constitutes a sort of cerebral map of corporal states. The *ventral* part of the *insula* instead works for the subsequent processing of this map to generate a sort of re-interpretation of the emotional experience. In short, the insula functions as an 'emotional eye' of corporal states, interpreting them, and generating, together with the ventromedial prefrontal cortex, choices and decisions. (Neural imaging tests could verify the hypothesis that recognition and one-reason-based heuristics rely on ventromedial prefrontal cortex and insula activation, and are therefore driven by emotional salience-based retrieval.)

Embodied representations and simulations

Central notions in Simon's approach to cognitive psychology and bounded rationality are those of mental representation and simulation. Characteristically, in Simon's framework, mental representations and simulations would be constituted of abstract and amodal 'symbols' (Newell & Simon, 1972, 1976). Embodied cognition does not completely rule out the role of representations and simulations in cognition (even if this is not true for all approaches to embodied cognition, see Petracca, 2017), but definitely rejects the idea that they are abstract and amodal.

One of the most exciting contributions of neuroscience to the debate about the nature of the human mind and its functional mechanisms is the discovery of the cognitive role of the cortical motor system. Empirical research has demonstrated, first in non-human primates and then in humans, that the cortical motor system is functionally organized in terms of motor goals. Many cortical motor neurons, both in the frontal and parietal lobes, do not discharge during the execution of elementary movements, but are only active before and during purposive motor acts, i.e., movements executed to accomplish specific motor outcomes, like grasping, tearing, holding, or manipulating objects. The teleological dimension of behavior thus entirely belongs to the functional properties of the motor system. A further element of novelty about the cognitive role of the motor system is provided by the robust evidence of its involvement in perception: premotor and parietal areas contain motor neurons that also perceptually respond to visual, auditory, and somatosensory inputs (see Gallese & Cuccio, 2015).

The discovery—first in macaque monkeys, then in humans—of "mirror neurons" revealed the cognitive role of the motor system in social cognition. Mirror neurons are motor neurons that respond both when a given movement or action is performed and when it is observed being performed by someone else. Mirror neurons reveal a new empirically founded notion of intersubjectivity connoted first and foremost as intercorporeality: the mutual resonance of intentionally meaningful sensorimotor behaviors. The ability to understand others as intentional agents does not exclusively depend on propositional competence, but it is in the first place dependent on the relational nature of action. According to this hypothesis, it is possible to directly understand others' basic actions by means of the motor equivalence between what others do and what the observer can do. Thus, intercorporeality becomes the primordial source of knowledge that we have of others.

These findings led to the "Motor Cognition" hypothesis (see Gallese et al., 2009): cognitive abilities like the mapping of space and its perception, the perception of objects occupying our visual landscape, the hierarchical representation of action with respect to a distal goal, the detection of others' motor goals, and the anticipation of their actions are possible because of the peculiar functional architecture of the motor system, organized in terms of goal-directed motor acts. The same motor circuits that control individuals' behavior within their environment also map distances, locations, and objects in that very same environment, thus defining and shaping in motor terms their representational content. The way the visual world is represented by the motor system incorporates agents' idiosyncratic way to interact with it.

Empirical research demonstrated that the human brain is also endowed with mirror mechanisms in the domain of emotions and sensations: the very same nervous structures involved in the subjective experience of emotions and sensations are also active when such emotions and sensations are recognized in others. For example, witnessing someone expressing a given emotion (e.g., disgust, pain, etc.) or undergoing a given sensation (e.g., touch) recruits some of the viscero-motor (e.g., *anterior insula*) and sensori-motor (e.g., SII, *ventral premotor cortex*) brain areas activated when one experiences the same emotion or sensation, respectively. Other cortical regions, though, are exclusively recruited for one's own and not for others' emotions, or are activated for one's own tactile sensation, but are actually deactivated when observing someone else being touched (for review, see Gallese, 2014; Gallese & Cuccio, 2015).

Embodied simulation theory makes use of a notion of embodiment according to which mental states or processes are embodied because of their bodily format. The bodily format of a mental representation constrains what such mental representation can represent, because of the bodily constraints posed by the specific nature of the human body. Similar constraints apply both to the representations of one's own actions, emotions, or sensations involved in actually acting and experiencing, and also to the corresponding representations involved when observing someone else performing a given action or experiencing a given emotion or sensation. These constraints are similar because the representations have a common bodily format. Hence, embodied simulation is the reuse of mental states and processes involving representations that have a bodily format. The nature and the range of what can be achieved with embodied simulation are constrained by the bodily format of the representations involved.

To put it simply, the producer and repository of representational content are not the brain per se, but the brain-body system, by means of its interactions with the world of which it is part. The proper development of this functional architecture likely scaffolds more cognitively sophisticated social cognitive abilities. As recently argued, embodied simulation as a component of cognitive models, when recruited by the situated and contextualized process of meaning construction, is an integral part of linguistic meaning, including conceptual knowledge (Cuccio & Gallese, 2018).

The disembodied approach of current social neurosciences

What is the position of social neuroscience research today with respect to embodied cognition? Carlos Alós-Ferrer (2018), in line with Cacioppo et al. (2006) and Schutt et al. (2015), attempts to survey the contribution of neuroscience to social sciences and economics. As recently noted (Viale, 2019), he correctly emphasizes that social sciences can no longer function without the empirical data provided by the research at the intersection between social cognitive psychology and neuroscience. This need not only results from an epistemological change in economics, but it is rooted in a deeper evolutionary argument: the bidirectionality between brain and the social world. The brain and the early forms of social organization coevolved over time. While the role of the neurocognitive apparatus in the genesis of social phenomena is now widely accepted, the importance of understanding social evolution for brain studies is not. As Alós-Ferrer writes:

> Understanding which characteristics this coevolution selected for and why they provided an evolutionary advantage provides a far better understanding of the nature and functioning of the brain than statistical studies on the relative proportion of neurons and glial cells in each brain region.
>
> *2018, p. 235*

And this integration between hereditary dimension, social environment, and biological component explains, among other things, also the development and the treatment of mental illness (as highlighted in Eric Kandell's recent book, Kandell, 2018). The representation made by Alós-Ferrer of the relation between neuroscience and society suffers, however, from a neuro-cognitivist bias, which is typical of neuroeconomics: forgetting the body as a fundamental bridge between the brain and the environment. Accordingly, this bias also regards bounded rationality as lacking conformity to the standards of economic rationality (thus making it a synonym for irrationality) and not as a way to adapt to an uncertain and complex social world.

Alós-Ferrer's approach adopts the epistemological stance of cognitivism with the sole difference that behavior and decision-making processes are analyzed on the basis of neurocognitive models, which are centered on the brain (Legrenzi & Umiltà, 2011; Gallagher, 2018a, 2018b). What is lacking in this analysis is the 'embodied' dimension of cognition, that is, the integration of central nervous system with all the other visceral, sensory, and motor body parts. The neurocognitivist bias of contemporary social neurosciences results in the polarization of the analysis of the social brain mostly in terms of theory of the mind (Theory Theory of the Mind, or TT). This focus on the theory of the mind as the central element of the social brain stems from a distance from ecological and embodied arguments. Accordingly, this leads to overlooking a fundamental component of that function altogether, namely, mind reading, originating in "embodied simulation" produced by the mirror neurons system (Rizzolatti et al., 2001; Goldman, 2006; Iacoboni, 2008; see above). According to the TT, the attribution of mental states to others is possible only through the construction and the development of a theory on these states (Premack & Woodruff, 1978). Understanding or predicting others' actions means engaging in a theoretical inference on propositional attitudes like beliefs, desires, and intentions of others, through conscious and intentional representations of the other person's mental states. In this perspective, there is no room for automatic, unconscious forms of "mind reading" or an empathetic interpretation of emotional states or "mind feeling" (Viale, 2011, 2012). TT is typically the expression of the "disembodied cognition" of the cognitivist approach, and finds its natural collocation in behavioral economics and neuroeconomics. According to Alós-Ferrer, the theory of the mind is the cognitive equivalent of the game theory, which is fundamental to understanding social interaction. As he writes: "Social neuroscience is to decision neuroscience as game theory is to decision theory" (Alós-Ferrer, 2018, p. 259).[1]

As noted, the mutual understanding of social behaviors seems to occur mostly through an embodied simulation mediated by the mirror neurons system. This type of study shows that the social brain cannot be reduced to the fronto-temporal network of the theory of the mind. On the contrary, it seems to point to the fact that conscious and intentional neurocognitive activity is the tip of the iceberg of our social interaction. Most of our social life takes place through processes of automatic, unconscious simulation that is often empathetic with other people's behavior, and, hence, embodied. The development and recognition of the self occur through the imitation of others, and one's personal identity seems shaped by a reflection onto others. The newborn child seems to develop mirror neurons through the repeated imitation of the expressions of the adults he or she interacts with. His/her brain, for example, associates the image of his/her mother's smiling face with the motor level intended to replicate it. Mirror neurons would therefore serve as the basis of the reflection of our behavior in others. Through mirror neurons, we see ourselves in others. Pfeiffer et al. (2008), for example, found a correlation in children between emotional empathy, measured according to the *Interpersonal Reactivity Index*, and the increase in mirror neurons' activity while observing facial expressions with an emotional component. The same increase was found in children who were more sociable, more open, and with more relations than others. Other data seem to indicate that mirror neurons are activated every time a social identification process occurs. This activation was observed, for example, with advertisements and the identification with political figures (Iacoboni, 2008). In this way, they seem to provide the basis for understanding social identity, one of the fundamental mechanisms at the origin of social interaction and the related decision-making processes.

In the emotional and empathetic dimension, mirror neurons also explain a series of emotional social contagions. A case in point is contagious laughter, as mirror neurons explain why we laugh more when we are in the company of others and why we laugh when others do. The "audience effect" of empathic resonance also occurs for negative expressions, like pain, disgust, anger, etc. While, on the one hand, we suffer more when we are in the presence of others, on the other hand, we identify ourselves, empathically, with the suffering of others (Chartrand & Bargh, 1999; Longo et al., 2008; Heyes, 2011). Lastly, the embodied simulation of mirror neurons is clearly a useful decision-making tool in social contexts. When we are making rapid and intuitive decisions, the capacity to simulate other people's emotions and actions provides important contextual elements to make adaptive choices. This type of simulation therefore plays a heuristic role that fits into the toolkit of bounded and ecological rationality.

Conclusion

The re-conceptualization of human rationality in light of the embodied perspective is gradually emerging in literature under the name of "embodied rationality" (see Spellman & Schnall, 2009; Mastrogiorgio & Petracca, 2015, 2016; Viale, 2017; Gallagher, 2018a, 2018b; see also Oullier & Basso, 2010). This chapter aims to show that the adaptive and ecological dimension of bounded rationality should be better analyzed by assuming an embodied cognition perspective. Ecological rationality and the functioning of simple heuristics, in particular, would greatly benefit from inputs from neurobiological and embodied cognition studies. Until now, few reflections about these opportunities have been made in the framework of the ecological rationality approach. It remains mainly characterized by reference to information processing psychology (see Petracca, 2017) and by a Marrian algorithmic level of analysis (Marr, 1982; Brighton, Chapter 17 in this volume). In fact, something is changing among ecological rationality scholars, in particular with reference to deeper analysis of the neurobiological dimension of heuristics decision making. According to Nordli and Todd (Chapter 19 in this volume), neurophysiological studies would promote a new theoretical framework for ecological rationality. For instance, those studies may contribute to understanding strategy selection in decision making, where strategy selection means the selection of a given heuristic for a particular context. The selection is successful when the selected heuristic matches the structure of a given situation. That may happen by developing a mapping between context structure and appropriate heuristics to use (Marewsky & Schooler, 2011). The mapping may be generated by a "strategy selection learning" procedure as proposed by Rieskamp and Otto (2006), as strategies are selected according to predictions regarding their expected results in particular tasks and contexts. According Nordli and Todd (Chapter 19 in this volume), the reinforcement learning-based mechanism of strategy selection

> is consistent with accounts that tie reinforcement learning processes to recurrent cortico-basal circuitry (e.g., Yin & Knowlton, 2006), which is the very same circuitry that is critical to the exploitation of past behavior in the form of habits and fixed action patterns.
>
> *Nordli & Todd, p. 320*

In particular, the basal ganglia seem to lie behind most ecologically rational behavior. Basal ganglia seem to evaluate context and select actions based on either motor or cognitive past behavior

(Graybel, 2008, quoted in Nordli & Todd, Chapter 19 in this volume). This neural mechanism allows the strategy selection of adaptive heuristics based on evaluation of past behavior.[2]

In conclusion, as the arguments in this chapter and previous references to strategy selection aim to show, embodied bounded rationality is the new framework to study adaptive decision-making processes.

Notes

1 This means that game theory overrides the theory of decision making and finds its equivalent in the whole of social neuroscience, which should rely on its formal rigor to prevent the fragmentation of neuroscientific research on the theory of the mind. This desire extends to the point of wishing that neuroscience, while thinking about thought, turns to game theory as a means to formalize the "thinking of the thought thinking the thought thinking …" This seems to be a wish of neoclassical and cognitivist inspiration—which is actually untenable, given the limited computation capacities of the human brain and particularly of its operative memory.

2 There are other examples of neural modeling of adaptive behavior. One is proposed by Bhui (in press). It is well known that the way we feel about an outcome depends on how we compare it to our past and present experiences. However, it is not so clear what kind of comparisons we make, or even why we make comparisons at all. Bhui refers to theoretical neuroscience to explain why this context dependence is adaptive. Our sense of value may adapt to our experiences for the same computational reason that our eyes adapt to light and dark: our neurons have a limited capacity to process information, which is best spent distinguishing among the stimulus values we expect to encounter in our local environment. Bhui shows that influential psychological theories of context-sensitive judgment can be derived from the neurocomputational principle of efficient coding. This unites conflicting cognitive, behavioral, and neural findings spanning both perceptual and value-based judgment across multiple species into a single neurobiologically-grounded framework.

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