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Silvano Zipoli Caiani
University of Milan, Italy

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SILVANO ZIPOLI CAIANI
University of Milan

FRAMING VISUAL PERCEPTION IN TERMS OF SENSORIMOTOR MAPPING

ABSTRACT: Two contrasting theories, or variants of them, are predominant in the current debate on visual cognition. The standard *inferential theory* sees perception as a process involving the role of memory, past experiences and semantic abilities, whereas the *direct theory* sees perception as a connection between the perceiver and the environment that does not recruit internal information processing. In particular, the direct theory has recently been invoked because it would be able to explain the sensorimotor coupling of perception and action in humans and animals without relying on controversial notions such as those of conceptualization and propositional information. This paper aims to show that even an inferential theory of perception has enough resources to account for sensorimotor processes without necessarily involving high level cognitive functions. My claim is that there are genuine instances of sensorimotor inferential processing that do not rely on conceptual structures and propositional knowledge. Several theoretical and empirical arguments are provided to support this statement.

1. INTRODUCTION

Our everyday life rests on the assumption that perception keeps us in contact with the world. But what does it mean to be in perceptual contact with something? Two contrasting accounts of visual perception

are currently predominant in the cognitive sciences. One is the *theory of inferential perception* (hereafter IP) originally introduced in the early works of Hermann von Helmholtz (1867), and developed by authors such as Fodor (1975), Marr (1982), and Pylyshyn (1986). The other is the *theory of direct perception* (thereafter DP) initially related to the ecological psychology of James J. Gibson (1979), and recently reformulated within different frameworks by authors such as Noë (2005), Gallagher (2008), and Chemero (2009). These two accounts are usually considered mutually incompatible, supporting opposing views of how visual perception relates to things and events in the world. Indeed, while the former has been traditionally conceived as supporting a mediated relationship between the environment and the percept, the latter aims to remove any mediation between the percept and the information conveyed by the stimulus.

According to IP, perceiving an object is an ordering process that combines the stimulus information with other internal resources. This view is committed to the poverty of the stimulus thesis, first developed by Chomsky to account for language acquisition, and then extended to perceptual processes as well. According to this view, the senses are provided with impoverished, inaccurate information about external objects and events, whereas perceptual processing is accurate and elaborate. This leads one to view the perceptual stimulus as inherently poor and in need of supplementation by intelligent processing. Since the perceptual stimulus is impoverished and inaccurate, it follows that an inner source of knowledge is required to overcome this deficiency, making it possible to infer generalizations and analogies. Traditionally, memories, conceptual structures, and propositional information have been seen as the elements enabling a complex percept to be derived from initially poor stimulation.

By contrast with inferentialism in perception, DP assumes that the visual stimulus suffices, and that no additional information is needed. According to this view, the system directly detects information about environmental properties without involving previously acquired propositional knowledge and conceptual structures. In light of this, DP has recently been invoked as the better way to account for the coupling of perception and action in pre-linguistic humans and animals, since it does not rely on high level cognitive abilities or *ad hoc* cognitive modules (e.g., Gallagher 2005; Noë 2005; Chemero 2009; Hutto & Myin 2013). However, it has been argued quite convincingly that DP is unable to account for the poverty of the stimulus in classification tasks, and for perceptual errors and illusions (e.g., Ulman 1980; Fodor & Pylyshyn 1981).

The aim of this paper is to argue that is possible to account for the coupling of perception and action in terms of inferential processing. To support this claim I introduce a dual theory of perceptual processing, and show that there is a kind of inferential process that does not involve the retrieval of previously acquired conceptual structures and propositional information. Moreover, I intend to provide a model of sensorimotor processing that, unlike other inferentialist approaches (e.g., Marr 1982; Fodor 1975), does not require the postulation of specialized cognitive modules.

In particular, I argue in favor of a refined approach to IP according to which the stimulus suffices for sensorimotor tasks without involving a rule for high level cognitive abilities. This is made possible by distinguishing between a *linear* kind and a *distributed* kind of processing, so that the former can be adopted to frame object recognition and conceptualization, while the latter serves in cases of pattern detection in sensorimotor processing. In particular, I argue that the sensorimotor matching system of the *dorsal stream* in visual processing can be regarded as an instance of linear processing serving perception of action possibilities in the environment without relying on propositional information and conceptual skills. To support this claim, I present two cases of visual agnosia – apperceptive vs associative – and argue that it is possible to discriminate between instances of the linear kind and the distributed kind of processing in the early stage of perception. Finally, my claim is that IP may provide a good account for a special instance of perception and action coupling, namely the case of affordance perception.

2. A REFINED APPROACH TO INFERENTIAL PERCEPTION

Inferentialism has been the mainstream view in cognitive science over the past decades. It is worth noticing that IP has been traditionally conceived as a *multistage* process involving the role of memory, past experiences, and semantic abilities. According to this traditional interpretation, inferential perception has been conceived as a form of *distributed processing* where the perceptual stimulus activates a larger pattern of multimodal components that are integrated through dedicated connections and areas. More precisely, when the perceptual stimulus elicits the activation of one of those components, the larger pattern is activated by the automatic triggering of a causal mechanism. Accordingly, after the stimulus reaches the perceptual apparatus, a network of internal components of semantic representation and conceptual schemas is activated. This is made possible by a multistage processing through which salient aspects are extracted from the selected stimulus via associative processes, and finally combined with other internal resources such as memory retrievals and propositional information. Notably, on this view, when an initial stimulus activates a larger system of functional representations, the propositional information conveyed by this system of representations complements the information that the stimulus conveys, making possible generalizations and other inferential reasoning.

However, this is not the only inferential model of perception. Indeed, it is possible to conceive IP as involving a form of *linear processing* that does not require the possession of high level cognitive functions as a precondition. Indeed, it could be that the perceptual stimulus activates modality-specific feature detectors in the early stage of information processing, and that during this processing specific neural networks are immediately activated by configural features, such as edges, line orientation, and surface shape, whereas others correlate with the perception of movements and actions (Zeki 1993; Palmer 1999; Barsalou 2005)). This makes it plausible to hypothesize that the external stimuli suffice to activate feature detectors endowed with a functional role to both represent the surrounding space and coordinate action-related behaviors. Remarkably, this linear processing does not require a complementary role for other internal resources, such as memories and propositional information.

It should be noted, moreover, that this dual theory of IP is not based on a mere distinction of functional areas in the brain, instead it is concerned with the difference between two structures of processing that are instantiated in perception. Actually, the distinction between the linear kind and the distributed kind of processing is not a question of localizing cortical functions, but rather of discriminating between different sequences of operations involved in perceptual information processing. Notably, while linear processing can be seen as the ability to select specific patterns from a complex stimulus, distributed processing requires that the information conveyed by the stimulus be *combined* with and *complemented* by other internal resources.

Interestingly, this dual-processing model reflects an important distinction between two cognitive abilities: *feature perception* and *conceptual binding*. The former is the ability to detect environmental features by using a specific sensitivity, whereas the latter is the ability to organize and recruit a distributed pattern of information into complex structures (Gerrans 2012). While feature perception is a relatively rigid process implemented by localized circuits, conceptual binding is more flexible and depends on the coordinated activity of a widely distributed information system (Ashby et al. 1996; Coltheart 1999).

Importantly, the distinction between a distributed and a linear kind of processing does not mirror the distinction between a representational form and a non-representational form of perception. Indeed, depending on the notions of representation and information we adopt, it is possible to conceive the linear kind of processing as conveying information *about* the motor related properties that characterize the environment, such as the shape, the size, and the orientation of a target object. Of course, this eventually requires admitting the possibility of non-propositional formats of representation (Butterfill & Sinigaglia 2012, see also the next section for an example).

Though they are different in structure and in the kind of information they convey, it is possible to assume that both linear and distributed information processing are involved in IP, serving different cognitive tasks (I will provide empirical evidence for this claim in the next two sections). For instance, when looking at an object in front of you, say a mug, you may have different aims. Your aim might be to grasp it to drink, or it might be to identify the kind of object you have in front of you. Accordingly, although the proximal stimulus is the same in both cases, different tasks require different perceptual abilities.

In the first case, what you need is to detect those patterns of stimulation that are usually correlated with the mug's possibilities of action according to your motor abilities and intentions to act. Therefore, it is not necessary that you recognize the mug *as* a certain kind of mug, such as a Chinese tea mug, or a cheaper plastic mug. The detection of specific edges and geometrical patterns might be sufficient to shape your action in accordance with your intention. As stated before, the detection of perceptual patterns that correlate with environmental properties may be described as a linear kind of processing, that is, as an activity of selection that does not involve conceptual and propositional resources that complement the stimulus.

On the other hand, in the second case, when you are looking at a mug in order to identify the kind of object you have in front of you, the retrieval of internal resources seems to be required. Indeed, the ability to detect those patterns of stimulation associated with the shape, the color, and other properties is not enough for the success of a recognition task. Rather, the activation of a system involving semantic abilities, memory, and propositional information about the mug is necessary in this case. Accordingly, since the information conveyed by the stimulus is not enough, this recognition task requires distributed processing and the triggering of high level cognitive mechanisms.

3. DISTRIBUTED AND LINEAR PROCESSING: TWO CASES OF AGNOSIA

Though, in a famous paragraph, Gibson states that perceiving possibilities of action does not involve classification (Gibson 1979, p. 134), it should be recognized that our lives depend on the ability to discern and direct our behavior toward different classes of objects and events that populate the environment. There are things and organisms that we do or do not eat, mate with, or grasp, and things among which, for different purposes, we tend to discriminate according to their interactions and uses.

Recently, Withagen & Chemero (2011) have argued that there are perceptual variables that carry information about objects being members of classes without specifying that those objects are members of those classes. Accordingly, by detecting those perceptual variables, one can engage in behavior that requires distinguishing between objects that are members of different classes, without the need of recognizing those objects as members of specific classes. This means that classification skills could be underwritten by low level cognitive processes only, without involving propositional information, memory retrieval and other forms of conceptual reasoning.

This issue gains even more importance in light of the influential dual-stream theory of visual perception (Goodale & Milner 1992; Milner & Goodale 1995; Norman 2002; Jacob & Jeannerod 2003). According to this view, after entering the brain, the visual stimulus splits into two different streams: the *dorsal path*, where the information is used to accomplish low level cognitive tasks such as representing space and guiding actions; and the *ventral path*, where the information is employed for high level cognitive tasks such as object *classification*. Interestingly, it has been argued that the dorsal path is based on a discriminatory capacity that is not mediated by propositional information, whereas the ventral-path requires the involvement of information stored in a semantic system, and is therefore considered to be always engaged in associative processing and high level cognitive tasks (Norman 2002).

According to the influential dual-stream theory of visual perception, it is in the ventral stream that the classification of the perceptual stimulus occurs (Milner & Goodale 1995; Norman 2002; Jacob & Jeannerod 2003). Since this operation requires integration of perceptual information with preexisting internal resources that complement the stimulus, perceptual classification should be thought of as relying on *distributed processing* (Marr 1982; Fodor & Pylyshyn 1981; Biederman 1995).

However, the view that our perceptual ability is based only on distributed processing is too simplistic, and needs to be amended in many respects. I argue that referring to two forms of *visual agnosia* can help to improve the distinction among different cases of perceptual information processing: one *distributed* kind that relies on propositional information, and another simpler kind that relies on a (non-propositional) direct matching system.

Visual agnosia is a neurophysiological syndrome characterized by a failure of object identification, resulting in difficulties in verbally naming, and behaviorally classifying things in the visual field. Interestingly, cases of visual agnosia do not impair action abilities, so that subjects suffering from this syndrome are able to reach for and grasp objects, but are unable to name and classify them.

This syndrome is generally associated with selective damage in the

ventral stream of the visual system (Riddoch & Humphreys 2003). Notably, an increasing amount of evidence has shown that there are two different ways in which object perception may be impaired following lesions at different levels of perceptual processing.[1] The first is called "associative agnosia", and involves damage to the connection between the perceptual stimulus and stored propositional information about the target (McCarthy & Warrington 1986). The second is called "apperceptive agnosia", and is caused by damage at the very early stage of processing perceptual features (Shelton et al. 1994).

Cases of associative agnosia have been variously explained by postulating a disconnect between visual information processing and the storing of semantic representations (Carlesimo et al. 1998; Geschwind 1965), but also by postulating the loss of propositional memory of the object (Mesulam 1985). More recently, Riddoch and Humphrey have proposed the possibility of two independent forms of internal resources serving object recognition: stored *semantic knowledge* and stored *structural descriptions* (Riddoch & Humphreys 2003). While semantic knowledge specifies our concept of an object, structural knowledge encodes the properties that characterize the perceptual description of the object.

For example, patient JB (Riddoch & Humphreys 1987) was able to visually describe objects, but relatively poor at making judgments about which objects from a group of three could be associated, despite being able to make the same judgments when dealing with the spoken names of the objects. This shows that JB has intact access to the structural information concerning objects, but a deficit in *visually accessing* stored semantic representations of them (Riddoch & Humphreys 2003).[2] In a different case, patient DM was able to provide semantic information concerning animate and inanimate items, but showed an impairment when asked to provide perceptual descriptions of presented objects. This suggests that DM has a disorder in stored structural knowledge of things, but intact access to semantic information (Riddoch & Humphreys 2003).

Interestingly, patients suffering from associative agnosia have their classification abilities impaired because of damage to the connection between the visual stimulus and their semantic representations of the object. This means that normal subjects have perceptual classification ability that relies on a distributed system involving the subject's beliefs, past experience, and propositional memory, whereas this skill is impaired in patients suffering from associative agnosia. Accordingly, cases of associative agnosia make it possible to isolate a perceptual classification ability that relies on a kind of distributed processing in the ventral stream serving inferential perception.

Something different occurs in cases of apperceptive agnosia. Patients suffering from this syndrome show a profound deficit in the normal coding of simple perceptual patterns, such as orientations, and shapes (Campion & Latto 1985; Vecera & Gilds 1998). An example of apperceptive agnosia is the much-studied case of patient DF (Milner et al. 1991) who suffered from a large bilateral occipital lesion disconnecting the inferior temporal lobes from visual inputs. DF's memory was good and she showed no impairment in her semantic ability. However, DF was unable to indicate the size of an object by imitating the distance with her fingers and showed a critical impairment in discriminating between lines with different angular orientations. Despite this, DF was able to reach and grasp a real object, shaping her hand according to the size of the object to be grasped. This condition has been explained as a consequence of the fact that the brain damage suffered by DF interrupted the normal flow of visual information, affecting the early coding of individual features such as shapes and contours. Since DF's primary visual cortex was largely intact, the information flow from this structure to the ventral stream had likely been compromised. However, the input to the dorsal stream remained essentially intact Milner et al. (1991); Milner & Goodale (1995); James et al. (2003).[3]

A different case of apperceptive agnosia is that of the patient HJA, who had a deficit in the identification of line drawings and figure shapes, and in their comparison as well Riddoch & Humphreys (1987, 2003)). HJA was able to process simple visual information, showing the ability to copy figures and normal performance in semantic and memory tasks. In particular, unlike DF, HJA was able to detect simple visual features in the environment, but she was not able to combine them into a coherent percept. This deficit has been explained as a problem in integrating individual visual information, resulting in a form of apperceptive agnosia (Riddoch & Humphreys 1987; Vecera & Gilds 1998).

Both cases of apperceptive agnosia exemplified by the patients DF and HJA make it possible to isolate a specific kind of perceptual ability

that is not served by the retrieval of semantic memory and propositional information. It is possible to hypothesize that, in normal organisms, simple perceptual classification tasks can be performed merely by relying on the early detection of specific visual patterns, without involving any role for previously stored propositional information. This means that an organism may be able to trace a member of a certain class of objects by detecting those visual patterns that recurrently denote its class, and do so by using only the information contained in the stimulus.

To sum up, the distinction between associative and apperceptive agnosia suggests the possibility of isolating two different levels of perceptual classification abilities. Associative agnosia is an impairment of a *high level* classification ability based on distributed processing combining visual information with memory and propositional representations. Patients suffering from this syndrome lose their ability to recognize an object *as* a member of a certain class. Instead, apperceptive agnosia is an impairment of a *lower level* ability that serves the classification of objects according to the detection of salient patterns in a complex stimulus, such as those relating to the object shape and orientation. Patients suffering from this syndrome lose their capacity to detect and manipulate elementary aspects of the environment through distributed processing, resulting in the inability to trace and classify the surrounding things.

4. THE SENSORIMOTOR MATCHING SYSTEM

An example from the recent neuroscience of visual perception may show that there is a way to account for the sensorimotor coupling of perception and action even at the level of information processing in the brain. Over the last decade, indeed, an increasing amount of evidence has shown that there are neurons in the *premotor cortex* of non-human and human primates that respond to particular classes of visual stimuli. The majority of neurons in the area F5 in monkeys, and inferior frontal gyrus in humans, for example, convert the layout properties of objects into the appropriate motor patterns for action execution (Rizzolatti et al. 1988; Rizzolatti & Luppino 2001). In a famous single cell recording experiment, Murata et al. (1997) found that almost half of the neurons in the premotor area of monkeys' brains responded significantly to the sight of graspable objects, independently of the actual execution of any action. Those "visuomotor" neurons showed a specific selectivity, discharging more strongly during fixation on certain solids as opposed to others, the difference between them depending on the kind of grip afforded by those objects — e.g., precision grip, finger prehension etc. (Rizzolatti & Luppino 2001). Similar data in humans show that the visual sight of graspable objects and tools somatopically activates the same cortical areas used to reach and act on the visual target, even independently of the subject's intentions, and the actual execution of actions (Chao & Martin 2000; Grèzes & Decety 2002; Petit et al. 2006). Further evidence (Sakata et al. 1995; Murata et al. 2000) demonstrates that this kind of sensorimotor selectivity is also present in the anterior intraparietal area AIP, which projects its connections directly into the premotor cortex (Borra et al. 2008). A large proportion of neurons in this area discharge during object fixation, and are selective for object properties such as shape, size, and orientation (Srivastava et al. 2009; Verhoef et al. 2010). Moreover, it has been shown that the functional inactivation of AIP has the consequence of impairing the ability to shape hand movement according to the geometrical characteristics of the object to be grasped (Gallese et al. 1994).

Such evidence shows that the parietofrontal circuit comprising the AIP and the premotor cortex — also called the *ventro-dorsal stream* (Rizzolatti & Matelli 2003) — has a critical role in the extraction of visuomotor properties for object-oriented hand actions (Shikata et al. 2003). Remarkably, it has been shown on the basis of anatomical data that the entire inferior intraparietal lobule IPL — of which the AIP is part — receives inputs from visual areas MT/V5, which in turn receive input from the primary visual cortex V1 (Galletti et al. 2001; Gamberini et al. 2002; Rizzolatti & Matelli 2003). This reveals the presence of a *direct connection* between the visual areas that get inputs from the retina and the sensorimotor areas of the parietofrontal circuit.

Remarkably, the ventro-dorsal path exploits a *direct matching system* that automatically maps the perceptual information on a specific motor plan for action (Gallese et al. 2002; Gallese & Sinigaglia 2011). This matching system makes it possible to detect the visuomotor patterns of action-related features in the environment without involving high-level cognitive functions, i.e., memory retrievals or propositional representations of the object. Accordingly, since the perceptual stimulus conveys enough information to activate the sensorimotor system in the parietofrontal circuit, the dorsal path instantiates an occurrence of *linear processing*.[4]

Interestingly, this example is consistent with the refined approach to IP introduced in Section 2. Actually, the information processing implemented within the dorsal stream suffices for the ecological needs of the organism (e.g. locating objects, grasping tools, etc.) and does not recruit other sources of information. This means that the dorsal stream can be considered to be conveying information — albeit in a non-propositional format – about the location of the target, its shape and the possibilities of actions that the environment provides (Nanay 2013; Butterfill & Sinigaglia 2012).

To sum up, the introduction of a direct matching system implemented by dorsal processing makes it possible to explain how the perceptual stimulus suffices to elicit the activation of the parietofrontal circuit involved in planning and executing motor actions. Accordingly, the large amount of evidence concerning perceptual processing in the dorsal stream shows that the sensorimotor coupling between perception and action can be well accounted for in terms of IP.

5. CONCLUSION

This paper focuses on the possibility of providing an inferential model of perception that does not involve propositional information and conceptual bindings. In particular, I have argued in favor of a distinction between a linear and a distributed kind of visual processing. The former serves the ability to perceive by directly detecting and tracing perceptual features in the environment, whereas the latter serves the ability to classify objects according to internal resources such as memory and propositional knowledge. I have supported this claim by showing that the visuomotor matching system instantiated by the dorsal stream of the visual system is actually a case of linear processing serving for visuomotor transformation.

Interestingly, this view opens the door to the development of a new theory of affordance perception, focusing on *how* the direct detection of action possibilities in the environment is made possible by information processing. Following this line, in the near future new trends of research could be addressed to the issue of bridging the gap between the standard ecological definition and the neurobiological approach to affordance perception.

Notes

[1] This distinction was first introduced by Lissauer (1890).

[2] Interestingly, this kind of deficit can be specific for objects belonging to a certain class. For example, it can be stronger for animate objects than for inanimate objects (Warrington & Shallice 1984; Humphreys et al. 1995; Caramazza & Shelton 1998).

[3] A different account of DF's visuomotor robustness has recently been proposed. Schenk (2010, 2012) argues that DF's preserved ability for visually guided actions might reflect the fact that many visuomotor tasks can be solved on the basis of feedbacks from different sensory modalities. In particular, DF's ability to adjust the shape of her hand according to the object's size would, he suggests, be prompted by haptic feedbacks about the object's size, thus bypassing her visual impairment. However, this view would require more information concerning the neurophysiology of the visual ventral path and its connections with the other different modalities, see Borra et al. (2008).

[4] The interaction between the dorsal stream and other areas of the brain is an open field of investigation. Borra et al. (2008) have observed robust connections between the AIP and the temporal areas. One hypothesis is that the information involved in object discrimination can be conveyed from the ventral path to the AIP in order to refine the selection among the detected action possibilities. If this is confirmed, the linearity of the processing in the dorso-ventral stream is likely to be limited to the path linking the primary visual area and the AIP.

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