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Neurophysiological bases underlying the organization of intentional actions and the understanding of others' intention

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ABSTRACT

Philosophical and neuroscientific investigation on intentional actions focused on several different aspects, making difficult to define what should be meant with the concept of intention. Most of our everyday actions are constituted by complex and finely organized motor sequences, planned and executed in order to attain a desired final goal. In this paper, we will identify the final goal of the action as the motor intention of the acting individual. First, we will review the relative contribution of the vast neuroscientific literature on the role of different cortical areas in the organization of goal-directed movement. In particular, we will describe recent data on the cortical organization of natural action sequences, showing that this organization could be at the basis not only of our capacity of acting intentionally, but also of our ability to understand the motor intentions underlying others' behaviour which is crucial during social interactions.

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1. Introduction

The concepts of “intention” and “intentionality” of human actions are, since centuries, the focus of philosophical reasoning and dispute, but in the last few decades even neuroscientists and biomedical engineers started focussing their efforts on decoding neuronal intentional signals from the human brain for building brain-machine interfaces (Andersen, Hwang, & Mulliken, 2010; Hochberg et al., 2006). However, in spite of the advances of modern neurophysiological and neuropsychological techniques and their crucial contribution to the clarification of the basic mechanisms underlying intentional actions, there are still some fundamental neuroscientific and theoretical issues that remain unresolved.

First, concepts such as “action” and “intention/motor intention” are still elusive and not well defined. Second, the relationships between an overt intentional behaviour and its correspondent covert representations must be clarified. This last issue is critical for any attempt to identify the neural mechanisms underlying our capacity to plan and perform intentional actions, as well as to predictively understand the motor intentions of others.

2. Movements, motor acts, actions and intentions: hierarchical organizations of goals in the motor system

According to Libet's seminal works, an act is regarded as intentional when (1) it arises endogenously, (2) there are no externally imposed restrictions or compulsions that directly or immediately control its initiation, and (3) subjects feel introspectively that they are performing the act on their own initiative, starting or not as they wish (Libet, 1985). In the time domain, “intentionality is the premotor detail of the desired result of movement (...): the choice of what to do before the doing of it”

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(Llinas, 2002). Most philosophical and neurophysiological studies in the literature dealt with the concepts of intention and intentionality in such a way, suggesting that the intention of doing a certain act is something that precedes its actual motor execution, and that it is usually associated with the conscious experience of ‘agency’.

Wittgenstein (1953) already envisioned the complexity of this issue by posing the question: “*what is left over if I subtract the fact that my arm goes up from the fact that I raise my arm?*” A plausible answer to this question could be “some sort of conscious experience to intentionally lift the arm”, but the philosophical debate has considered the concept of “intention” as by far more complex. One of the most influential of these views (Searle, 1983) maintains that intentions can be considered at two distinct levels: prior intentions (e.g. to replace a burned out light bulb *later on*) and intention-in-action (i.e. the internal state that guides and monitors the arm lifting movement *while* reaching the light bulb). Several other theorists followed this dualistic approach, distinguishing between prospective and immediate intentions (Brand, 1984), future- and present-directed intentions (Bratman, 1987), distal and proximal intentions (Mele, 1992), while others proposed even more articulated models (Pacherie, 2008), identifying distal, proximal and motor intentions. What appears to be shared by all these views is some concept of motor goal that – although at different levels of complexity – constitutes the core of what intentions represent, that is, “*goals and means to those goals*” (Pacherie, 2008).

The concept of goal is also central to the neurophysiological literature dealing with the correlates of intentional actions. Let’s consider a simple example. Opening a candy box can constitute the goal of an agent and, therefore, the content of his/her intention. However, to attain this goal, the agent must organize a reaching-grasping action formed by a sequence of motor acts (see Rizzolatti et al., 1988), each of which is aimed at an immediate motor goal (e.g. reaching, grasping, lifting the handle of the lid). Motor acts are formed by more elementary muscle synergies, often called simple movements, which could serve for the execution of several different acts and actions, regardless of their goal. Thus, what is the agent’s intention in this example? One might say to grasp the lid, to remove the lid or even to eat a candy. This action clearly includes many goals and sub-goals, but it is unclear firstly at which level we should search for the agent’s intention in this motor hierarchy and, secondly, if some unifying concept of intention does exist at all.

Usually, by definition, we consider an action as associated with only one goal. Bernstein (1996), for example, defined actions as “*whole sequences of movements that together solve a motor problem (...) and all the movements parts of such a chain are related to each other by meaning of the problem*”. In this definition “motor problem” clearly refers to what we usually identify with the concept of motor goal. Nevertheless, even very simple discrete movements – such as arm reaches, saccades or extension/flexion of a finger – can be considered as goal-directed, provided that they are performed in order to reach a specific state and their execution is under voluntary control. This latter consideration is extremely useful in order to reconcile the many and diverse findings reported by neurophysiological studies on intentional actions, using behavioural paradigms extremely different one from the other in terms of motor complexity.

2.1. When, what and how of intentional actions

Many authors employed different behavioural paradigms to investigate intentional actions focussing on motor details that are specified in advance to the actual movement execution. Neurophysiological studies showed, for example, that mesial premotor regions (supplementary and pre-supplementary motor areas) and rostral cingulate motor cortex encode ‘*when*’ a general intention to act rises (Fried, Mukamel, & Kreiman, 2011; Hoshi, Sawamura, & Tanji, 2005), particularly prior to self-generated actions (see Passingham, Bengtsson, & Lau, 2010). Others (Andersen & Buneo, 2002; Snyder, Batista, & Andersen, 1997) studied neuronal activity during the planning phase of simple reaching and saccadic movements directed to a target and showed that lateral intraparietal neurons specifically encodes ‘*what*’ the monkey intends to do (a reaching act or a saccade) prior to movement onset. Other authors, although not explicitly focussing on the issue of motor intention, demonstrated that planning-related neuronal activity in different premotor and parietal areas can specify ‘*how*’ an act has to be done, either in terms of specificity for the direction of the forthcoming reaching (Cisek & Kalaska, 2005) or for the grip selectivity of the planned grasping (Baumann, Fluet, & Scherberger, 2009), as soon as contextual information sufficient to make a decision becomes available (see Andersen & Cui, 2009). Taken together, these studies suggest that an intentional action stems from decisional processes carried out on potential concurrent motor plans simultaneously activated in a network of parietal and frontal areas and specifying the ‘*whether*’, ‘*when*’, ‘*what*’ and ‘*how*’ of the action to be performed (see Haggard, 2008).

Most of these processes can occur covertly, automatically and without any need of conscious access: when grasping a handful of popcorn while watching a movie, we will not be certainly attending to when starting to move or how shaping the hand for doing it. Nevertheless, we could, if we want, carefully look at a single popcorn, precisely grasping it between our thumb and index finger tips, and specifically attending to when we decide to start the movement, what action to perform or even how to do it (Lau, Rogers, Haggard, & Passingham, 2004): in both cases, i.e. attending or not to the action, our phenomenological experience of acting intentionally appears to us as a sort of unitary perception that is always inherent in our own voluntary behaviour. However, motor intention cannot be considered, as our phenomenological experience would suggest, a unitary phenomenon from a neurophysiological point of view, since different brain areas have been shown to play a role in processing different aspects of intentional actions. The pioneering studies by Penfield and Boldrey (1937) and more recent data by Desmurget et al. (2009) have shown that it is possible to dissociate the processes leading to motor execution of an action from those related to the awareness of the corresponding motor intention. For example, by means of electrical stimulation of the human right inferior parietal cortex, Desmurget and coworkers evoked the patients’ subjective feeling of

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