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ORIGINAL RESEARCH

An all-purpose framework for affordances. Reconciling the behavioral and the neuroscientific stories

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Abstract
Research on the concept of affordance generated different interpretations, which are due to different stories aimed at describing how this notion accounts for visually guided motor behaviors. On the one hand, *dispositional accounts of affordances* explain how affordances emerge from the encounter of the agent's perceptual-motor skills, with an object offering possible interactions, as *behavioral dispositional properties*. On the other hand, *cognitive neuroscience* explains what neural mechanisms are required for agents to detect affordances, resulting from an internal *processing*. As the literature recognized, it would be beneficial to connect these two stories. We propose an important step into this connection, showing how a *dispositional notion* of affordance can be distinguished into two versions, the *Dispositional Account of Nomological Affordance Response* and the *Dispositional Account of Probable Affordance Response*, and how to complement different aspects of *visuomotor processing* for affordance extraction, discussed in *neuroscience*, with them. An important benefit of our proposal is that it suggests, for the first time, that we should not prefer one *dispositional* account at the expense of the other. Indeed, we show that different *dispositional* accounts can capture distinct aspects of the plethora of complex manifestations, at the neurocognitive level of visuomotor-processing, that affordances can display in humans, both in healthy and pathological subjects.

Keywords Affordance · Vision · Action · Motoric

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1 Introduction

Over the last few decades, the research field on perception has displayed a growing interest in the relations between vision and action. Among the most discussed topics in this field, there is the issue of explaining how vision manages information about the opportunities for actions that are offered by the environment (few classical examples are: Chemero, 2011; Gibson, 1979; Marr et al., 2010; Milner & Goodale, 1995; Noë, 2004; Pylyshyn, 2007; for a recent review, see Ferretti & Zipoli Caiani, 2018, 2019, 2021). In this respect, performing suitable object interactions requires that a subject tracks a given target within the surrounding environment and, accordingly, perceives whether it is possible for her to perform an action on it, based on her bodily configuration, motor skills and with respect to the motor context (Ibid.). Along this line, a crucial question has gained relevance in the debate: how does visual perception 'inform' the agent that a possibility for action is available in the environment? Interestingly, although no consensus has been reached yet on how to fully answer to this question, many scholars have directed their attention to the notion of *affordance* to tackle this problem (for recent reviews, de Wit et al., 2017; Favela, 2024; Ferretti, 2021a; Osiurak et al., 2017; Sakreida et al., 2016).

In this respect, in recent years, the interest about the notion of affordance has given rise to many interpretations characterized by very different views, concerning what an affordance is, and how it is supposed to account for the evidence concerning the relation between vision and action in visually guided motor behavior. Indeed, different notions of affordances are proposed within different branches of the literature.

However, the purpose of this article is to show that different notions of affordance can coexist, as they serve different purposes, within several domains. In particular, we discuss the power and limits of the different *dispositional* accounts of affordance, and the way they can be complemented with the *visuomotor-processing* account of affordance coming from *neuroscience*. Not only will this show the possibility of their co-existence, but also the way this can help us to better model human visuomotor behavior, with respect to different explanatory aims.

Notably, we distinguish (§3) between two *dispositional* notions of affordance: the '*necessity*' view by Turvey (1992), related to affordances as linked to effectivities, concerning a *Dispositional Account of Nomological Affordance Response* (§3.1) and the '*conditional*' view by Scarantino (2003), a *Dispositional Account of Probable Affordance Response* (cfr. Vetter, 2020) (§3.2). Then, we examine empirical evidence from *neuroscience* (§4) to show that these two *dispositional* notions of affordance can capture different but nonetheless related aspects of how, according to the results on *visuomotor processing*, visual perception can guide the execution of overt and covert visuomotor responses for action-related behaviors in different motor contexts.

More precisely, we show that the *conditional* view can account for (a) what happens during usual affordance perception in healthy individuals, with the possibility of performing overt actions, which are not necessarily actualized (§4.1). Instead, the *necessity* view can account either for cases in which (b) the visuomotor system automatically responds to an object for potential action via the covert activation of the relevant neural mechanisms, even if overt action will not follow (§4.2), or (c) brain damaged patients exhibit a pathological behavior and cannot avoid interacting with objects offering opportunities of interaction (§4.3). Before introducing our proposal, we need to set the theoretical ground.

2 Affordances. Two views, one desideratum

Gibson's notion of affordance is widely recognized as one of the most influencing notions in the interdisciplinary literature on cognitive science:

"Forty years have passed since James J. Gibson (1977) coined the term "affordance" to refer to the action possibilities offered to an animal by the environment with reference to the animal's action capabilities. Since then, the notion of affordance has gained huge popularity, becoming a common term in the jargon of researchers, but also students in psychology or neurosciences. There is hardly a week that passes without a colleague saying during lunchtime: "Hey, did you see that? I grasped and used the fork because of its affordance!" (Osiurak et al., 2017: p. 403).

But it is also one of the most discussed:

> As many popular notions, the paradox is that the notion of affordance raises serious theoretical issues, notably when the time comes to define precisely what it is. The fact is that it has acquired a multitude of connotations, generating confusion in the published literature (...). The risk is that it becomes progressively useless, losing its heuristic value by eventually meaning everything and its opposite (Osiurak et al., 2017: p. 403).

Most of the time, an analysis of the literature does not solve the exegetical issue:

> a search through the literature quickly shows that there is no singular definition of affordances and that discussions of the concept do not adhere strictly to the theoretical work conducted by Gibson (Chong & Proctor, 2020, p. 120).

In this respect, not all psychologists and neuroscientists relying on the notion of affordance automatically inherit all the Gibsonian theoretical commitments about perception (Ferretti, 2021a). Bearing in mind the complexity of any philological attempt to frame this notion, we sketch two stories on affordances that are relevant for our proposal.

We start from the dichotomy between the story of *Dispositional Accounts*, and the story of *Neuroscience*, which relies on a *Visuomotor-Processing Account*. Then, we'll try to unify these two approaches.

2.1 Dispositional accounts of affordances

The concept of affordance was originally coined by Gibson (1979), referring to the possible actions *afforded* by targets perceptually found in the environment by human and non-human animals. This is doubtless one of the most debated concepts in the last twenty years in interdisciplinary research in psychology, philosophy and neuroscience (Chemero, 2011; Ferretti, 2021a; Heft, 2001).

Although Gibson's work has inspired a generation of scholars, it is broadly recognized, by himself, that his theory could be revised in the future: "These terms and concepts are subject to revision as the ecological approach to perception becomes clear" (Gibson, 1979, p. 311). Many scholars have been, indeed, attracted from the need of clarifying the nature of *affordances*, fueling an exciting debate that is still far from ending (Chemero, 2011; de Wit et al., 2017; Osiurak et al., 2017).

Now, starting from Gibson's insights to the last decade of the past century, the notion of affordance has been defended against the computational/representational models of vision (for a review of this point, see Michaels & Carello, 1981; Turvey et al., 1981; more recently: Chemero, 2011, Chong & Proctor, 2020; Dotov et al., 2012; for different uses, see also Borghini and Ferretti 2021, Ferretti 2021a, 2021b, 2021c; Zipoli Caiani, 2013).

In this framework, the notion was commonly associated with the capacity of directly perceiving action possibilities in the environment without involving internal representations, supposing that the information coming from a light source is directly available within the ambient optic array (Gibson, 1979, 140).

Among the most interesting attempts to clarify the notion of affordance, there are those by Gibson's early fellows. Since the 1980's, they have worked on a theoretically sound and empirically fruitful version of Gibson's theory, providing an invaluable contribution in making the notion of affordance compatible with the materialistic and naturalistic framework of the cognitive sciences (e.g., Carello et al., 1989; Heft, 2001; Michaels & Carello, 1981; Stoffregen, 2003; Turvey, 1992; Turvey et al., 1981).

One interesting view is that of Turvey (1992), who conceived affordances as potentialities of certain objects, suitable targets for actions, in the environment, inasmuch as they complement the dispositional properties of certain agents. According to this view, an affordance emerges, so to speak, from the encounter between a specific agent and a given object, both located in a common ecological niche hosting a motor context offering specific motor interactions.

Furthermore, the theoretical works of Shaw et al. (1982), and Michaels and Carello (1981), the experimental results by Warren (1984), but also the contentious articles by Fodor and Phylyshyn (1981) are representative of this idea (for a detailed review see Lobo et al., 2018). From this initial conception of the theory of affordances, the literature interested in affordances has taken several directions, embracing different conceptual commitments to the notion.

Indeed, Post-Gisbonian proposals modelled affordance responses in terms of dispositions actualized within the animal/environment interaction. In this view, an affordance emerges from a system in which a given property of the animal's body and a given environmental property meet, so that, given the suitable ecological circumstances, the affordance has the *causal propensity to actualize* (Scarantino, 2003; Stoffregen, 2003; Turvey, 1992; Turvey et al., 1981).

There have been, along this line, further forms of theorizing about the *relational* notion of affordances. All of them inherit many aspects from the dispositional one, according to which a certain organism's disposition to act is manifested in terms of the complementarity between that organism and the relevant property of environment, so that an affordance is the result of a dynamical relation between the two (see also Chemero, 2003; Rietveld & Kiverstein, 2014). In this paper, we do not rely on a distinction between these forms of dispositional/relational notions. This is what we call here the *dispositional notion* of affordance,[1] which we'll discuss more in detail in (§3), with respect to its different formulations.

Importantly, while the *dispositional story* is very interesting, there is another story, coming from *neuroscience*, that goes beyond this framework, which we analyze in the next section, the story about *brain visuomotor processing* for affordance extraction.

2.2 Affordances, neuroscience, and the visuomotor-processing account

The *dispositional concept* of affordance has been deeply influential (Chemero, 2003; Heft, 2001; Heras-Escribano, 2019; Scarantino, 2003; Stoffregen, 2003; Turvey, 1992; Vetter, 2020). In this respect, Turvey's (1992) *dispositional view* postulates laws relating the overt behavioral activities of the agents to the external properties of the environment by conceiving both in terms of dispositions. This view, however, has deliberately ignored, for a long time, the neural mechanisms underlying visuomotor processing (see the analysis by de Wit et al., 2017; de Wit & Withagen, 2019).

In this respect, beyond this trend, the notion of affordance has become so famous as to gradually extend its influence outside the boundaries of *psychology*, to the field of *cognitive neuroscience* (Borghi & Riggio, 2015; Bruineberg & Rietveld, 2019; de Wit et al., 2017; Ferretti, 2021a; Osiurak et al., 2017; Sakreida et al., 2016).

In the last 20 years, indeed, an increasing number of works in cognitive neuroscience (and its philosophy) have adopted the notion of affordance to investigate the brain mechanisms involved in the visual processing of objects for the purpose of interacting with them.

When using the notion of affordance, neuroscientists typically refer to the cortical visuomotor mechanisms giving raise to *representational computations* of visually detected action possibilities, instead of dispositional properties of the agent-environment system (for this point, see Borghi & Riggio, 2015; Chong & Proctor, 2020; Cisek, 2007; de Wit et al., 2017; Dotov et al., 2012; Ferretti, forthcoming, 2021a, 2021b, 2021c; Osiurak et al., 2017; Sakreida et al., 2016; Tillas et al., 2017; Zipoli Caiani, 2013).

This interest is characterized by the assimilation of the notion of affordance within the computational paradigm (Chong & Proctor, 2020; Costall & Morris, 2015; Dotov et al., 2012; Ferretti, 2021a; Zipoli Caiani, 2013), with a special attention, at least in certain relevant cases, to the pragmatic format of mental representations (Ferretti & Zipoli Caiani, 2019, 2021).

In particular, the discovery of the visuomotor functions of the parieto-premotor network in non-human and human primates has favored the use of the notion of affordance in relation to the computational mechanisms underlying the purpose to detect them (Borghi & Riggio, 2015; Ferretti, 2016c, 2019, 2020, 2021a; Sakreida et al., 2016; Zipoli Caiani, 2013). Indeed, specific mechanisms in the brain have

[1] Based on specific assumptions, several scholars pushed the line of overcoming a subject-object distinction, and give up the representational conception of perception (Bruineberg & Rietveld, 2014; Chemero, 2003, 2011; de Wit et al., 2017; Heft, 2001; Heras-Escribano, 2019; Hutto & Myin, 2012; Spivey, 2008; Withagen and Chemero, 2012). Note that the dispositional view does not equate to stimulus–response behaviorism (see Withagen et al., 2012, 2017).

been interpreted as the neural representational *loci of affordance extraction* through *visuomotor transformation* of objects' spatial properties into motor commands (Ibid.). Importantly, it is a matter of fact that the activity of certain areas of the motor and premotor cortex has been interpreted by scholars as underlying the visual detection of affordances in the environment. However, the fact that the perception of affordances has been identified with the *representational function* of certain brain circuits does not imply a realist take on representations, as deflationist and pragmatist positions are also available (Egan, 2020, see also Favela & Machery, 2023).

In this respect, most of the research on affordances in neuroscience has been devoted to provide pieces of evidence on the several and highly specialized cortical motor networks responsible for the extraction of spatial features, related to an affordance, of objects, especially graspable objects (and in tool use) (Anelli et al., 2012; Borghi & Riggio, 2015; Borghi et al., 2012; Castiello, 2005; Castiello & Begliomini, 2008; Caligiore et al., 2013; Chinellato & del Pobil, 2016; Chinellato et al., 2019; Cisek, 2007; Cisek & Kalaska, 2010; Costantini et al., 2010, 2011; Fadiga et al., 2000; Ferretti, 2016a, 2016b, 2017, 2018, 2021a, 2023; Ferretti & Chinellato, 2019; Gallese, 2000, 2007; Gallese & Sinigaglia, 2011; Jacob & Jeannerod, 2003; Jeannerod, 2006; Maranesi et al., 2014; Norman, 2002; Pezzulo et al., 2010; Rizzolatti & Matelli, 2003; Rizzolatti & Sinigaglia, 2008; Sakreida et al., 2016; Sim et al., 2015; Thill et al., 2013; Tillas et al., 2017; Turella & Lignau, 2014; Young, 2006; Zipoli Caiani & Ferretti, 2017; Zipoli Caiani, 2013, 2017, 2018). Not by chance, scholars have been looking for the neural mechanisms responsible for different kinds of affordance extraction within these neural networks (Sakreida et al., 2016; Borghi & Riggio, 2015; for a discussion, see Ferretti, 2021a).

In this framework, neuroscience has come to use the notion of affordance mostly to relate to representations in the brain that are action-oriented to the objects we perceive (for a review, see de Wit et al., 2017; Ferretti, 2021a). This is because affordances seem to be detected, for what concerns humans and other mammals, thanks to a neurocognitive component (Osiurak et al., 2017). And, indeed, different kinds of affordances seem to need specific forms of computational processing in distinct parts of the brain (Sakreida et al., 2016), especially when facing different affordances, depending on the context (Cisek, 2007, see also Cisek & Kalaska, 2010).[2]

These neuroscientific accounts have been giving "relevance to the interactions between the environment and the organisms as a whole, taking into account not only the dynamics of these interactions but also their neural representation: in this respect, this view departs from Gibson's externalist approach, as a famous quote clarifies: "Ask not what's inside your head, but what your head's inside of." Adopting this second view has led to an increased interest for the neural representation of affordances and has produced impressive behavioral and neural results in the last years" (Borghi & Riggio, 2015: p. 2).

[2] Interestingly, Cisek (2007) has proposed that the encoding of the multiple affordances elicited at the same time by one object is driven by a process which assigns an agent-relative hierarchy of values to the available affordances, in relation to the goal the agent wants to pursue. Processes occurring along a ventral visual pathway can thus fruitfully influence processes occurring in parallel along a dorsal visual pathway, shaping both the selection and encoding of sensorimotor patterns, as well as the related plans for action execution.

Let us take stock. So far, we have considered two apparently incompatible views about the notion of affordance. On the one hand, we have the *dispositional view*, according to which affordances born from the encounter between an animal and an environmental feature which, given the suitable ecological circumstances, let the affordance to actualize. On this view, the affordances are immediately perceived by an organism connected to the environment.

On the other hand, we have a view on *visuomotor-processing*, coming from *cognitive neuroscience*, according to which the animal needs a representational process capable of extracting the affordances from the environmental target, stressing the neurocognitive component of the perceiver for the affordance to be detected from environmental features.

How do we decide between these two views, one from *dispositional theories* and one from *cognitive neuroscience*? Are the *dispositional* story and the *neurocognitive*, *visuomotor-processing* story compatible? We'll argue that they are.

2.3 How many meanings for the notion of affordance, then?

It is clear that the notion of affordance represents a challenge. Leaving aside *philological reasons* concerning the original Gibsonian notion of affordance (Chemero, 2011; Chong & Proctor, 2020; Costall & Morris, 2015; Dotov et al., 2012; Ferretti, 2021a; Zipoli Caiani, 2013), it is interesting to understand how the dispositional account and the one provided from neuroscience are related for *epistemic reasons*.

This is interesting as different meanings of this notion can be awarded with explanatory success, though within different theoretical frameworks, in the light of our recent, deeper understanding of the visuomotor system. Importantly, using in one theory concepts not sufficiently defined, clearly analyzed or borrowed from another theory may be dangerous and generate confusion concerning the interpretation of experimental results building on such concepts. This is clear in the case of the notion of affordance (Ferretti, 2021a; Osiurak et al., 2017). To better appreciate the importance of clarifying how two different notions of affordance can coexist in the description and explanation of vision for action, it is important to keep in mind that this form of clarification is a problem common to other areas of science. Let us go slowly on this.

In the history of science, there are emblematic cases where the same term figures within different theoretical frameworks, with various meanings. One for all is the case of the term 'mass', which is ubiquitous within the many fields of contemporary physical sciences, although it acquires different connotations based on the type of phenomena to which it refers, and with respect to the different theoretical frameworks, and levels of description thereof, it appears in. Nowadays, there are at least three notions of mass at work in physics: a *newtonian* notion of mass, a *relativistic* notion of mass and a *quantum* notion of mass. Importantly, the only thing that is relevant for one of those notions to be part of a framework in physics is that it figures in the explanation of the relevant evidence. Accordingly, if more than one notion of mass figures in such explanations, we then have sufficient reasons for admitting more than one notion of mass to be part of physics.

As in the case of the notion of *mass*, here the notion of affordance, *as per* the possibility of action that is tracked by an animal, can be described under different frameworks, and with different levels of grain. Then, the only thing that is relevant for the notion of affordance to be part of cognitive science is that it figures in a respectable explanation of the relevant evidence. As a consequence of this assumption, if more than one notion of *affordance* is adopted to account for the relevant evidence (bear in mind the way the notion of mass is used, and the different conceptions on the notion of affordance), we then have good reasons for admitting more than one notion of affordance, and for one of those to be part of cognitive neuroscience. However, it must be noted that the notion of affordance was developed by Gibson precisely to avoid representationalist/computationalist views of perception. Thus, the appropriation of this notion in the case of cognitive neuroscience seems less innocent than the use of mass in the case of quantum mechanics.

Do we have such good reasons? Is more than one notion of affordance needed to account for the available evidence? What is such evidence, and how can the *dispositional view* coming from psychology and the *Visuomotor-Processing view* coming from *cognitive neuroscience* come together? These questions are essential to understand the value of the argument we propose.

This issue has never been tackled up to now, in these explicit terms, in the interdisciplinary debate on affordances. Let us briefly explore what is the challenge when trying to answer these questions. This will pave the way for developing our account.

2.4 The challenge

The *dispositional* story is, *prima facie*, hard to couple with the story about visuomotor processing from *cognitive neuroscience*. This is an interesting challenge for the literature. But we should not give up. For example, it has been proposed to conceptualize the neural activities of sensorimotor brain regions as *dispositional properties* whose actualization relates to opportunities for action, without involving representational functions for the neural system (de Witt et al., 2017): the mechanisms of the agent's sensorimotor system are the complement of the action-related properties of the environment.

Conceiving affordances as features coming from the interaction between an animal and an object, thanks to the encounter of the dispositional properties of objects, complemented with the activity of the animal sensorimotor brain areas, allows us to *extend* the use of this notion from psychology to cognitive neuroscience (Borghi & Riggio, 2015), while saving the original spirit which characterized the Gibsonian approach and that of his early fellows. In this picture, indeed, affordances are not reducible to any of these two single components: the environmental aspects as well as the animal nervous system are both contributing to the affordance. Indeed, meta-reviews have tried to map the neural regions at the basis of affordance detection with respect to the environment (Sakreida et al., 2016).

Thus, we think it is interesting to account for the dispositional notion of affordance in a way that complements these different stories with what neuroscience tells us about sensorimotor processing for affordance detection (de Wit et al., 2017; Ferretti, 2021a; Osiurak et al., 2017; Tillas et al., 2017; Zipoli Caiani, 2013).

In this paper, we propose a crucial step into this theoretical connection, by showing, for the first time, how these different *dispositional stories* can be complemented with different aspects of *visuomotor processing* in different motor contexts related to affordances. This new fully-fledged theory of affordance is crucial, as it suggests that we should not prefer one *dispositional* account at the expense of the other, by showing that different accounts can capture the plethora of complex manifestations, whether in covert or overt motor behavior, that affordances can display in humans, both in healthy and pathological conditions. This shows that different *dispositional* notions of affordance can figure in the same model, along with the results coming from the *cognitive neuroscience* of *visuomotor processing*, depending on the aspects of the visual guidance of action we are interested to explain. Our analysis provides a way to couple the *dispositional account* with the *Visuomotor-Processing* account coming from *neuroscience*. As the reader can appreciate, at this point, we are interested in dispositional accounts of affordances, as complemented with the visuomotor-processing account.[3]

Let's start with the dispositional view(s). Then we can show how the different dispositional accounts complement the evidence from neuroscience about the alleged visuomotor processing of affordance extraction.

3 A Distinction about the dispositional notion of affordance

Neo-Gibsonians suggested that affordances are *dispositional* properties of the environment with salience for specific motor behaviors, in a given environmental context, which can be complemented by specific properties of an organism, given its bodily morphology, its biological structure and its motor skills, as well as its perceptual capacities.

Since Gibson introduced the notion of affordance, two dispositional views with a common *desideratum* have emerged in the literature. We name them, respectively, the *necessity* view and the *conditional* view. Before offering our story on how these different dispositional accounts can fit the evidence from neuroscience, we need to say something about these views, to better understand the place of the present paper within the literature as a step further.

[3] We are then not focusing on others viable accounts in ecological psychology, such as *emergentism* (Stoffregen, 2000, 2003) and *relationism* (Chemero, 2011) and their respective differences. In this respect, note that some authors have been focusing on the general view of ecological psychology to be related with the activity of the brain. Indeed, specific attempts have tried to offer an ecological view of the brain (Favela, 2024), and an ecological theory of the cognitive resonance of the animal to its environment (Raja, 2018; see also Falandays et al., 2023; see also Michaels 2000; Crippen and Shulkin, 2020). It is interesting to note, however, that these important works do not focus, precisely, on the specific relation between dispositional accounts of affordances and neural visuomotor processing (especially in the light of the evidence we are discussing here). However, it would be interesting to clarify the relation between the notion of affordance mentioned in the neuroscience of visuomotor processing (cfr. the literature we discuss) and the dispositional accounts of affordances. For this reason, here we are focusing on the relation between the *dispositional* account of affordances and the specific evidence on visuomotor processing that is taken to be related to affordances in neuroscience.

Usually, dispositional properties are accounted for in terms of counterfactual conditionals, describing how things are *disposed* to behave, i.e., which behaviors they are *disposed* to display in certain circumstances. For example, an object O has the disposition D, given certain background circumstances C, if and only if O is the bearer of a given property T such that, if C were the case, and if O were to retain T for a sufficient time, C and T would then jointly lead O to actualize D. Dispositions can also be seen as law-like relational properties, which actualize when coming along with specific circumstances.

The ascription of a dispositional property to a given object O always involves the ascription of a *complementary* property to a situation S. Moreover, given specific circumstances, the actualization of a dispositional property always involves the manifestation of an event (e.g., the solution of the sugar in water or the passage of electricity through the copper). So, according to a dispositional theory, the perception of an affordance involves a *nomological* relation between certain properties of the agent's body and the relevant properties of the environment. This explains the agent's motor performance:

> *The Dispositional Notion of Affordance*: Visually guided behaviors are explained by the nomological relation between the dispositional properties of the relevant objects in the environment and the complementary properties of the agent's body, given certain background circumstances.

When conceiving affordances in terms of dispositions, there are two main theoretical options, which we discuss in what follows.

3.1 If suitable affording conditions occur, do it!

The first dispositional view, which we call the *Dispositional Account of Nomological Affordance Response*, has been introduced by Turvey (1992).

Following a famous neo-Gibsonian approach (Shaw et al., 1982), affordances are relational properties pertaining to a physical, material and concrete object that, given suitable background conditions, *necessarily* actualize in a given context, i.e., leading an organism, once the affordance is perceived, to act upon it accordingly. Importantly, the notion of necessity involved here is not in the metaphysical sense of 'true in all possible worlds', but in the nomological sense of 'true by virtue of a law of nature'. Therefore, when we refer to the execution of a behavior as a necessary event, this is considered in a nomological sense.

In addition to this, following Turvey et al. (1981), a given object O affords an activity A to a perceiving agent P, if and only if, given certain background circumstances, a certain property of O is complemented by a particular property of P, so that P executes an action on O (p. 261). Affordances are then dispositional properties concerning the potentialities of an object, with respect to an agent in a suitable circumstance. In formal words, given a system J(Op, Pq) composed by the things O (an object) and P (an organism), where p is a property of O and q is a property of P, p is an affordance of O and q an effectivity of P (i.e., a complementary property for p), if, and only if there is a third property r, the actualization of p, such that: (1) the system J(Op, Pq) possesses r; (2) J(Op, Pq) possesses neither p nor q; and (3) neither O nor P alone possesses r (Turvey, 1992, p. 180.)

According to this view, an affordance is a state of affairs which, given specific background conditions, has the *propensity to actualize* (Turvey, 1992, p. 179, cfr. footnote 3). This scenario is possible by following the general idea of *ecological laws* (Gibson, 1979; Turvey et al., 1981), according to which a one-to-one relation is needed for the light arrays to offer information concerning specific dispositional properties of objects in the environment; information which can be tracked by the perceptual system of the agent (Michaels & Carello, 1981; Shaw et al., 1982). Neo-Gibsonians have then postulated a *symmetry principle*: given the appropriate background circumstances, the tracking (or pickup) of specific perceptual patterns in the ambient array is both necessary and sufficient for the detection of an affordance in the environment in which the object offering it is detected (Turvey et al., 1981, 1999). According to this story, an affordance, which can be thought of an action-related dispositional property of the environment, is *univocally specified* starting from the peculiar structure of the perceptual stimulus: the detection of the stimulus equals to perceiving the affordance (for a complete overview, see Zipoli Caiani, 2013; Chemero, 2011).

An important clarification is that the notion of *necessity* here is not a *modal notion*, but instead it captures the *nomological aspect* of motor behavior related to the laws governing this phenomenon. Such laws are not like the laws of physics, but ecological, and concern highly context specific scenarios of animal-object interaction. If there are suitable conditions for which the affordance can pop out from the environment, given the encounter between a given animal and a specific environmental condition, the affordance will actualize, according to the related ecological law. What we cash out from this dispositional story about affordances is that:

> *Dispositional Account of Nomological Affordance Response*. Given a system composed by both the affordance and the related effectivity, if the appropriate background circumstances are met, the affordance will then necessarily actualize, according to the ecological law.

But this is not the whole story, as we have a second, more flexible dispositional account. In the next section, we will examine this account.

3.2 If suitable affording conditions occur, you may do it

Scarantino (2003) suggested an alternative account, which we call the *Dispositional Account of Probable Affordance Response*. In this view, affordances can be described in relation to the *probability* of the manifestation of a given action. This probabilistic dispositional definition of affordances suggests that "if is it true that, given background circumstances C, an organism O can at t engage in an event that qualifies as a doing or a happening M and involves X, then X is, at t, an affordance bearer with manifestation relative to O in circumstances C" (Scarantino, 2003, p. 958). Thus, provided a suitable ecological context, if an organism interacts with an object with a specific positive probability p, the object can then be considered the bearer of a dispositional property with respect to that specific organism and the related motor performance (Scarantino, 2003, pp. 956, 959–960).

For Scarantino, as for Turvey, affordances are specific properties of the objects in the environment, which can be complemented by specific properties of an organism. However, Scarantino conceives affordances in relation to a *positive probability*, rather than the *causal propensity to actualize*, within a context in which suitable circumstances occur[4]:

> *Dispositional Account of Probable Affordance Response*. Given a system composed by both the affordance and the related effectivity, if the appropriate background circumstances are met, the affordance may actualize with a probability greater than zero.

So, the two dispositional accounts differ in the way they conceive the actualization of the affordance by means of a motor act, as the agent is in front of an object that offers the affordance, and the other suitable conditions are met.

There is an important point here. On the one hand, the *probabilistic view* may be considered as controversial in the literature on affordances, *as per* the relation between perception and action. On the other, some researchers have suggested that we need to model the way in which organisms do not always respond to affordances when they're available, while sometimes they must respond. In this framework, there is a co-influence between the agent and the environment, which can be always modulated with respect to the strength of the call for action and the related response. Thus, affordances are seen as *invitations* to action. For this reason, agents can select a given affordance among many others, and act upon it, but also resist to an affordance. This means that, while affordances are given by the agent-environment coupling, they are not always satisfied, i.e., responded to. This suggests the variety in affordance responses, or lack thereof (for this interesting perspective, see Withagen et al., 2012, 2017). This is in line with what we have been saying up to now about the different affordance responses.

Now, we want to propose, for the first time, that we should not select just one dispositional account and give up the other, for they both have important explanatory power, as they lead to capture different aspects of the evidence concerning the relation between the visuomotor processing of actions and the properties of the environment, in the affordance relation.

4 How the dispositional account and the visuomotor-processing account can be complemented

We now show how these two *dispositional accounts* capture different aspects of visuomotor responses. The *Dispositional Account of Probable Affordance Response* captures what happens in the case of healthy individuals whose overt action is best understood in terms of probability of manifestation (§4.1). The *Dispositional Account*

[4] There can be more than one affordance in the same visual scenario (cfr. footnote 2). The selection of one affordance at the expense of the others may depend on different contextual factors we do not discuss here (Ferretti, 2016a, 2016b, 2016c; Rietveld & Kiverstein, 2014). Our account focuses on when the affordance selected may be satisfied from the visuomotor system.

of Nomological Affordance Response captures what happens in the case of automatic motor simulation and covert mental action in healthy individuals (§4.2), as well as of pathological overt action tendencies in patients with *Utilization Behavior*, *Magnetic Apraxia* and *Alien Hand Syndrome* (§4.3).

Before providing the details, just to explicit our position, the possibility or the necessity of the affordance response does not merely capture (only) a brain condition, according to our view. Rather, it models the way agency, overall, works in different contexts (of course, also considering the brain mechanisms thanks to which this is possible), with respect to the encounter between an agent and a target in the environment.

In healthy subjects, the capacity of generating a suitable action performance relies on the possibility of having a motor simulation that triggers the relevant areas of the brain, which consequently allows them to give rise, in case needed, to motor performance (*overt* motor action).

In this case, the automatic response that happens whenever the subject's visuomotor system spots an affordance is modeled, with respect to *covert motor aspects of agency*, under a *Dispositional Account of Nomological Affordance Response*: the visuomotor system *systematically* and *automatically* triggers the cortical areas involved in planning and executing the act to be used. This is at the basis, from a computational point of view, of the possibility of building the correct motor act we may use in motor interaction, given the detection of a certain affordance. *Overt motor execution* follows *covert motor simulation* (but not vice versa). This is a classic and crucial point in motor neuroscience (Jeannerod, 2006).

But, in this respect, given that, from this *covert representation* of the motor act via simulation, the *overt execution* of the motor act does not necessarily follow every time the subject spots an affordance (as said a few lines above), we need a *Dispositional Account of Probable Affordance Response*, to model this *overt motor aspect of agency*.

Differently, in the case of pathological aspects, the *covert simulation* of action will always be followed by the corresponding *overt motor* action execution. This can be captured by the *Dispositional Account of Nomological Affordance Response*.

Thus, the two dispositional accounts do not capture different brain states, but different conditions under which *covert* and *overt*, as well as *necessary* and *potential* aspects of action on affordances work, with respect to the characteristics of the agent.

Of course, in any case, there will be a brain counterpart in the response to the affordance, that is, a role for the brain in the visuomotor processing of the affordance. This processing is responsible for whether *overt action* execution will take place in the case of an affordance. However, this aspect, captured by the *visuomotor-processing* account, is not what the complementation we propose here should be reduced to.

Indeed, the *Dispositional Account of Nomological Affordance Response* is efficient in modeling what happens in *healthy* conditions of *covert action* representation, but also in *pathological* conditions of *overt agency*, with affordances. Thus, it's efficient on different levels of descriptions of agency (either healthy neural responses only, or pathological neural responses plus pathological action execution). The *Dispositional Account of Probable Affordance Response* is efficient in modeling what happens in healthy conditions of *overt agency* (healthy action execution, on top of healthy neural responses, modeled by the other account).

Furthermore, exactly for this reason, the merit of our article is to show that the *Dispositional Account of Nomological Affordance Response* and the *Dispositional Account of Probable Affordance Response* are not mutually exclusive, but each of them can be used to describe some conditions in cases concerning, respectively, subjects with specific pathologies of the visuomotor system and healthy subjects. Thus, and this is one important benefit of our account, we do not need to select one at the expense of the other. Indeed, both can be complemented with different aspects of *visuomotor processing* discussed in neuroscience. Let's see how, in details.

4.1 I may do it. The dispositional account of probable affordance response and overt action performance

We show here that The *Dispositional Account of Probable Affordance Response* captures what usually happens in the case of overt action performance in healthy individuals.

Usually, agents can confront with many aspects of affordances. First of all, the perception of an affordance depends on the correct functioning of the visual apparatus of the individual. But it also depends on the motor responses used to interact with the object source of the visual stimulus. This, in turn, depends on the structure of the body of the individual, as well as on her motor skills (Chemero, 2011). And we also need to consider which portions of the visual array the individual is paying attention to, and whether one is focusing on the functional meaning of the visual target (Zipoli Caiani & Ferretti, 2017).

Over the decades, research on dynamical learning systems has shown how an agent, equipped with a body suited for probing the environment, can obtain specific sensitivity to action-related properties through plastic adaption (Haken et al., 1985; Lopresti-Goodman et al., 2011; Szokolszky et al., 2019; Thelen & Smith, 1996). According to this view, visual perception is sensitive to particular visual aspects of the world, which can display a motoric salience, as a result of a history of visuomotor interaction with the objects that populate the visual environment, so that specific regularities have emerged over time (Bruineberg & Rietveld, 2014; Rietveld & Kiverstein, 2014).

However, these regularities do not necessarily entail the actualization of the affordance-related behavior. An individual may spot the possibility for action offered by an object, but action is then conditional on several aspects. Of course, the most crucial one is the intention, ruling whether the motor act for the affordance relation to take place will be executed. One may spot the possibility of grasping the handle of a mug. But whether one does it or not depends on whether one intends to do it. Even if one detects the affordance, and has the motor expertise to do what it takes to actualize it, the motor act will not necessarily take place.

So, the *Dispositional Account of Probable Affordance Response* perfectly captures the fact that, in these cases, the visuomotor expertise capable of satisfying an affordance may or may not actualize, depending on the context: there is a probability greater than 0, based on the agent's decisions and intentions.

So far so good. But the visuomotor expertise based on past experiences of motoric interaction with the environment can be accounted also (but not only) by mentioning how our brain has built the visuomotor network leading vision to detect affordances in the environment and how it has stored information about them in the visuomotor memory. To describe these processes in a dispositional framework, we need the *Dispositional Account of Nomological Affordance Response*.

4.2 I can do it. The dispositional account of nomological affordance response, motor simulation and covert mental action

Here we suggest that the *Dispositional Account of Nomological Affordance Response* captures what happens with motor simulation in covert mental action in healthy individuals, which is at the basis of accurate, overt performance, described in the previous section. Let's start from the basis.

In healthy individuals, the possibility of overt action performance depends on the motor preparation that lurks behind the expressed motor behavior. Activities of the visual and motor regions of the brain, which mediate between sensory inputs and motor outputs, give raise to visuomotor processing that elaborates the parameters of an action with respect to the salient motor properties detected in the environment—properties the detection of which is crucial for the performance of an action. These visuomotor activities, thus, permit to actualize an affordance, by converting the visual stimulus into a motor command, i.e., by generating an action that can be used upon the visual target.

In particular, a visual object rich of possibilities of action causes specific regions of the neural system to be differentially activated in accordance with their functional associations, to recall the information of suitable movements in the visuomotor context (de Wit et al., 2017; Rietveld & Kiverstein, 2014), so that the final behavior of the organism in this situation will be ultimately determined by the competition among the activity of these regions (Cisek, 2007; Cisek & Kalaska, 2010; de Wit et al., 2017).

Interestingly, this neural activity can be conceived as a motor *simulation* triggered by a visual stimulus (Gallese & Sinigaglia, 2011; Jeannerod, 2006). We refer to this phenomenon in terms of 'simulation', as it is the most widespread jargon in the literature. Importantly, the competition among the simulation activities of the visually elicited motor regions can be conceived as a *covert competition* between different neural activities that are correlated with the motor acts suitable to satisfy an affordance in the environment. At the end of the process, the dominant activity will eventually satisfy the selected possibility of action by activating the overt motor execution of the related behavior (if other suitable background circumstances are met).

This competition between the simulation activity of the motor regions and the related affordance perception are taken to depend on the processing of different portions of our visuomotor system. Let us explain this mechanism.

First off, the automatic visuomotor transformation of visual stimuli into motor actions, via motor simulation, relies on the functioning of the dorsal stream, more specifically, of a defined parieto-premotor network lying in between the parietal cortex and the ventral premotor cortex (Borghi & Riggio, 2015; Chinellato & del Pobil, 2016; Ferretti, 2016a, 2016b, 2021a; Rizzolatti et al., 1988). A portion of the dorsal stream, the ventro-dorsal sub-stream (V–D), whose main components for these tasks are the anterior intraparietal (AIP) area and F5 (in the most rostral part of the ventral premotor cortex), permit the transition from the perception of (dispositional) action properties to the related motor acts (Ibid.). The functioning of these areas is the heart of the so-called dorsal visuo*motor path*.

The AIP is one of the end-stage areas of the dorsal stream (see Culham et al., 2006). AIP neurons respond selectively to targets during both passive observation and grasping actions, extracting visual information about action possibilities for grasping responses (Borra et al., 2008; Raos et al., 2006; Romero et al., 2014). F5 visuomotor *canonical* neurons make use of the information obtained from AIP about action properties of the objects to generate the motor commands for suitable interaction. Canonical neurons also fire during object fixation, regardless that execution of action will follow. They display a deep connection between their peculiar selectivity for a specific kind of grip (executed grip) and the visual selectivity for targets that, even if different in shape, require this grip to be grasped (Raos et al., 2006).

AIP-F5 is then considered the heart of affordance visuomotor extraction (Ferretti, 2016a, 2016b, 2021a; Raos et al., 2006; Romero et al., 2014; Zipoli Caiani, 2013): the motor response is part of the visual encoding, so much that this is a form of motor perception (Fadiga et al., 2000).

Several converging sets of evidence all point to this alleged role for this neural network to translate object spatial features into motor commands, *ipso facto* being responsible for detecting affordances and computing the motor acts that can suitably satisfy them (Sakreida et al., 2016; Borghi & Riggio, 2015; Ferretti, 2016a, 2016b, 2021a; Zipoli Caiani & Ferretti, 2017; Zipoli Caiani, 2013; Tillas et al., 2017; Chinellato & del Pobil, 2016; Jeannerod, 2006; Jacob & Jeannerod, 2003; Turella & Lignau, 2014; Fadiga et al., 2000; Thill et al., 2013; Anelli et al., 2012; Borghi et al., 2012; Cisek, 2007; Cisek & Kalaska, 2010; Costantini et al., 2010, 2011; Maranesi et al., 2014; Pezzulo et al., 2010; Young, 2006; Castiello, 2005; Castiello & Begliomini, 2008; Norman, 2002). (Several pieces of evidence have found similarities, in humans and monkeys, with respect to the organization of these cortical sites, as these references show).

But this is not the whole story. This visuomotor response is linked to a motor simulation, as a neural rehearsal in the ventro-dorsal stream and connected premotor areas, that is, a neurophysiological simulation of the mechanisms involved in real action generation (Jeannerod, 2006), of the specific motor commands at the basis of the motor acts able to actualize an action possibility related to the object, in order to give raise to automatic, suitable interaction with it, if other background conditions are given.

Motor activation, in this case, is automatic and highly specific to the action that is rehearsed, in relation to the visual target, involving the main neural structures used in action execution. So, when action possibilities are visually detected, a specific series of motor functions is activated by means of a simulated potential action (though it can immediately decay when the action is not performed) (Gallese, 2000, 2007).

The mechanism of *simulation* is, thus, specifically related to the one of *visuomotor transformation*. During the visuomotor translation, as a visual stimulus is presented, it directly triggers the simulation of the related motor act which, regardless of whether the action is executed, translates the visual stimulus into motor coordinates.

Thus, overt action execution is always preceded by covert visuomotor response and simulation, while covert visuomotor response and simulation are not always followed by overt execution (a sort of golden rule in motor neuroscience; for critical discussion, see Jeannerod 2006). Indeed, each of our motor performances is preceded by a triggered simulation of the motor act suitable for the potential motor context given at that specific time and with very specific motor requirements (kinematic, biomechanical, among other aspects) concerning the visual stimulus.

Importantly, *visuomotor transformation* and *motor simulation* are crucially related to a third specific process. Most of the neurons in F5 (and in the homologue area in the human brain, Ferri et al., 2015) are not functionally related to mere *elementary movements* (e.g. flexing an arm), but to complex *motor acts* (e.g. coordinated movements with specific goals: extending an arm in a selected direction to reach and catch a glass, Rizzolatti & Sinigaglia, 2008; Gallese & Metzinger, 2003; Chinellato & del Pobil, 2016; Ferri et al., 2015). There are, thus, as different groups of neurons in F5 as different actions is the agent capable of performing: hand-grasping neurons, grasping-with-the-mouth neurons, etc. This happens because, during the ontogenetic development, based on our experience, the neural populations, within F5, connected to the most important motor acts, are selected and remain stable for future employment. This grants appropriate motor response to a given affordance.

All this suggests that, when one intends to act, thanks to the visuomotor transformation and the motor simulation, the activity of the neural motor system is functionally coupled with the relevant *dispositional* properties of the environment that are needed to build the motor act in a successful way.[5] At this point, it is easy to realize why this is relevant for our claim on The *Dispositional Account of Nomological Affordance Response*.

The *Dispositional Account of Probable Affordance Response* captures what happens in the case of overt action performance in healthy individuals that can control the execution of their actions according to their intentions. But the possibility of overt action performance, captured by that *account*, depends on the covert activity of the cortical areas, illustrated in this section, responsible for motor preparation that lurks behind the expressed overt motor behavior.

These functions are perfectly captured by the description offered by the *Dispositional Account of Nomological Affordance Response*. Recall that this *account* says that, given a system composed by both the affordance and the related effectivity, the affordance will necessarily actualize (§4.1).

In line with the *dispositional view*, there must be certain environmental conditions, e.g., (i) a given object for which the agent possesses the motor expertise to interact with, (ii) a neural representation of this motor interaction that can be triggered during motor simulation, and finally, (iii) the perceptual state solicited as to let the object trigger the motor simulation to be tracked in the environment. These are all crucial aspects granting the necessity, in the sense of motor simulation, in dispositional terms.

[5] We are focusing on a general neural mechanism for affordance detection. However, different portions of the brain encode different aspects of affordance perception. But all these mechanisms display similar characteristics concerning response for motor simulation. So, all we are saying here about how these neural responses work can be said of most of other affordance related neural mechanisms (Borghi & Riggio, 2015; Ferretti, 2021a; Sakreida et al., 2016).

Things being so, the *Dispositional Account of Nomological Affordance Response* captures what happens behind the *Dispositional Account of Probable Affordance Response*. When a dispositional property of an object meets a subject with a given visuomotor expertise, the visuomotor brain will trigger the activation of the motor action which may be used to act upon the object, according to a nomological relation.

So, in these cases, given a system composed by both the affordance and the related effectivity, then the (covert motor neurophysiological simulation involved in real action generation related to the) affordance will necessarily actualize (in a nomological sense).

Summing up, healthy individuals have at their disposal correct motor behaviors that lead to the potential scenarios described by the *Dispositional Account of Probable Affordance Response*, simply because they can rely on the functioning of the specific areas of the visuomotor system that can be coupled with the affordances of the environment, captured by the *Dispositional Account of Nomological Affordance Response*.

That said, any description on correct functional behavior must also account for cases in which such behavior is dysfunctional, or pathologic.

We now show that the *Dispositional Account of Nomological Affordance Response*, while not capturing what happens in the case of healthy individuals in overt motor behavior, as the *Dispositional Account of Probable Affordance Response* does, nonetheless captures what happens in the case of overt action of patients with *Utilization Behavior*, *Magnetic Apraxia* and *Alien Hand Syndrome*. In these pathological scenarios, there is no dissociation between covert motor simulation and consequent overt action performance, as the systematic response to an affordance is not only concerning the covert motor preparation in the brain, but also the overt interaction with the object.[6]

4.3 I must do it. The dispositional account of nomological affordance response meets utilization behavior, magnetic apraxia and alien hand syndrome

The *Dispositional Account of Nomological Affordance Response* is not exhausted by the case of motor simulation in covert action, but it also captures the pathological action tendencies concerning overt action performance of individuals suffering from similar disorders, such as *Utilization Behavior*, *Magnetic Apraxia* and *Alien Hand Syndrome*. Let us briefly discuss them to show how this account can describe what happens in their case.

(1) Utilization Behavior

Here is a definition of this pathological behavior: "Utilization behavior is the act of grasping or using objects that are within reach or in the field of vision. While objects may be used correctly, the behavior occurs in a context that is inappropriate. For

[6] It is important to mention that, in some cases, we can also imagine which action we could perform upon a given object (Ferretti, 2019), without performing it. In this case, we could select the *Dispositional Account of Probable Affordance Response* or the *Dispositional Account of Nomological Affordance Response* based on the different circumstances.

example, when shown a pair of glasses, a patient is likely to put on the glasses" (Price & Libon, 2011, p. 2579).

This neurobehavioral disorder forces the subject to perform an action upon objects that offer an affordance. Though the motor command is proper, the motor response is generated in an inappropriate scenario (see also Price & Libon, 2011; see also Eslinger, 2002; Ishihara et al., 2012; Archibald et al., 2001).

In other words, patients suffering from this disease have difficulty in resisting the impulse to act on objects for which they can visually process affordances: their behaviors are immediately triggered by the action-related properties of the environment.

Interestingly, patients affected by *Utilization Behavior* do not find any divergence between their intentions and the unpreventable execution of the related actions, so they will claim that they wanted to perform the action (Iaccarino et al., 2014, p.1).

However, note that saying that patients with *utilization behavior* will *automatically select and respond to an* affordance does not entail that they will *necessarily select and respond to all* affordances detected in the environment. Even here context is crucial: for any given object, there are many affordances that the patient will probably not perform (e.g., throwing a pen instead of placing it). The selection of a given affordance will depend on the motor expertise, the attentional resources, and the way the scene is perceived by the subject, as well as on the detectable semantic properties of the affordance (Borghi & Riggio, 2015; Cisek, 2007; Cisek & Kalaska, 2010), and, of course, on the orientation of the pathology within the individual character trait of the subject, as the literature shows (for different angles, see Price & Libon, 2011; see also Eslinger, 2002; Ishihara et al., 2012; Archibald et al., 2001).

In this case, all the visuomotor mechanisms triggered in the sensorimotor networks described above are in play. However, as said, in normal circumstances, motor simulation and visuomotor transformation at the basis of motor preparation in *covert* action representation (triggered without any intention to act) should not be always followed by *overt* action execution (Ferretti, 2016b; Jacob & Jeannerod, 2003; Jeannerod, 2006). Indeed, and this complements the story we offered above, several inhibitory mechanisms (located in different cortical networks) should usually prevent the subject from acting, when there is no need to act (Algom et al., 2004; Anelli et al., 2012; Borghi & Riggio, 2015; Caligiore et al., 2013; Ferretti, 2016b; Munakata et al., 2011). In the case of *Utilization Behavior*, these mechanisms are not in play, due to malfunction of the neural correlates responsible for them, such as different areas of the prefrontal and frontal cortex (Archibald et al., 2001; Eslinger, 2002; Ishihara et al., 2012). Indeed, prefrontal responses usually are responsible of actualizing or inhibiting the motor programs computed in the parietal and motor cortex. But this communication is impaired in utilization behavior.

(2) Magnetic Apraxia

Another interesting disorder to consider here is that of *Magnetic Apraxia*, i.e., "The compulsive tactile exploration and object grasping which often occurs in the contralesional hand after left or right frontal lobe damage is called Magnetic Apraxia (...). In this condition, the mere visual presence of an object near the hand (or touching the hand) triggers groping movements as well as grasping. In spite of the fact that these movements appear to be goal directed, they are totally involuntary and the patient is not able to inhibit the behavior of the hand. Magnetic Apraxia is often associated with grasping, an inability to release the grip (Forced grasping response) and groping (i.e., movements toward a stimulus based on the mere proximity of the stimulus and not triggered by tactile stimulation). In addition, utilization behavior (i.e., involuntary and inappropriate use of objects) and the compulsive involuntary manipulation of tools may be present" (Canzano et al., 2016, p. 6).

Differently from patients affected by *Utilization Behavior*, which are not aware of any disjunction between the non-requested motor act and the response to an affordance they spot, patients displaying *Magnetic Apraxia* may sometimes recognize that the motoric response is not appropriate to the context (but the debate is open in the literature). Nonetheless, they cannot stop the action to be triggered and unfold. That is, in both cases, there is involuntary response to an affordance. However, while the former patients will, as we have seen, report their intention to satisfy the affordance, the latter patients are aware they cannot stop this action they are aware of to be improper (also due to some problems in the process of inhibiting affordance responses, above described).[7]

"*Magnetic*" here gives a clue of the *necessary* and *automatic* response from the subject. There is here "an inability to inhibit involuntary actions and the exacerbation of automatic responses. The result is a dysfunctional use of objects" (Ibid.).

As in the case of *Utilization Behavior*, the *selection of an automatic response to* a given affordance with respect to a specific object may vary with respect to the motor context and the skills of the agent (as well as with respect to the comorbidity of other disorders this impairment can correlate with).

And, as for *Utilization Behavior*, the problem here is located at the level of the frontal processing concerning the inhibition of motor responses toward objects offering grasping affordances (Canzano et al., 2016; Denny-Brown, 1958; Moro et al., 2015).

(3) Alien hand syndrome

Another related phenomenon worth mentioning is that of the *Alien Hand Syndrome*. Following Goldberg and Goodwin (2017), "The core observation is the patient report that one of his/her hands is displaying purposeful, coordinated, and goal-directed behavior over which the patient feels he/she has no voluntary control. The patient fails to recognize the action of one of his hands as his own. The hand, effectively, appears to manifest a "will of its own." This unique involuntary movement disorder is characterized by coordinated, well-organized, and clearly goal-directed limb movements that would otherwise be indistinguishable from normal voluntary movement" (p. 84).

Now, this is a relatively rare disease in which, differently from *Utilization Behavior*, and similarly to *Magnetic Apraxia*, the patient reports a discrepancy between her intentions and what seem to be goal-oriented movements of her hand, on top of the fact that also the ownership of the action seems to be lost (see also Espinosa et al., 2006; McBride et al., 2013).

With respect to the other impairments, it is possible to postulate here that much more attention is devoted to the hand per se, so that the subject is more aware, surely

[7] This can correlate with *Utilization Behavior*, indeed, and so they are not the same disorder. As already quoted: "In addition, utilization behavior (i.e., involuntary and inappropriate use of objects) and the compulsive involuntary manipulation of tools may be present" (Canzano et al., 2016, p. 6).

compared to *Utilization Behavior*, that her *overall* will to (not) satisfy a given affordance does not match the specific overt motor behavior of her hand, precisely, the hand afflicted by the syndrome.

And, even here, the *automatic and necessary selection and response* of the hand to a given affordance, with respect to another, may sometimes vary in relation to the motor context.

Even in this case, as for *Utilization Behavior* and *Magnetic Apraxia*, there may be problems with different stages of the frontal processing responsible for inhibiting the responses of the motor system, in terms of action execution, to visually detected affordances (for different impairments to different portions of the frontal lobe, with respect to different manifestations, see Goldberg and Goodwin 2017; Abolitz et al., 2003; Assal et al., 2007; Biran et al., 2006; Espinosa et al., 2006).

(4) Utilization behavior, magnetic apraxia, alien hand syndrome and affordances

These disorders in overt motor behavior are very complex, and a review that can coherently describe their differences and similarities (in terms of both behavior and neural underpinnings) is hard to offer, even in neurological research (Abolitz et al., 2003; Canzano et al., 2016).

This counts also for determining how these disorders afflict, in addition to the frontal portions of the brain involved in inhibition, also the sensory side or the motor side of the *visuomotor processing* and *simulation*, within parietal and motor sites, during the motoric responses to visually represented objects. Indeed, as there can be distinct visual stages (the pieces of processing detecting the spatial features of the object) and motor stages (the pieces of processing encoding motor commands suitable to manipulate these spatial features) (Borghi & Riggio, 2015; Chinellato & del Pobil, 2016; Ferretti, 2016b), there can also be different impairments on these different stages (Canzano et al., 2016; Jacob & Jeannerod, 2003), though we are talking about visuo-motor responses (Fadiga et al., 2000).

That said, as the reader can clearly note, the *Dispositional Account of Nomological Affordance Response* successfully captures what happens in pathological cases of *Utilization Behavior*, *Alien Hand Syndrome*, and *Magnetic Apraxia*.

Indeed, this account captures not only the *covert* component of the action, which these patients share with healthy individuals, but also the *pathologic automatic and overt* component related to action execution triggered by the presence of action-related properties of the environment, which *the subject is forced to interact with* (though in different manners and for different reasons). In these cases, very similar (admitting all the slight differences), the *Dispositional Account of Nomological Affordance Response* can perfectly model what's happening.

When a subject S (with a given impairment of the kind above described) will face an object O, the call to action from the object, on the basis of an affordance detected, will lead to *automatically and necessarily* trigger not only the motor simulation of a suitable motor response, which nonetheless remains at the level of *covert* action representation, as with healthy subjects, but also the *overt execution* of the motor action, differently with respect to healthy subjects. The affordance will *necessarily* be satisfied, even if the motor response is inappropriate or unwanted.

That said, there are two crucial specifications here. First, in line with the *dispositional view*, there are of course highly context dependent aspects that must be in play in order for this behavior to actualize. A certain brain disorder, prone to give rise to a motor execution, with respect to a certain perceptual state, must be settled in an environment that presents specific objects, capable of triggering the exact behavioral dispositions resulting from this disorder. These are all crucial aspects granting the *nomological necessity*, in the sense of pathological motor behaviors, in dispositional terms.

Second, note that '*inappropriate*' here does not mean that the motor act is not a correct one, in motor terms, for the purpose of satisfying the given affordance. This only means that it satisfies a given affordance, in proper motor terms, indeed, which is nonetheless detected in a context in which this satisfaction is not requested. For example, an apple is properly grasped with a power grip, relying on the opening of the whole hand. However, there was no need to perform such an action. Whether or not the patients are aware of this, a response is solicited.

Then, the description of the impairment at the level of *visuomotor processing* meets the description given from a *dispositional account*, in a pathological scenario. The *covert* mechanisms of affordance extraction and satisfaction, as well as the related *overt* visuomotor behavior, are triggered even when there is no actual need for the action satisfying the affordance to take place.

At this point, the reader may appreciate how the context is crucial for both the *dispositional account* and the *visuomotor processing* account, as well as for their relation, in this framework.

First, the *dispositional account* is related to the context as, for the perception of an affordance to give rise to the execution of an appropriate motor act, certain circumstances must occur. It is precisely the definition of these circumstances that allows us to establish the appropriateness of the performed act. These circumstances may concern the bodily properties of the subject, the characteristics of its relevant effectors, but also aspects of the environment, including the socio-cultural one. Whether the subject is healthy or not, and whether action performance is covert or overt, will be a crucial aspect of the motor context we are analyzing. This will be important to select one *dispositional account* over the other, in the description of a specific affordance behavior.

Second, also the *visuomotor-processing account* is related to the context. The motor context in which the subject is embedded will determine the way in which we may assume that a given motor response, provided by the *visuomotor-processing account*, whether covert or overt, is appropriate to the stimulus or not, healthy or not, with respect to the object (or the objects) the subject is dealing with.

Of course, the *level of description* of the affordance response, in relation to the *visuomotor processing* we are focusing on, will be another crucial aspect related to the context. Looking at brain activations for covert motor response, and looking at overt motor behavior will guide our selection of a dispositional account at the expense of the other.

Finally, all these context-dependent ingredients above mentioned, together, will determine which *dispositional account* we may want to select in relation to the specific form of *visuomotor processing* analyzed, in order to better describe the affordance within a given organism-environment interaction (whether healthy or pathological, proper or improper, overt or covert).

A conclusive important remark is that all these pathological responses to affordances concern the so-called *canonical* affordances, i.e., responses to canonical uses of objects (e.g., sitting for a chair, grasping for a mug) (for discussion, see Costall, 2012; Chong & Proctor, 2020; Norman, 1999, 2002). This is not a problem. Here we are interested in the way the brain responds to affordances, and the fact that these examples are about canonical affordances is not problematic, and indeed offers an important source of analysis. Most of the time, we are dealing with objects and artifacts displaying canonical uses. Thus, investigating the relation between the different *dispositional* accounts and the various forms of *visuomotor-processing*, with respect to canonical affordances, still offers a valuable contribution (in accordance with the literature, above mentioned, on pathological responses, in case of tools; cfr. Canzano et al. 2016).

5 Conclusion

In this paper, we distinguished between the explanatory competences of the two main versions of the *dispositional account of affordances*, with respect to the *Visuomotor-Processing* account on affordances advocated in cognitive neuroscience.

We have shown that, though the *Dispositional Account of Probable Affordance Response* captures the most common behavioral manifestations of affordance-related phenomena in healthy subjects, the *Dispositional Account of Nomological Affordance Response* is suitable to account for two other very important facts concerning visually guided behaviors. In particular, it accounts for the phenomenon of covert motor simulation in healthy individuals, as well as for the unpreventable pathological behaviors of patients suffering from *Utilization Behavior*, *Magnetic Apraxia* and *Alien Hand Syndrome*.

So, the *Dispositional Account of Nomological Affordance Response* and the *Dispositional Account of Probable Affordance Response* fit the overall description of affordance related behavior: in the case of *covert* motor simulation in healthy subjects, the presence of a dispositional affordance in the visual environment will necessarily elicit, in the agent, the activity of those motor areas that are functionally related to the execution of the action that complement that affordance, as captured by the *Dispositional Account of Nomological Affordance Response*. In this case, however, the *overt* action may also be not executed. It is only probable, as stated by the *Dispositional Account of Probable Affordance Response*.

Differently, in the case of *Utilization Behavior*, *Magnetic Apraxia* and *Alien Hand Syndrome*, the presence of a dispositional affordance in the visual environment will lead to both the *covert* motor simulation of the complementary action, and the *overt* execution of that action, in line with the *Dispositional Account of Nomological Affordance Response*.[8]

[8] These pathologic motor behaviors are on the opposite with respect to the affordance (non-)behaviors displayed by some peculiar patients affected from schizophrenia, whereas there is no form of automatic visuo-motor simulation (Sevos et al., 2013), and for which neither the *Dispositional Account of Nomological Affordance Response*, nor the *Dispositional Account of Probable Affordance Response* would directly have

Summing up, we have shown, for the first time, how different *dispositional* theories of affordance should not compete to be the unique theoretical tool we consider. And they should not compete with these accounts explaining how affordances are processed by our visuomotor brain, following the evidence from neuroscience. We should, instead, use these different accounts, together, to describe different but related and crucial aspects of action on affordances, concerning overt motor execution, its mental covert counterpart given by preparation through simulation, and its degeneration in case of brain diseases.

To conclude, we aim to clarify that we do not intend to argue that some versions of the dispositional approach to affordances can be replaced by, or be reduced to the mechanistic description provided by neuroscience (or vice versa).

Differently, our argument aims to show that the *dispositional* approaches and the *neurocognitive* approach can describe, from different points of view, and with different methodological assumptions, the same evidence available in the literature, so much that they can be complemented within the same story, and offer some benefits to the researcher interested in a multi-layered description of affordances.

This is something enormously beneficial for the interdisciplinary literature to meet at a theoretical crossroad that is supported by the several sets of evidence.

Importantly, indeed, in the case of dispositional approaches, the evidence is explained without referring to computational mechanisms, as instead happens in the neurocognitive approach, which nonetheless does not make a clear distinction between the different dispositions, especially concerning these cases we consider here. We hope this new account will open to new possibilities in future research.

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Declarations

Conflict of interest All authors declares that they have no conflict of interest to disclose.

Footnote 8 continued
something to say, as no covert motoric response is elicited. A similar case would be the one of affordance response in depression, where the potential call to action does not solicit any strong overt response from the subject (de Haan et al. 2013, 2015). Note that, instead, our account can also model other pathological behaviors, such as obsessive-compulsive-disorder, in which the patient obsessively, necessarily responds just to some call for actions, related to her obsession, but not to others, which are, motorically speaking, equally available (Ibid.). The focus on this complex scenario of mental disorder may have to wait another occasion to be discussed.

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