



HAL
open science

Grasping the affordances, understanding the reasoning. Toward a dialectical theory of human tool use

François Osiurak, Christophe Jarry, Didier Le Gall

► **To cite this version:**

François Osiurak, Christophe Jarry, Didier Le Gall. Grasping the affordances, understanding the reasoning. Toward a dialectical theory of human tool use. *Psychological Review*, 2010, 117 (2), pp.517-540. <halshs-00485348>

HAL Id: halshs-00485348

<https://shs.hal.science/halshs-00485348v1>

Submitted on 20 May 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

GRASPING THE AFFORDANCES, UNDERSTANDING THE REASONING. TOWARDS A DIALECTICAL THEORY OF HUMAN TOOL USE

François Osiurak^{1,2}, Christophe Jarry^{1,2}, and Didier Le Gall^{1,2}

¹Laboratory of Psychology UPRES EA 2646, University of Angers, France.

²Neuropsychological Unit, Department of Neurology, University Hospital of Angers, France.

CORRESPONDENCE

François Osiurak is now at Laboratory of Psychology UPRES EA-SIS 4129, University of Lyon 2, France. Correspondence concerning this article should be addressed to François Osiurak, Institut de Psychologie, 5, avenue Pierre-Mendès-France, 69676 Bron Cedex, France.

Email: Francois.Osiurak@univ-lyon2.fr

RUNNING HEAD: Grasping the affordances, understanding the reasoning

ABSTRACT

One of the most exciting issues in psychology is what are the psychological mechanisms underlying human tool use? The computational approach assumes that the use of a tool (e.g., a hammer) requires the extraction of sensory information about object properties (heavy, rigid), which can then be translated into appropriate motor outputs (grasping, hammering). The ecological approach suggests that we do not perceive the properties of tools per se but what they afford (a heavy, rigid object affords pounding). This is the theory of affordances. In this article, we examine the potential of the computational view and the ecological view to account for human tool use. To anticipate our conclusions, neither of these approaches is likely to be satisfactory, notably because of their incapacity to resolve the issue of why humans spontaneously use tools. In response, we offer an original theoretical framework based on the idea that affordance perception and technical reasoning work together in a dialectical way. The thesis we defend here is that humans have the ability to view body action as a problem to be solved. And it is precisely at this point that technical reasoning occurs. But, even if the ability to do technical reasoning gives humans the illusion of constantly doing less (e.g., TV remote control), they are still forced to use body action – and to perceive affordances – to operate the product of the reasoning (pushing buttons with the fingers). This is the principle of dialectic.

KEY WORDS: Action, Anthropology, Apraxia, Perception, Technology.

INTRODUCTION

One of the most exciting issues in psychology is what are the psychological mechanisms underlying human tool use? Surprisingly, this question has received very little attention from psychologists (Johnson-Frey, 2004; Le Gall, 1992). A certain number of attempts have nevertheless been made to model how humans perform tool behaviour (referred to hereafter as the HOW issue). These attempts fall into two categories. The first category assumes that tools have no inherent meaning, and thus the meaning must be created internally and stored by the user. The other category assumes that tools have inherent meanings, which is detected and exploited by the user without mental calculation. Most attempts fall into the former category (e.g., Buxbaum, 2001; Rothi, Ochipa, & Heilman, 1991; Roy & Square, 1985; Yoon, Heinke, & Humphreys, 2002). They all are computational models, based on the core assumption that the use of a tool (e.g., a hammer) requires the extraction of sensory information about object properties (heavy, rigid), which can then be translated *directly* or *indirectly*¹ into appropriate motor outputs (grasping, hammering). J.J. Gibson's ecological approach to perception falls into the latter category. For J. J. Gibson (1979), we do not perceive the properties of tools but what they afford (a heavy, rigid object affords pounding). This is the theory of affordances.

Besides the question as to how humans perform tool behaviour, another important question concerns the specificity of human tool use. It has been pointed out that human tool use differs from that known to occur in non-humans in different ways. Only humans possess a vast repertoire of tool use skills (Johnson-Frey, 2007), make one tool to create another (McGrew, 1992) or spontaneously engage in object-object manipulations (K. R. Gibson, 1991). In broad terms, humans seem to have the capacity of spontaneously and almost systematically use tools so as to modify their way of interacting with the world, a feature which characterizes humans of all cultures through the ages (Leroi-Gourhan, 1971, 1973). For instance, humans use horses, bicycles, cars, boats or aeroplanes to move. Likewise, they use spears, traps, guns, and

bows to hunt, or rucksacks, baskets, jags, cans and heavy goods vehicle to transport things. In fact, the relationship existing between humans and the environment is constantly changing, a specificity which is much more visible at the species level through the technical evolution. Just think about what the place where you grew up looks like now (kitchen utensils, household equipment, TV sets, computers, street equipment, cars, houses, and so on), and you will have a pretty good snapshot of it. So, to be complete, any theory that is supposed to describe the mental mechanisms of *human* tool use must not only address the HOW issue, but should also be concerned with the question as to why do humans spontaneously use tools? (Referred to hereafter as the WHY issue)

The purpose of the paper is threefold. Firstly, we address two tricky epistemological issues concerning tool use. The first one is what a tool is? Most papers on the topic do not define precisely what they mean by “tool use”, probably because they view tool behaviour as something obvious. Through this work, we wish to emphasize that tool behaviour is anything but obvious, however. The second is what does it mean to consider two behaviours to be analogous? A growing body of literature has described observations of tool use in a wide range of species. It is worth emphasizing that some reports in a species arise from a single individual on one occasion or only from observations in captivity (Beck, 1980; see also Chappell & Kacelnik, 2002). This contrasts markedly with the use of tools by humans which is very spontaneous and frequent. So, the question arises as to which extent tool use by humans and non-humans can be considered analogous.

The second purpose is to examine the potential of the computational view and the ecological view to account for human tool use. To anticipate our conclusions, neither of these approaches is likely to be satisfactory because of their incapacity to resolve the WHY issue. Nevertheless, with regard to the HOW issue, the ecological approach provides a better account of the perception of the relationships between an organism and the environment,

notably by stressing that perception is “designed” for action.

In response, we offer an original theoretical framework based on the idea that affordance perception and technical reasoning work together in a dialectical way and this is the third purpose of this paper. Briefly, the thesis we defend here is that humans have the ability to view body action as a problem to be solved. And it is precisely at this point that technical reasoning occurs. But, even if the ability to do technical reasoning gives humans the illusion of constantly doing less (e.g., TV remote control), they are still forced to use body action – and to perceive affordances – to operate the product of the reasoning (pushing buttons with the fingers). This is the principle of dialectic. The dialectical theory of human tool use we propose here is inspired by the theory of affordances (J. J. Gibson, 1979) as well as the work of Gagnepain (1990) on the dialectical functioning of the human mind.

EPISTEMOLOGICAL ISSUES ABOUT TOOL USE

WHAT IS A TOOL?

Classically, the notion of “tool” refers to any handheld physical implement that is used to make changes to other objects in the environment. A nail is not a tool but the hammer used for pounding it into a wall is. Likewise, a house is not a tool but the trowel used for building it is. Table 1 summarizes the definitions proposed by some of the leading authors in the subject. As shown, a high degree of consensus emerges about three defining features. First, tools are discrete, unattached environmental objects. Second, tools amplify the user’s sensorimotor capabilities. Third, tools are restricted to what is manipulated by the user. Overall, these set of features are organized around the central idea that tools are extensions of the upper limbs.

[INSERT TABLE 1 ABOUT HERE]

A noteworthy aspect of this definition is that it applies to both human and non-human actions. Anthropologists once considered tool use to be a highly characteristic feature of

genus *Homo* (Oakley, 1949). Reports of tool use in non-humans, however, led them to revise their view (e.g., see van Lawick-Goodall, 1970). Since then, a growing body of evidence has emerged (for reviews, Baber, 2003; Beck, 1980; van Schaik, Deaner, & Merrill, 1999) and it is now largely accepted that tool behaviour is not peculiar to humans. In this article, we do not intend to challenge the view that some animals can also exhibit tool behaviours. After all, humans are not alone in having the biological equipment appropriate for manipulating things. And, to the extent that a necessary condition for being a tool user is the ability to manipulate things, it is more than obvious that tool behaviour can be observed in non-humans. But, beyond the question of whether some animals are tool users, a more interesting question is whether animals exhibit tool behaviour frequently and spontaneously. As Chappell and Kacelnik (2002) pointed out, some reports of tool use in a species arise from a single individual on one occasion, or only from observations in captivity (see also Beck, 1980; van Schaik et al., 1999). For instance, only about twenty of an estimated 8,600 known species of birds have been reported to use tools. And, in most of these cases, only a small number of individuals do so (Boswall, 1977). This contrasts markedly with human tool use, which is very spontaneous and frequent. Therefore, the fundamental question is not whether tool use is unique to humans, but what is unique in human tool use. By this, we wish to stress that our aim is not to propose a new definition of tool use, aiming to capture the essence of human behaviour, but rather to use this definition as a methodological basis for investigating the uniqueness of human “technology”.

Another interesting aspect of the definition of tool use is that it excludes construction behaviour displayed by non-humans (e.g., nest building) as well as humans. The viewpoint adopted by some of the authors who have largely contributed to the study of tool behaviour is somehow more subtle. Beck (1980) himself thought that it would be a mistake to see tool use as biologically distinct from construction behaviour, thereby suggesting that it is fundamental

to keep in mind that any definition of tool use is one of convenience rather than biological distinctness. Despite this warning, many scientists view tool use as a sign of higher cognitive abilities because of its suggested relation to human lineage (see Hansell & Ruxton, 2008).

Perhaps a good way to demonstrate that any definition of tool use contains no presumption of psychological abilities and only describes a category of behaviour is to show how surprisingly difficult it is to recognize what is the tool in some tool behaviour, an intriguing paradox. Let us take the example of one of the features mentioned above: Tools are restricted to what is manipulated by the user. St Amand and Horton (2008) proposed that when a chimpanzee wedges a stone under another stone to use as an anvil, then places a nut on the anvil and cracks it open with a stone hammer (see Matsuzawa, 2001), the only tool is the hammer stone. Similarly, they argued that when a carpenter clamps a piece of work between two lengths of scrap wood to avoid dents, wraps a sheet of sandpaper around a wooden block, dons a pair of goggles, and then begins to sand, the only tool is the sheet of sandpaper.

Some authors have criticised the anthropocentrism (Shettleworth, 1998) and arbitrariness (Hansell, 1987) of considering a tool as what is manipulated, yet it is still largely accepted that “true” tools are detached from the environment and directly held by the animal in the mouth or hand whereas “borderline” tools are part of a substrate, such as anvils on which prey are dropped or battered (Beck, 1980; Boswall, 1977; Lefebvre, Nicolakakis, & Boire, 2002; McFarland, 1982; Parker & K. R. Gibson, 1977; van Lawick-Goodall, 1970, Vauclair, 1997).

It is true that this approach works relatively well when the manipulation is done with only one limb, or when the object (e.g., nail) that receives the action exerted by the tool (hammer) is not held by the user. But, what about if the carpenter lays the sheet of sandpaper on the ground, grasps the wooden block firmly in the hands and then begins to sand? Does the wooden block become the tool and the sandpaper the recipient of the action? Likewise, what about if the carpenter holds the wooden block in one hand and the sheet of sandpaper in the

other? Ambiguity also occurs in animal tool users. Egyptian vultures can use a stone, held in the beak, to hammer or throw at the egg, but they can also crack eggs by smashing them on the ground (van Lawick-Goodall, 1970). One way to resolve the ambiguity is to assume that, when two objects are used together, the tool is the one that alters the physical properties of the other. So, in the example of Egyptian vultures, the stone but not the egg is the tool. Although this solution may appear attractive, it is unacceptable because it violates the basic principle that a tool is *necessarily* what is manipulated.

In sum, this confirms that, while labelling behaviour as tool use may appear to be relatively easy and obvious, recognizing what is the tool is, paradoxically, something difficult and non-obvious. Therefore, the viewpoint adopted in the present paper is that any definition of tool is one of convenience rather than psychological distinctness, corroborating the idea that there is little justification for the separation of tool use from construction behaviour.

WHAT DOES IT MEAN TO CONSIDER TWO BEHAVIOURS TO BE ANALOGOUS?

The idea of a psychological continuity among species is deeply ingrained in the minds of comparative psychologists and neuroscientists alike (Povinelli, Bering, & Giambrone, 2000; Penn, Holyoak, & Povinelli, 2008). This hypothesis has been originally formulated more than a century ago by Darwin (1871/1981) and Romanes (1883), the two founders of comparative psychology. They advocated that in cases in which other species exhibit behaviour similar to our own, similar psychological causes are at work (argument by analogy). This hypothesis has been challenged by a substantial body of evidence indicating serious limitations on the ability to non-human animals to solve tool use situations that are relatively simple for humans (e.g., Povinelli, 2000; Visalberghi & Limongelli, 1994). We return to this point later. Beyond the lack of evidence supporting the psychological continuity hypothesis, a very important question is to which extent two behaviours can be considered analogous. There are at least three ways to answer this question.

The first is to compare the behaviours at an *action* level. Imagine for instance a chimpanzee using a twig to fish termites and a human using a fishing rod. By adopting this viewpoint, one may limit the observation time to the period needed for one cycle of fishing (inserting the twig into the termite nest, removing the twig from the termite nest, checking whether there are termites on the twig; dipping the hook into water, removing the hook from water, checking whether there is fish on the hook). This is the level of analysis which is generally preferred, leading to highlight similarities between humans and non-humans (Breuer, Ndoundou-Hockemba, & Fishlock, 2005; Hart, Hart, McCoy, & Sarath, 2001; Pruetz & Bertolani, 2007). Indeed, given that the emphasis is on the sequence of actions required to use a tool, and since the use of tools requires manipulation, similarities become evident.

The second is to compare the behaviours at an *individual* level, involving that the observation time is extended to the lifetime of the individual. At this level, things drastically change. It has been extensively reported that in non-human animals tool use is rare and incidental in the wild (Beck, 1980; Byrne, 2004; Chappell & Kacelnik, 2002; van Schaik et al., 1999, van Schaik, Fox, & Fechtman, 2003). By contrast, humans use a wide range of tools everyday and during all the life. And, only humans engage spontaneously in object-object manipulations (K. R. Gibson, 1991). So, at this level, human tool use differs significantly from that known to occur in non-humans.

Differences become even more visible when attention shifts from the individual to the *species* level (third level). Only humans are able to transcend their natural abilities and to radically alter his environment. They walk on the Moon, see through the atmosphere, fly in the air, and communicate with peers situated at the other end of the Earth. Taking a look at a species level reveals another important phenomenon: All human societies develop technical equipments, which are modified and improved (Leroi-Gourhan, 1971, 1973), indicating that the constant desire to innovate and move away from previous technical equipments is not

specific to some societies – notably modern occidental societies –, but a defining feature of humans. Furthermore, whereas in animals significant changes in behavioural repertoires require the cumulative effects of several generations, in humans important technical modifications can occur within one generation, and sometimes can even represent the effort of a single individual (i.e., inventor). Hence, at a species level, it is no longer possible to assert that some animals exhibit behaviours seemingly analogous to human ones.

In broad terms, considering two behaviours to be analogous is far more subtle than it might appear at first glance. In most studies, the focus is generally on the action level. Of course, this way of addressing behaviour is fundamental to understand how individuals guide their own behaviours (the HOW issue) and, as a result, to determine what is common in tool use between humans and non-humans. But, it is not because two behaviours are seemingly analogous that the underlying mental mechanisms are analogous too (Penn et al., 2008). Studies on tool use by non-humans provide support for this view (see below). Moreover, what renders a piece of behaviour strongly analogous to another one does not lie merely in the rough description of the sequence of actions required to perform it, but also in taking into account the occurrence and diversity of the behaviour. However, this is made possible only if the focus shifts to the individual level or even the species level, a methodological view developed by folk psychology. For Wundt (1912), what happens at the species level inevitably reflects the psychological functioning of each individual. Adopting such a view allows us to go beyond the morphological similarities existing between humans and some animals – notably those who use tools – and thus to reason about why do humans spontaneously use tools? (The WHY issue) An attempt to answer to this question is made explicitly in the last sections of this paper. Before doing so, we examine the capacity of the computational view and the ecological view to account for human tool use.

THE COMPUTATIONAL APPROACH TO TOOL USE

THE NON-SEMANTIC ROUTE HYPOTHESIS

Until very recently, our understanding of the processes involved in using tools came exclusively from studies of brain-damaged patients, particularly those who experience difficulties in using tools (De Renzi & Lucchelli, 1988; De Renzi, Pieczuro, & Vignolo, 1968). For instance, when asked to light a candle, the patient may light the candle correctly but then put it to the mouth in an attempt to smoke it. Errors of misuse do not occur only during the performance of complex actions, but also when the patient is tested with single objects (De Renzi & Lucchelli, 1988; Osiurak et al., 2009). These patients have been described as suffering from ideational apraxia, a disorder of skilled movement that cannot be attributed to elementary sensorimotor deficit or aphasia (De Renzi, 1989).

Ideational apraxia has long been interpreted as semantic memory disturbance (De Renzi & Lucchelli, 1988; Ochipa, Rothi, & Heilman, 1989, 1992; Rothi et al., 1991; Roy & Square, 1985). In cognitive psychology, semantic memory is defined as a component of long-term memory that contains information about the meaning of words, concepts and facts (Tulving, 1985). However, recent evidence has demonstrated that brain damage can affect the use of tools and semantic knowledge independently from each other, suggesting that it is not because people know in which context or for which purpose an object is used that they are able to use it in an appropriate manner (Bartolo, Daumüller, Goldenberg, & Della Sala, 2007; Bozeat, Lambon Ralph, Patterson, & Hodges, 2002; Buxbaum, Schwartz, & Carew, 1997; Forde & Humphreys, 2000; Goldenberg & Spatt, 2009; Hodges, Bozeat, Lambon Ralph, Patterson, & Spatt, 2000; Lauro-Grotto, Piccini, & Shallice, 1997; Negri, Lunardelli, Reverberi, Gigli, & Rumiati, 2007; Osiurak et al., 2008b, 2009; Silveri & Ciccarelli, 2009).

Hence, growing attention has been paid to the possibility of a non-semantic route between a “structural description system” that extracts the visual features of objects and an “action selection system” that contains stored spatiotemporal gesture representations (Buxbaum,

2001; Humphreys, 2001; Pilgrim & Humphreys, 1991; Rothi et al., 1991; Rumiati & Humphreys, 1998; Yoon et al., 2002). Put differently, the use of a tool (e.g., a pencil) requires the extraction of sensory information about object properties (light, rigid), which can then be translated directly – in a computational sense – into appropriate motor outputs (grasping, writing). This section aims to examine the validity of this hypothesis in more detail.

WHAT EVIDENCE FOR A DIRECT ROUTE BETWEEN VISION AND ACTION?

Priming. The major challenge of the computational approach lies in demonstrating that the possibilities for action offered by tools – i.e., object-object complementarities – are “directly” perceived from visual input. In other words, the mere observation of a tool (e.g., a hammer) should be sufficient to activate motor representations in which both the tool and another object (e.g., a nail) are involved. Support for this view comes from priming studies and particularly from studies using a stimulus-response paradigm with photographs of common graspable tools (knife, teapot, frying pan, aerosol can) as stimuli (Craighero, Fadiga, Rizzolatti, & Umiltà, 1999; Ellis & Tucker, 2000; Tucker & Ellis, 1998, 2001). In their seminal work, Tucker and Ellis (1998) asked participants to make push-button responses with the left or right hand depending on whether the tool was upright or inverted. The orientation of the tools’ handle was irrelevant to the response. Nevertheless, they found that faster right hand responses were produced when the tool’s handle was oriented to the right than when the tool’s handle was oriented to the left, and vice versa, suggesting that seen tools automatically potentiate components of the actions they afford.

Do these findings demonstrate that the mere observation of tools directly activates motor representations of how to use them with other objects? A more likely hypothesis is that tools, like any other components of the environment, automatically elicit motor responses on the basis of actor-object complementarities. Vingerhoets, Vandamme, and Vercammen (2009) recently found similar priming effects for simple graspable shapes, for which no use could be

inferred. They wisely pointed out that “these priming effects appear to be nothing more than embryonic reaching and grasping movements towards graspable stimuli...[and that] it remains to be determined that an armchair automatically affords sitting and a banana automatically affords peeling” (Vingerhoets et al., 2009, p. 488).

Neuroimaging. Neuroimaging studies have revealed that pictures of graspable tools – in comparison to non-graspable familiar objects (e.g., house) – elicit activity in a distributed network of cortical regions that prominently include the left ventral premotor cortex and the left posterior parietal cortex (Chao & Martin, 2000; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Grezès & Decety, 2002; Grezès, Tucker, Armony, Ellis, & Passingham, 2003; Martin, Wiggs, Ungerleider, & Haxby, 1996). As discussed just above, the activation of this network can be considered as being due to the presence of *graspable* stimuli, thereby suggesting that people can directly perceive actor-object complementarities. Two lines of evidence, however, would support that this network is responsible for motor representations of how to use tools with other objects – i.e., object-object complementarities.

First, single-unit recording studies in monkeys have shown that some neurons in area F5 of the premotor cortex discharge during specific goal-related movements such as holding, grasping and manipulation, whereas other discharge in association with particular types of grip such as finger prehension, precision grip or whole hand prehension (Rizzolatti et al., 1988). Several classes of neurons involved in hand actions and located in the anterior intraparietal area have also been disclosed (Taira, Mine, Georgopoulos, Murata, & Sakata, 1990). Area F5 is reciprocally connected with the anterior intraparietal area, suggesting that there is a neural circuit devoted to the visuomotor transformation process required for planning skilled hand-object interactions (Jeannerod, Arbib, Rizzolatti, & Sakata, 1995; Rizzolatti & Matelli, 2003). So, in monkeys too, activation of representations of possible actions can be caused by the sight of objects. On the basis of the close similarity between

these findings and those obtained in neuroimaging studies, it has been argued that in humans this (parietofrontal) system might store all the motor representations related to hand-object interactions, including the use of tools (Chao & Martin, 2000; Johnson-Frey & Grafton, 2003). This conclusion is somewhat debatable since there is no evidence eliminating the possibility that this network is devoted to nothing else but to detect what can be grasped (i.e., actor-object complementarities).

The second line of evidence comes from neuropsychological studies showing that patients who experience difficulties in pantomiming the use of objects (to verbal or visual command) suffer from lesions in the left inferior parietal region (Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005a; Buxbaum, Kyle, Grossman, & Coslett, 2007; Buxbaum, Kyle, & Menon, 2005b; Buxbaum, Sirigu, Schwartz, & Klatzky, 2003; see also Johnson-Frey & Grafton, 2003; Rothi et al., 1991). It has been proposed that skilled gesture representations of tool use might rely on this region (Buxbaum, 2001; Heilman, Rothi, & Valenstein, 1982). In a very comprehensive review, Goldenberg (2008) nevertheless concluded that the impact of parietal lobe damage on pantomime of tool use is inconstant if not absent altogether. In broad terms, the question is still open as to whether the activation of a frontoparietal network during the observation of graspable tools, as shown by neuroimaging studies, demonstrates that people directly perceive how to use tools with other objects – i.e., object-object complementarities.

Experimental. Rumiati and Humphreys (1998; see also Yoon et al., 2002) asked normal subjects to name or make gesture to drawings of objects under deadline conditions. The results indicated that, in gesturing, subjects made more visual errors and fewer semantic/mixed errors in comparison to naming. Rumiati and Humphreys (1998) interpreted these results as evidence of the operation of a direct visual route to action in response to objects. One important feature of this work is that the stimuli were line drawings and not the real tools. Thus, the implicit hypothesis is that the structural description system can extract the

same kind of information from drawings than from real objects and, as a result, that this kind of information can directly be associated with the appropriate motor programs. This is a debatable point that deserves further consideration.

It has been widely suggested that object representations are essentially based on shape (Biederman, 1987; Marr & Nishihara, 1978). For example, the theory of recognition-by-components assumes that objects are represented as an arrangement of simple, convex, volumetric primitives (cones, wedges, blocks, cylinders), which can be specified by the edges provided (Biederman, 1987). The important corollary that follows is that the same kind of information can be extracted from drawings and real objects, thereby implying that there is no “real” difference at a perceptual level, between recognizing that a picture represents a hammer, recognizing that a toy represents a hammer or recognizing that a real object is a hammer. This is certainly true if the intended aim is to describe the world with words, but this appears to be far less true for tool use.

Indeed, it is not because you name a toy “hammer” that you can use it to pound a nail (e.g., a small plastic toy hammer). Likewise, it is not because you recognize a hammer drawn on a sheet of paper that you will use the sheet of paper to pound a nail (see Foucault’s essay untitled “This is not a pipe”; Foucault & Howard, 1976). If you use a hammer to pound a nail it is because you are able to extract from the physical attributes of the hammer the information relevant to the action “pounding a nail”. But, to pound a nail, you may also use any other object which possesses the attributes of the hammer, even if it is not a hammer (e.g., a shoe, pliers). Said in other words, humans seem to have two distinct way of “interpreting” the world: One which leads to describe the world with words and, as a result, to give the same name to objects whose use differs considerably (e.g., hand hammer, small plastic toy hammer, a picture/drawing of a hammer); another which leads to specify the use of tools and, thereby, to determine that objects with different names can be used for the same action (e.g., hammer,

pliers, shoe). This is the long-standing distinction between language and tool use, which can be illustrated, for example, by the dissociation described above between visual apraxia and optic aphasia.

So, it is very unlikely that a drawing of an object provides the information which is relevant to directly activate the motor representations associated with the use of the object, suggesting that the data collected by Rumiati and Humphreys (1998) cannot be interpreted in this way. Moreover, this view is confronted with a major problem. If the observation of a drawing of an object activates the motor representations of the use of the drawn object, then what activates the sheet of paper on which the object is drawn? A more likely possibility is that the demonstration of the use of a drawn object requires a system which translates the information contained in the drawing into a representation of the real object, a possibility which challenges the idea of a direct route between vision and action. It is noteworthy, however, that this possibility is not in conflict with theories of object recognition assuming that the shape of an object is fundamental to name it, regardless of whether it is the real object or one symbolic representation of this object (picture, drawing, toy).

Neuropsychological. Support for the direct visual route to action in response to objects also comes from neuropsychological work, particularly from the study of patients with optic aphasia, those patients who are able to gesture to sight of objects they are unable to name. It has been suggested that it reflects impaired access to a supra-modal semantic system from vision, and that the preserved ability to gesture to visually presented objects reflects the operation of a non-semantic direct route from object structural properties to gesture representations (Humphreys, 2001; Riddoch & Humphreys, 1987). Interestingly, the opposite pattern of deficit has been observed in patients with “visual apraxia”, those patients who may be impaired at making actions to visually presented objects, but may make appropriate gestures when given the object’s name and even name the object in front of them (De Renzi,

Faglioni, & Sorgato, 1982; Riddoch, Humphreys, & Price, 1989).

The hypothesis of a direct link between vision and action is implicitly grounded in the idea that human behaviour is based either on declarative knowledge or on procedural knowledge (e.g., Anderson, 1983; Tulving, 1985), thereby involving that the preserved ability to use tools in the presence of deficits of semantic memory necessarily involves the recruitment of procedural knowledge. But, it is not because some patients are unable to form semantic representations that their preserved ability to use tools must be viewed as emerging from routine-based learning-by-doing – we return to these matters later. In broad terms, although the dissociation between optic aphasia and visual apraxia clearly shows that the ability to name objects is supported by mental mechanisms distinct from those that support the ability to use objects, there is no clear evidence that this distinction demonstrates the existence of a direct route between vision and action.

Riddoch, Humphreys, Edwards, Baker, and Willson (2003; see also Humphreys, Riddoch, Forti, & Ackroyd, 2004) studied parietal patients who showed extinction when trying to report the names of two simultaneously presented objects. When stimuli were presented together but were not placed in the incorrect relative positions for action (the corkscrew going into the bottom of the wine bottle), these patients could report the name of one stimulus but not of both. When stimuli were placed in the correct relative positions for action (the corkscrew going into the cork at the top of the wine bottle), both stimuli were reported accurately significantly more often. These data were interpreted as indicating that implicit coding of the action relationship modulates visual selection, an interpretation which is consistent with the hypothesis of a direct link between vision and action.

This view is however debatable for two reasons. First, as in the previously cited studies, stimuli were pictures and not real objects. Again, it remains to be demonstrated that a picture of an object provides the information which is relevant to directly activate the motor

representations associated with the use of the object. Second, there is an alternative interpretation of these data which is that in patients with extinction visual selection is influenced, not by *action relations* between objects, but by *usual spatial relations* between objects. This alternative can be tested by comparing performance of patients with visual extinction for non-tool objects or things that are placed in the position in which we usually see them (the sun above a mountain, a man on a horse) with performance for non-tool objects or things that are not. The hypothesis of a direct link between vision and action predicts that selection should not be influenced by this experimental manipulation. Unfortunately, there is no such data available in the literature. In other words, the data obtained by Riddoch et al. (2003) are not sufficient to conclude that, in the context of naming, visual selection is influenced by action.

Further evidence. The hypothesis of a non-semantic route between vision and action assumes that posture selection should be guided by visual information, thus enabling patients to plan appropriate postures during tool use. Inversely, patients who perform appropriate postures during tool use should be able to use tools correctly. Recently, we tested these predictions by examining 16 left brain-damaged patients on a grip preference test (Osiurak et al., 2008a). Patients were required to pick up a familiar object (e.g., hammer) and to demonstrate how to use it with the corresponding object (nail). They could grasp the handle of the object with the (base of the) thumb either toward the instrumental part of the object (the head of the hammer) or away from it. Since patients were asked to use power grips, “thumb-toward” grips were considered to be appropriate and “thumb-away” grips inappropriate. Object orientation was manipulated (the handle toward versus away from the patient). We found that only one patient selected inappropriate grips. More interestingly, out of the 15 patients who performed appropriate grips, 4 patients showed difficulties in using objects correctly. These results challenge the hypothesis of a direct route between vision and action

by showing that during tool use the ability to plan appropriate postures use does not necessarily lead to use tools correctly².

In sum, it appears that (i) seeing *graspable* stimuli automatically activates grasping movements, (ii) these priming effects can be related to a specific neural network, as evidenced by neuroimaging studies and, (iii) a somewhat similar neural substrate devoted to the same purpose also exists in other primates. But, there is no clear evidence that the mere observation of a tool is sufficient to determine how to use it with other objects.

WHAT EVIDENCE FOR A DIRECT ROUTE BETWEEN TOUCH AND ACTION?

Vision plays a critical role in humans, yet it is not the only sensory modality used for interacting with the environment. For instance, it has been widely demonstrated that patients with deficits in pantomime frequently improve when they are allowed to actually use the tool (Clark et al., 1994; De Renzi et al., 1982; Geschwind, 1965; Wada et al., 1999). To account for this effect, it has been assumed that tactile and kinaesthetic feedback from the manipulated object may facilitate access to the adequate motor program and/or provide a direct link between object structure and function (Chainay, Louarn, & Humphreys, 2006; Geschwind, 1965; Graham, Zeman, Young, Patterson, & Hodges, 1999; Wada et al., 1999; Westwood et al., 2001). In other words, in a manner strongly similar to the idea of a direct route between vision and action, the hypothesis of a direct tactile route for object use has been posited. Support for this view comes from two studies that have reported a significant improvement in pantomiming when apraxic patients are allowed to grasp a neutral object during their performance (Graham et al., 1999; Wada et al., 1999).

Research for the two last decades has shown that the perception of objects' structural properties by touch is not passive, but is carried out by a variety of active "exploratory procedures" (Klatzky & Lederman, 2002). These manual procedures differ for distinct objects' qualities. For instance, enclosing an object briefly is sufficient to extract broad

information about it, such as volume or global shape. Rubbing can be used to explore texture, static contact to estimate the temperature and pressing to explore hardness of an object. Invariants based in an object's mass distribution, and specific to its geometric properties, can also be detected by dynamic touch. This is the kind of touch that occurs when one grasps an object firmly for the purpose of support and wielding (Carello, Thuot, Anderson, & Turvey, 1999; Carello & Turvey, 2000; Turvey, 1996). Evidence for the existence of the exploratory procedures has also been provided by neuropsychological studies of tactile apraxia (Binkofski, Kunesch, Classen, Seitz, & Freund, 2001; Valenza et al., 2001).

These findings are in disagreement with the idea that there is a direct route between touch and action, raising the question as to why apraxic patients improve their pantomiming performance when manipulating neutral non-tool objects. In fact, this conclusion was recently challenged by Hermsdörfer, Hentze and Goldenberg (2006) who did not find such improvement. They also stressed a certain number of limitations inherent to the work of Graham et al. (1999) and Wada et al. (1999) which seriously questioned the validity of their findings (see also Goldenberg, Hentze, & Hermsdörfer, 2004).

Besides, it is noteworthy that the improvement generally does not occur between the visual-only and tactile-only conditions, but between the visual and visual-plus-tactile conditions. Therefore, it can be reasonably suggested that the handling of the object, at least in part, correct the movement executed by the patients, particularly by forcing them to adopt an appropriate hand posture, a feature which is often used to assess pantomime (e.g., Buxbaum et al., 2005a, 2007). This may lead the clinician to consider the performance to be better. Moreover, unlike pantomime, actual use has to obey the mechanical demands of the task (e.g., the position of a nail determines the target of a hammer blow), which can guide the movement (Clark et al., 1994; Goldenberg et al., 2004; Hermsdörfer et al., 2006). Another likely hypothesis is that the actual use of the object avoids patients creating a mental image of

the object, emphasizing the role of mental imagery for pantomime (Goldenberg, 2003; Osiurak et al., 2009). In sum, no clear evidence indicates that tactile and kinaesthetic feedback provides a direct link between object structure and function.

THEORETICAL SHORTCOMINGS

So far we have discussed the lack of evidence for the computational hypothesis of a direct route between vision/touch and action. Of course, an absence of evidence does not constitute an evidence of absence. But, the computational hypothesis also suffers from theoretical shortcomings which, together with the empirical limitations, seriously question its capacity to account for human tool use.

The computational approach assumes that the human mind works as a computer system which receives sensory stimuli from the environment that it converts into symbol structures in memory (Vera & Simon, 1993). So, the human mind needs a “modular, structural description system” which extracts sensory information about object properties (e.g., colour, rigidity, texture, size, shape, etc.). All cognitive models of tool use posit the existence of such a system (e.g., Buxbaum, 2001; Rothi et al., 1991; Roy & Square, 1985; Yoon et al., 2002). Two fundamental questions nevertheless arise: What is a property? And, how does this modular system extract this property?

In modern philosophy, a property is an attribute of an object. Thus, a light object is said to have the property of lightness and a solid object is said to have the property of solidity (for discussion on this point, see Turvey, 1992). Therefore, according to the computational approach, the structural description system should be able, for instance, to extract the property “lightness” from the information contained in a wooden pencil. But, what does “a wooden pencil is light” mean? It can be considered to be light because it can be freely handled. However, this may be true for an adult but not for a very young child. Likewise, it can be too light to knock a bear out, but heavy enough to crush an ant. In broad terms, the properties we

ascribe to things are always relative to the actions we intend to perform with them. The same thing can be either light or heavy, either rigid or flexible, either dark or transparent, and so on. This corroborates the idea put forward more than a century ago by James (1890/2007b), and more recently by J. J. Gibson (1979), that we do not perceive the world without any intention³.

“All ways of conceiving a concrete fact, if they are true ways at all, are equally true ways. *There is no property ABSOLUTELY essential to any one thing.* The same property which figures at the essence of a thing on one occasion becomes a very inessential feature upon another. Now that I am writing, it is essential that I conceive my paper as a surface for inscription. If I failed to do that, I should have to stop my work. But if I wished to light a fire, and no other materials were by, the essential way of conceiving the paper would be as combustible material; and I need then have no thought of any of its other destinations. It is really *all* that it is: a combustible, a writing surface, a thin thing, a hydrocarbonaceous thing, a thing of eight inches one way and ten another, a thing just furlong east of a certain stone in my neighbor’s field, an American thing, etc., etc., *ad infinitum.*” (James, 1890/2007b, p. 333)

So to the question “How does the structural description system extract objects properties?” the answer is “By anticipating what information will be useful for other processing modules”, thereby suggesting that the functioning of the structural description system would be largely influenced by the other modules. However, this is formally incoherent with the proper definition of “modular” (Fodor, 1983; for discussion on this point; see Shaw, 2003; Turvey et al., 1981). Put differently, the hypothesis of a direct route between vision and action seems to be based on a paradoxical reasoning (Figure 1)⁴.

[INSERT FIGURE 1 ABOUT HERE]

One very likely reason for this paradox is that computational theories concentrate on how humans recognize the use of tools, leaving aside the question of the intentionality of the use. This has important implications for the methodology employed. To answer this question, the procedure generally used is to ask normal subjects or brain-damaged patients to pantomime the use of a single object (e.g., Chainay et al., 2006; Cubelli, Marchetti, Boscolo, & Della Sala, 2000; Heilman et al., 1982; Rumiati & Humphreys, 1998). But, how many times in your life have you been confronted with this kind of situations? Very few, probably. In fact, these

experimental situations do not reflect the relationships we usually have with tools. As J. J. Gibson (1979) stressed, in everyday life, the perception of the possibilities for action provided by the environment is guided by the intention of the organism at a given moment. So, the same tool can offer different possibilities for action at different times, suggesting that we do not “systematically” recognize the – usual – use of tools, but rather extract information from tools in order to fulfil our intentions.

The use of such a procedure also raises another tricky question: How does the experimenter decide what the correct use is? Generally, the correct use is the conventional use of the tool. For instance, when asked to demonstrate how a wooden pencil can be used, the expected response is a writing gesture. If an individual demonstrates that he or she can use it to crush an ant, the response will be probably considered as erroneous. Hence, this procedure is deeply ambiguous since what is really expected is that subjects do not demonstrate a possible use but the conventional use of the object (i.e., the usage). The implicit corollary is that subjects are supposed to directly perceive the use for which the tool has been manufactured. But, this would suggest that the structural description system is able to extract “essential” properties which are inherent to the human manufacture. However, as James (1890/2007b) stressed, “There is no property absolutely essential to any thing”. A possibility is that determining the usual use of an object requires semantic knowledge about the purpose for which the tool is usually used (Osiurak et al., 2008b, 2009). But if so, it is no longer possible to assume that the mere observation of a tool is sufficient to determine its utilization.

SUMMARY

Classically, it has been suggested that tool use is supported by semantic knowledge of object function. However, a substantial body of evidence has challenged this hypothesis (e.g., see Osiurak et al., 2008b, 2009). Hence, the hypothesis of a direct route between vision/touch and action has been formulated. This hypothesis assumes that the mere observation of a tool is

sufficient to activate the motor representations associated with the use of the tool with other objects. But, there is no clear evidence supporting it. In other words, the computational approach appears to be inappropriate for understanding the psychological basis of human tool use. Moreover, concentrating on “how humans recognize the use of tools” appears to be an epistemological obstacle to the understanding of human tool use. Of course, this is not to say that this way of addressing the question of tool use is completely uninteresting. It may be particularly useful for developing artificial systems which perform specific behaviour in response to a given stimulation. Put differently, it may be particularly useful for modelling systems which have only one way of interacting with the world, namely, according to the purpose for which they have been built. But, humans are different. As James (1890/2007b) and J. J. Gibson (1979) claimed, we do not perceive the world without any intention. And this is certainly this “intention” which enables us to envisage only one way of interacting with a given object, while this object can be used in a multitude of other ways. In other words, the specificity of human tool use can only be apprehended if we shift our attention from the question of “How do humans recognize the use of tools?” to the question of “Why do humans spontaneously use tools?”

THE ECOLOGICAL VIEW ON TOOL USE

THE CONCEPT OF AFFORDANCE

One long-standing question in psychology is how perception can guide action. Unlike serial stage models which claim that perception and action are linked to each other by a stimulus-response translation mechanism, J. J. Gibson (1966, 1979) argued that perception is “designed” for action: We do not perceive the properties of objects (e.g., stone is heavy), but their properties in relation to ourselves, that is, in terms of what they afford us (a small and light object is *grasp-able*). Thus, it has been demonstrated that, in the absence of any overt movement, people are able to judge whether or not a stair is climbable (Warren, 1984),

whether or not it is possible to walk through apertures (Warren & Whang, 1987), or whether or not an object is reachable by extending the arm (Carello, Groszofsky, Reichel, Solomon, & Turvey, 1989). To account for this, J. J. Gibson (1966) coined the term affordance.

J. J. Gibson (1979) strongly rejected the dichotomy between physical (objective, meaningless) and mental (subjective, meaningful) properties, in favour of the concept of an ecological level of reality. More precisely, he did not deny the existence of the environment as a whole with its unlimited possibilities, but believed that each animal perceives the environment differently, depending on the possibilities for action that the environment affords to it. Thus, the same environment can be perceived in different ways by organisms belonging to different species, but also by organisms of the same species or by the same organism at different times.

For J. J. Gibson (1979), affordances are action-referential properties of the environment that may or may not be perceived. This definition focuses on contributions of the physical system: Affordances are not created in the act of perception, they exist independent of it. If affordances are dispositions, they depend on the presence of an animal that can actualize them. Turvey (1992; see also Shaw et al., 1982) suggested that affordances are complemented by abilities, also termed effectivities⁵ (for a somewhat similar view, see Greeno, 1994; Michaels, 2003; Reed, 1996). Other have preferred not to define affordances as properties of the environment only, but rather as properties of the animal-environment system, thus arguing that they are emergent properties that do not inhere in the animal or the environment (Chemero, 2003; Stoffregen, 2003).

In sum, and even if the concept of affordance is still in development, all ecological psychologists agree that (i) affordances are animal-relative properties of the environment and (ii) the perception of affordances rests on the observer's ability to pick up invariant information from the world.

AFFORDANCE, GOAL AND FLEXIBILITY

For James (1890/2007a), we humans have the propensity to fail to notice that, when we are engaged in the analysis of what we are perceiving, we typically do not analyse what we are perceiving, but the outcome of the analysis. James called this error “psychologist’s fallacy”, an error which is typically committed in modern cognitive science (see Heft, 2003). The paradox shown in Figure 1 is one good illustration. The ecological approach strives to not commit this error and, as a result, assumes that the same environmental object can provide different affordances for an organism. Imagine for instance a cat which chases a mouse in a park. This park is enclosed by a two-metre wall, and in one of the sections of the wall there is a hole large enough to permit the mouse to pass through. During the chase, the mouse chooses this alternative, forcing the cat to see the wall as “jump-able”. Imagine now that the cat is chased by a dog. The same wall may be perceived as “perch-able” by the cat.

But, if the same object can provide different affordances, the crucial question obviously is: How does the organism choose among them? (For discussion; see Michaels, 2003; Michaels & Carello, 2001; Stoffregen, 2003; Turvey, 1992) To answer to this question, Michaels (2003) suggested that an affordance is an action required to satisfy some need. In broad terms, an affordance allows the establishment of a goal and a means for reaching it. This is well illustrated in the example above. Whereas the cat perceives the wall as “jump-able” (Affordance) when attempting to catch the mouse in order to feed (Goal), it perceives the wall as “perch-able” (Affordance) when attempting to escape from the dog in order to protect his life (Goal). But, interestingly, this does not imply that the wall is seen as “jump-able” by the cat only when it chases the mouse to feed. If this cat is a male, it may also see the wall as “jump-able” (Affordance) when attempting to get to a female cat which is at the other side of the wall in order to reproduce (Goal). So, although the perception of affordances is “guided” by the intention of the organism at a given moment (Michaels, 2003), the organism can perceive the same affordance as suitable for reaching different goals. In sum, the perception

of affordances is an adaptive process which enables the animal to have a certain kind of *flexibility* in the way of interacting with the world.

TOOLS AFFORD USE

Traditionally, the study of tool use has not been the focus of attention in the ecological approach, primarily dealing with immediate organism – environment couplings such as spatial orientation and posture maintenance (van Leeuwen, Smitsman, & van Leeuwen, 1994). J. J. Gibson (1979; see also Turvey, 1992) claimed that what we perceive when we look at “detached objects” – i.e., tools – are not their qualities (e.g., colour, rigidity, texture, size, shape, etc.) but their affordances, that is, invariant combinations of variables which satisfy a goal. For instance, an elongated object of moderate size and weight affords wielding. But, if used to hit or strike, it is a club or hammer.

A major challenge of the ecological approach lies in the determination of specificity (Turvey & Shaw, 1995, 1999). For example, what information specifies that an aperture is walk-through-able by a human? Warren and Whang (1987) asked normal subjects to walk through apertures of different widths to determine empirically the critical aperture-to-shoulder-width ratio (A/S) marking the transition from frontal walking to body rotation. They demonstrated that the critical point in free walking occurs at $A/S = 1.30$ and that the perception of “passability” is based on body-scaled eye-height information.

The same kind of questions has been posed for tool use. For instance, what information specifies that an object is “hammer-with-able” or “poke-with-able”? As mentioned above, dynamic touch is the type of touch used when an object is grasped and wielded by means of muscular effort (J. J. Gibson, 1966). Objects have different mass distributions and, as a result, resist in different ways when they are rotated in different directions. The quantification of mass distribution in terms of the inertia tensor provides a basis for distinguishing different object properties (Carello & Turvey, 2000; Shockley, Carello, & Turvey, 2004; Turvey,

1996). Wagman and Carello (2001; see also Wagman & Carello, 2003) asked normal participants to rate the “hammer-with-ability” and “poke-with-ability” of wooden rods by dynamic touch. They found that the two affordances are actually perceptible by dynamic touch, confirming that the perception of affordance can be extended to the domain of tools.

THEORETICAL SHORTCOMINGS

The question of tool use is relatively delicate because it implies not only relationships between an organism and a tool (e.g., a screwdriver) and between an organism and an object (screw), but also a dual relationship between a tool and an object (Drillis, 1963). This latter relationship cannot be expressed in terms of the ratios between the organism and the environment (van Leeuwen et al., 1994). After all, it is not because a twig is wield-able for a chimpanzee that its size is suitable for a termite nest. There are actually a great number of twigs that a chimpanzee can handle which are too large for a termite nest. Likewise, birds can manipulate a great number of things with their beak, but only some of these things are suitable for building nests. This is even more significant for humans. For instance, we are able to determine that an airplane is heavy enough to crush a car or a tree trunk is long enough to be used as a bridge linking the two banks of a river, while we can manipulate neither the airplane nor the car, neither the river nor the tree trunk. In other words, the dual relationship between a tool and an object cannot be “constrained” by the organism’s effectivities.

Of course, the mere thought of a relation (e.g., an airplane can crush a car) is not sufficient to produce it. Tools cannot be used without the intervention of the user. This is also true for construction behaviour, since no construction can be made without the intervention of the builder. It is possible to envisage that the perception of affordances can be crucial to guide the selection of the most appropriate objects to perform the task. But, as mentioned above, the perception of affordances appears inappropriate to explain how the dual relationship between a tool and an object, or the relationship existing between the different components of a

construction⁶ is determined. The study conducted by Wagman and Carello (2001) provides a good description of it.

Wagman and Carello (2001) argued that a paradigmatic poker is an elongated and somewhat bottom-heavy implement, such as a billiard cue. Actually, this presupposes that the target is an object of the size of a billiard ball, since a billiard cue is far from appropriate for poking a heavy table or a car. Inversely, a billiard cue can be suited for hammering a nail or a pin into a wall. So, to demonstrate poking, the experimenter showed the subjects a horizontally oriented wooden rod loosely situated in a wooden block and used the tip of another wooden rod to poke the rod through the block. To demonstrate hammering, the experimenter showed the subjects a vertically oriented wooden rod firmly situated in a wooden block and used the shaft of another rod to pound the rod through the wooden block. In other words, subjects had to rate the “hammer-with-ability” and “poke-with-ability” of the wooden rods when used in these precise situations, suggesting that they were not asked to decide whether the tasks of hammering or poking were possible or not. In fact, they could not have made such a decision without knowing the objects which were supposed to be hammered and poked. This study provides strong support for the proposal that once the idea of the task to accomplish is formed, the perception of affordances can guide the selection of the most appropriate objects to perform the task (among the potential objects, which one is the best suited for executing the movement of hammering). But, it is not because the subjects rated one of the wooden rods as “not particularly appropriate” for poking, that they considered that it could not be used for poking⁷. In sum, this study tells us nothing about the psychological mechanisms which enable the user to establish the dual relationship between the tool and the object, nor does it tell us about whether the notion of affordance is still appropriate for defining this kind of dual relationships, that is, a major issue for the ecological approach.

Turvey (1992) is clear on this issue.

“8.4. An affordance is a particular kind of disposition, one whose complement is a dispositional property of the organism”. (Turvey, 1992, p. 179)

“Before proceeding, however, I should address the scope of Item 8.4. First, it does not delimit the dispositionals of significance to animal activity. There are significant dispositionals whose complements are not properties of organisms. Nest building, tool use, and the like, depend on the selection of propertied things (e.g., twigs of a certain range of magnitude and pliability) that are functionally suited to other propertied things (e.g., a particular configuration of tree branches), neither of which may be in the class of organism. Second, Item 8.4. does not delimit the organism with the complementing property as the would-be actor. In the form stated, 8.4. encompasses both affordances for the self and affordances for another.” (Turvey, 1992, p. 180)

We are sympathetic to the idea that the properties of an object can only emerge in relation to another object, regardless of whether these two objects are two organisms, an organism and the environment or two environmental objects used together by an organism. As Turvey (1992) suggested, there is certainly no difference at a physical level between a twig used by a chimpanzee to fish termites and a fishing rod used by a human, or between a nest built by a bird and a house built by a human. In all these cases, the occurrence of the phenomenon (e.g., the nest) is entirely due to the existence of physical invariants (twigs of a certain range of magnitude and pliability). However, such a definition of affordance contributes more to the description of physical phenomena – this definition being nothing else than a synonym for “disposition” – than to the understanding of the psychological mechanisms which support them (Chemero, 2003).

J. J. Gibson (1979) supported a view somewhat similar to Turvey (1992) by considering that the theory of affordances also applies to the perception of the function of tools, namely, the relation between tools and objects. However, this view is contradictory with the fundamental principle of the theory of affordances, namely: Affordances are action-referential properties of the environment. More precisely, to be “ecological”, the theory of affordances assumes that objects have inherent meanings which are detected by the organism in function of its intended goals. Thus, an organism can perceive that “an object is small and light enough to afford grasping” or that “a surface is solid enough to afford walking”. But, the question

remains open as to how an organism's possibilities for action can constrain to perceive that "the object α is heavy enough to afford hammering with the object β but not the object γ ", or that "the object π is friable and dark enough to afford writing with the object σ but not the object μ ". So, the theory of affordances needs to be extended and modified to include new hypotheses about the psychological mechanisms supporting tool use. But, by assuming that affordances are not necessarily action-referential properties of the environment (Turvey, 1992) or by arguing that the theory of affordances applies to tool use without explaining how it is possible, the concept of relevance might lose its relevance (Heft, 2003; Michaels, 2003).

The ability to use tools requires more than the mere perception of affordances provided by tools: This also requires determining a dual relationship between the tool and the object. As Drillis (1963) suggested, a tool (i) must be able to perform the function for which it is intended (relationship between the tool and the object) and ii) must be proportioned to the dimensions of the user (relationship between the user and the tool). In line with Michaels (2003), we posit that the concept of affordances must be restricted to the ability for an animal to detect relationships between its "body" and the environment (Point 2 of Drillis, 1963).

SUMMARY

The major contribution of the ecological approach is to bypass the problem of the modularity by arguing that organisms do not perceive the world without any intention. In this way, the theory of affordances provides an appropriate account of the perception of the relationships between the organism and the environment (Heft, 2003; Michaels, 2003). However, this approach fails to account for how humans determine the dual relationships between tools and objects, which is particularly problematic to understand what is so special about human tool use since it is certainly at this level that humans differ from non-human animals.

The aim of the ecological doctrine of necessary specificity is the search of the laws of the

ecological scale – the scale at which animals and environment are defined – that make cognition possible. Consistent with this, we are firmly convinced that the way in which humans and non-humans alike interacts with the world can be specified through these laws. In other words, the theory of affordances offers an appropriate account of the perception of the relationships between the organism and the environment, when the scope is at the action level. But, as mentioned above, when we shift our attention to other levels of analysis (individual, species), things change dramatically, with only humans using spontaneously and constantly tools. So, although the ecological approach allows us to formulate laws which explain how organisms perceive possibilities for action, the challenge remains to formulate an additional principle which could account for the specificity of human tool use. In addition, not to hypothesize a cognitive functioning that would be entirely unique to humans, it appears necessary to maintain the idea that humans like animals interact with the environment through the perception of affordances. We return to the issue of Hume's touchstone later. Before doing so, we offer a new approach that aims to overcome the challenge formulated above.

THE DIALECTICAL THEORY OF HUMAN TOOL USE

DISCONTINUITY BETWEEN HUMAN AND NON-HUMAN MINDS

There is a growing body of evidence indicating that tool use is not a characteristic feature of genus *Homo* (for reviews, Baber, 2003; Beck, 1980; van-Lawick-Goodall, 1970). In the previous section, we have concluded that the perception of affordances cannot account for how the user establishes relations between environmental objects. So, two fundamental questions arise: Which is the nature of the mental mechanisms underlying tool use? And, is it the same mechanisms in humans and non-humans?

A series of studies have revealed serious limitations on the ability to non-human animals to solve tool use situations that are relatively simple for humans. Capuchin monkeys are dexterous tool-users in captivity as well as in the wild (van Schaik et al., 1999). Visalberghi

and Limongelli (1994) tested four adult capuchin monkeys to reach a piece of food placed inside a transparent tube using a stick (i.e., the “trap-tube task”). There was in the middle of the tube a visible hole with a small transparent cup attached. If the capuchin pushed the piece of food over the trap-hole, the reward fell into the cup and became inaccessible. The results indicated that, after about 90 trials, only one out of the four capuchin monkeys learned to push the piece of food away from the hole. Visalberghi and Limongelli (1994) then rotated the tube so that the hole was facing up and irrelevant. They found that the only successful capuchin still persisted in treating the trap-hole as if it needed to be avoided. In contrast, children over 3 years of age succeed in the trap-tube task after only a few trials (Visalberghi & Tomasello, 1998). Many other studies have provided evidence for the absence of any “intuitive” theory among non-human primates (Fujita, Kuroshima, & Asai, 2003; Limongelli, Boysen, & Visalberghi, 1995; Povinelli, 2000; Santos, Pearson, Spaepen, Tsao, & Hauser, 2006; Visalberghi & Trinca, 1989) as well as in woodpecker finches, which are famous for their spontaneous tool use behaviour in the wild (Tebbich & Bshary, 2004; see also Seed, Tebbich, Emery, & Clayton, 2006; Tebbich, Seed, Emery, & Clayton, 2007).

These findings are instructive for at least two reasons. Firstly, they indicate that it is not because some animals exhibit behaviour seemingly analogous to human ones that the underlying mental mechanisms are analogous too. After all, the similarity between human and non-human tool behaviour can be merely due to the presence of similar morphological characteristics (e.g., the ability to handle objects), which phenomenologically leads to the observation of analogous behaviour. So, it seems necessary to escape the argument by analogy in order to finally admit the existence of a *psychological* diversity (Penn et al., 2008; Penn & Povinelli, 2007; Povinelli, 2004; Povinelli et al., 2000; Vonk & Povinelli, 2006).

Secondly, by demonstrating that animals cannot “understand” unobservable properties of objects, these findings open interesting perspectives as to the nature of mental mechanisms

underlying animal tool behaviour. One plausible account is that tool-using behaviour in non-humans stems from an associative learning process, progressively leading the animal to associate one action (e.g., grasping a twig with the hand, picking up a stone with the beak) with another (inserting the twig in a hole, throwing the stone at the ground), and so forth (Penn & Povinelli, 2007; Povinelli, 2000, 2004; Tebbich & Bshary, 2004; Tomasello & Call, 1997; Vonk & Povinelli, 2006). Put differently, tool behaviour in non-humans may be supported by the perception of affordances, associated with a trial-and-error learning process.

It is crucial to note that this proposal is not in conflict with other proposals that stress the ability of some non-human animals to execute a sequence of tool behaviours in a flexible way (e.g., Baber, 2003). Chimpanzees, for example, have been shown to be capable of completing four or more steps to manufacture spear-like tools during hunting, including breaking off living branches, trimming leaves and side branches from the main branch or trimming off one or both ends of branch. The sequence of steps is hierarchically organized, with some steps that can be repeated and others that can be omitted, demonstrating the flexibility involved in an otherwise structured process (Pruetz & Bertoni, 2007). A comparable degree of flexibility has also been observed in tool-making (Hunt & Gray, 2004) and nest construction (Barnett, 1998) by birds. Recently, it has also been demonstrated that rooks, which does not appear to use tools in the wild, are able to solve a complex tool-use problem, consisting in raising the level of water of a pitcher so that a floating worm moves into reach (Bird & Emery, 2009). Interestingly, all four subjects solved the problem with an appreciation of precisely how many stones were needed, and three rooks also quickly learned to use large stones over small ones, and that sawdust cannot be manipulated in the same manner as water.

However, the findings reported above indicate that, despite this possible flexibility, non-human animals, tool users as non-tool users, are not able to incorporate an abstract representation of the underlying generative mechanisms involved and, as a result, cannot

transfer the relations they learn to other situations (Penn et al., 2008; Penn & Povinelli, 2007; Povinelli, 2004; Vonk & Povinelli, 2006).

TOOL, TECHNIQUE AND PURPOSE

Leroi-Gourhan (1971, 1973) pointed out that the technical evolution of all human societies is characterized by the ability to acquire a technique to reach a specific goal and to transfer it to reach another goal. To paraphrase him, the same knife, for instance, can be either a weapon or a tool according to the intended goal. When used for cutting a piece of wood, it is a tool. When used for cutting bread, it is a kitchen utensil, unless it is the knife used by a baker, and it becomes again a tool. It can also be used for cutting the throat of a sheep, and it becomes a tool. But, if it is used for cutting the throat of a human being, it is a weapon. Finally, if this knife is near a bowl of fruits, it can be used for peeling a fruit, but if it is on a desk, it can be used for opening letters. In broad terms, there is no close relationship between techniques and purposes, so that the same technique (cutting action) can be used to achieve several distinct goals (to feed, to hunt, to defend oneself) and, inversely, the same goal (to defend oneself) can be achieved by several distinct techniques (cutting action, pounding action, and so on) (for a discussion on this point, see Osiurak et al., 2008b, 2009; Osiurak, Jarry, & Le Gall, in press).

Things are different in non-humans. Chimpanzees are known to use stone tools to crack nuts (e.g., Matsuzawa, 2001). However, they do not use the technique of percussion for other purposes. After all, they do not drop heavy stones or nuts from the top of trees onto enemies. Likewise, beavers are known to be great dam builders (see Hansell & Ruxton, 2008). So, why have they not built wooden houses throughout Canada? Or, why have they not used their long-standing knowledge about construction to build bridges or fish pens and cages? These comments are clearly consistent with the claims of Penn et al. (2008) that non-human animals do not understand “unobservable causal properties” such as support and gravity, nor do they reason about the higher-order relation between causal relations in an analogical fashion.

Instead, they appear to solve “tool-use problems based on evolved, domain-specific expectations about what perceptual features are likely to be most salient in a given context and a general ability to reason about the causal relation between observable contingencies in a flexible, goal-directed but task-specific fashion.” (Penn et al., 2008; p. 119)

In summary, the ideas presented by Penn et al. (2008) and Leroi-Gourhan (1971, 1973) are complementary, with one proposing that humans alone are able to do “analogical reasoning”, and the other pointing out that the ability to transfer a technique from one goal to another – that is, to do analogical reasoning – is possible only if there is no close relationship between techniques and goals.

THE TECHNICAL REASONING HYPOTHESIS

There is a subtle belief which is deeply ingrained in the minds of psychologists and neurologists alike, that is, tool use is supported by implicit, procedural knowledge. Many models of human memory assume the distinction between procedural and declarative knowledge (Anderson, 1983; Squire, 1987; Tulving, 1985). Declarative knowledge is knowledge of facts and principles. It is represented symbolically and is accessible to conscious recollection. By contrast, procedural knowledge is thought as a set of learned behavioural routines that fit various situations, including tool use. The influence of this belief is clearly apparent in modern cognitive models of apraxia in which the distinction between declarative and non-declarative knowledge is generally drawn (Buxbaum, 2001; Cubelli et al., 2000; Rothi et al., 1991; Roy & Square, 1985).

However, this view is challenged by the findings described above indicating that human tool use is based on a specific ability to do analogical reasoning (Penn et al., 2008). Of course, this is not to say that we, humans, are able to form a declarative representation of each of the underlying generative mechanisms we understand. We probably learn the “lever” principle or the “tracing” principle well before being able to specify them with precise concepts. But, it is

not because we are not able to form such representations that our understanding of these principles can be viewed as emerging from routine-based learning-by-doing. In fact, the idea that human tool use requires reasoning about the physical properties of objects is relatively old. For example, it is in the chapter devoted to reasoning that James (1890/2007b) concluded that “*there is no property absolutely essential to any one thing*” (see above). The idea that human tool use can be performed by means of a certain kind of reasoning has also been put forward under the notions of naïve physics reasoning (McCloskey, 1983), analogical reasoning (Penn et al., 2008; Povinelli, 2000), causal beliefs (Wolpert, 2003) or direct inference of function from structure (Goldenberg & Hagmann, 1998; Johnson-Frey, 2003).

Likewise, we recently proposed that human tool use is supported by the ability to do technical reasoning (Osiurak et al., 2008b, 2009; see also Gagnepain, 1990; Le Gall, 1998). Although this hypothesis shares some resemblance with the proposals cited just above, it differs in one crucial way: It does not assume that object properties can be “objectively” extracted and then used for later processing (inferential or causal), a view inspired by the computational approach and which is highly debatable (see above). By contrast, the technical reasoning hypothesis posits that technical reasoning is based on abstract, technical laws. Let us consider the example of the technical law “tracing”: An object which is friable and either darker or clearer than another object that is porous affords tracing⁸. An individual acquiring the principle of “tracing” will be able to determine that this can be performed by using a pencil with a sheet of paper or with a white wall, by using a white chalk with a black board or with a tarmac surface, by using an eye pencil with an eyelid or with a sheet of paper, and so on. In other words, once an individual acquires a technical law, he or she can reify it in a multitude of things so as to achieve a wide range of goals. Furthermore, the properties “transparent/dark” and “friable/porous” does not exist independently from the technique “tracing” (Gagnepain, 1990). Said in other words, each technical law involves a close

relationship between object properties and a technique in a manner similar that the perception of affordances involves a close relationship between object properties and the “capacities” of an organism. This is the reason why we posit that technical principles are laws and not rules (for discussion on this distinction, see Shaw, 2003).

One major corollary is that there is no overlapping between the *technical* reality and the *physical* reality. Indeed, the same physical material (e.g., glass) can provide distinct technical materials (resistant, sharp, transparent, etc.) and, inversely, the same technical material (e.g., resistant) can be provided by distinct physical materials (wood, metal, plastic, etc.). In addition, the same physical material does not always provide the technical material suitable for an intended action since, for instance, the lead of a pencil is friable when applied to paper but not to leather. In broad terms, technical laws are abstract principles acquired with experience, which are not linked with any specific object representation.

EVIDENCE FOR THE TECHNICAL REASONING HYPOTHESIS

The technical reasoning hypothesis predicts that the inability to do technical reasoning should impair performance in any situation requiring the use of objects. Several lines of evidence support this idea. For instance, Goldenberg and Hagmann (1998) developed a test of mechanical problem solving requiring the selection and application of novel tools. They found a strong association in left brain-damaged patients between mechanical problem-solving skills and the capacity to use familiar objects (see also Goldenberg & Spatt, 2009; Hartmann, Goldenberg, Daumüller, & Hermsdörfer, 2005). Mechanical problem-solving skills can also be disrupted in patients with corticobasal degeneration, who are known to be impaired in everyday activities involving object use (Hodges, Spatt, & Patterson, 1999; Spatt, Bak, Bozeat, Patterson, & Hodges, 2002).

Recently, we examined 20 left brain-damaged patients, 11 right brain-damaged patients and 41 healthy controls on a test assessing the conventional use of familiar objects (e.g.,

screwing a screw with a screwdriver) as well as on the Unusual Use of Objects test, which demands unusual applications of objects to achieve a purpose for which the usually applied object is not provided (e.g., screwing a screw with a knife) (Osiurak et al., 2009). We found that left brain-damaged patients have more difficulties on the Unusual Use of Objects Test than controls or right brain-damaged patients, and that the severity of their impairment was correlated with that on conventional use of objects. These findings provide additional support for the technical reasoning hypothesis.

NOT COMPETITIVE, BUT RATHER COMPLEMENTARY

In neuropsychology and cognitive science, the mechanisms responsible for the use of tools are generally not considered as complementary but rather as competitive (Figure 2). This is the famous “multiple routes for action” (Pilgrim & Humphreys, 1991; Rothi et al., 1991; Roy & Square, 1985; Rumiati & Humphreys, 1998). The same logic has been applied to “affordances” and “technical reasoning” (e.g., Bozeat et al., 2002; Hodges et al., 2000). From what we have said so far, this view is debatable.

[INSERT FIGURE 2 ABOUT HERE]

First, according to some computational models, the mere observation of tools directly activates motor representations of how to use them with other objects. This is the hypothesis of a direct route between perception and action, a view which has been largely inspired by the ecological theory of affordances (e.g., Humphreys, 2001). Experimental, neuropsychological and neuroimaging data have been provided to support this hypothesis. But, as discussed above, these data only demonstrate that the mere observation of *graspable* stimuli directly elicits detection of actor-object complementarities. In broad terms, the direct route hypothesis cannot account for how humans use tools with other objects.

Likewise, we have concluded that the ecological theory of affordances is greatly insufficient to explain the specificity of human tool use. Of course, this is not to deny that, in

non-human animals, the perception of affordances, associated with a trial-and-error learning process, could be the means by which tool use is performed (for a somewhat similar viewpoint, see Povinelli, 2000; Tomasello & Call, 1997). After all, given that tools are manipulable objects, all species endowed with manipulative skills can exhibit tool behaviour. But, the process of trial-and-error learning is highly context-dependant – or rather tool-dependant – and, as a result, does not allow to users to understand the physical principles involved. The corollary is that in animals tool behaviour is supposed to take place only when certain favourable environmental conditions are satisfied, corroborating for instance the literature on non-human primates, which clearly indicates that tool use is rare and incidental in the wild (Byrne, 2004; van Schaik et al., 1999, 2003; for a similar conclusion for birds, see Beck, 1980; Chappell & Kacelnik, 2002). By contrast, humans use a wide range of different tools everyday and can learn how to use new tools very easily as well as transfer the underlying physical principles to other objects. In other words, the process by which human behaviour is guided during tool use cannot be supported merely by the perception of affordances, associated with a trial-and-error learning process (Figure 2).

Second, as discussed earlier, there is evidence supporting the idea that technical reasoning is a uniquely human trait. Although the technical reasoning hypothesis may be particularly convenient to explain what is so special about human tool use, an important issue remains to be solved: How can the product of this reasoning, which is abstract, guide human behaviour in real world? The most likely possibility is that the translation of this reasoning into actions is accomplished through a “sensorimotor interface”. Whatever the nature of the interface is, technical reasoning alone does not allow humans to interact with the world (Figure 2).

So, it appears that neither technical reasoning alone nor the perception of affordances alone account for human tool use. To solve this apparent dilemma, we propose that these two mechanisms are not competitive, but rather complementary (Figure 3). More precisely,

although technical reasoning enables humans to imagine other ways of acting, the product of this reasoning is abstract and, therefore, needs to be translated into affordances in order to interact with the environment accordingly.

[INSERT FIGURE 3 ABOUT HERE]

THE PARADOX OF HUMAN TOOL USE

To understand why do humans spontaneously use tools, it is fundamental to wonder first: What benefit do we seek from using tools? It has been repeatedly argued that an important feature of tools is that they enable the user to amplify its sensorimotor capabilities (Baber, 2003; Beck, 1980; Goldenberg & Iriki, 2007; Johnson-Frey, 2004, 2007; van-Lawick-Goodall, 1970). Said in other words, tools enable the user to improve its way of interacting with the environment. This is certainly true, but it is crucial to note that “improvement” cannot arise unless there is something to be improved. The corollary is that humans are actually never satisfied with the tools they use (Leroi-Gourhan, 1971, 1973). It is worth to stressing that this feeling does not stem from the fact that tools are ineffective for the intended purposes. They are inevitably appropriate since otherwise prehistoric people could not have survived. After all, a stone is as suitable as an electrical knife for cutting meat. So, the question arises: Why make new ways of cutting meat?

One way to solve this problem is to take into consideration the paradox inherent to the use of any tool, namely: While our tools give us the illusion of constantly doing less (e.g., TV remote control), we are still forced to use body action in order to operate them (pushing buttons with the fingers). After all, even though an electrical knife enables us to cut without having to “gesticulate” too much, it is not *the* solution because it must be firmly held during its utilization. Likewise, although travelling by car is far less exhausting than travelling by horse, the car is not *the* solution. We must drive it and stay inside of it throughout the journey. Typewriters and computers are also not *the* solution, since they require staying in front of

them during the use, and they do not work unless we strike their keys. In a way, technical progress does not exist per se, since humans are always forced to intervene to operate the tools they use. So, to the question “What benefit do we seek from using tools?” our answer is “the benefit of having to do less to reach a given goal”, which is paradoxical since tools, like any other elements of the environment, need our body to work.

THE PRINCIPLE OF DIALECTIC

The thesis we defend here is that humans have the ability to think that body action is a problem to be solved. And it is precisely at this point that technical reasoning occurs. But, even if the ability to do technical reasoning gives to humans the illusion of constantly doing less (e.g., TV remote control), they are still forced to use body action – and to detect affordances – to operate the product of the reasoning (pushing buttons with the fingers). This is the principle of dialectic, which was originally introduced in the field of tool use by Gagnepain (1990).

It is noteworthy that the main feature of the principle of dialectic is to take into consideration both the specificity of human reasoning and the natural, animal abilities of humans. Humans are able to imagine that they communicate without having to speak (i.e., telepathy), they move objects without having to touch them (i.e., telekinesis) or they move themselves without having to move (i.e., teleportation). But, all of these are only the product of technical reasoning, and the physical constraints of their body force them to use far less imaginative devices. Thus, although an electrical knife is less tedious and time-consuming than a stone to cut meat, it still requires to be handled. Likewise, a car cannot be driven without a steering wheel. And even if an individual designs a car which can be driven at a distance, he still needs a remote control device to steer the car. But, interestingly, it is precisely because we can never be free from the necessity to perform body action in order to interact with the environment and, as a result, to operate our tools, that we always have

“technical” problems to be solved.

Another important feature of the principle of dialectic is not to apply merely to tool use. The definition of tool use is one of convenience rather than psychological distinctness (Beck, 1980; Hansell & Ruxton, 2008) and, as mentioned above, we do not challenge the view that non-human animals can exhibit tool behaviour in a manner similar to humans. Therefore, humans do not only “think” that the actions performed with the hands can be problems, but that all body actions can be problematic. Cars, airplanes, bicycles, and carriages were and are still used to solve the problem: Having to walk to get from the point *A* to the point *B*. The problem is essentially the same for elevators, bridges, roads, and even for TV monitors which solve the problem of going out to watch movies, shows and sport, or to get information. In fact, even the mere fact of having to stay at a place without having anything to do may be viewed as a problem to be solved, because it also requires body action. Think for instance when you wait for a friend in front of his or her door. It has certainly happened to most of us to view this situation as problematic and to seek solutions to solve this problem, such as leaving a message on the door or calling the friend on the phone. In sum, the present theory posits that all the artefacts which surround us (cars, bridges, roads, airplanes, computers, telephones, and so on) are the product of the dialectical functioning of the human mind.

HUMANS DIG THE DITCHES THEY HAVE TO PASS OVER

To fully understand the principle of dialectic, let us illustrate it with the “set-of-shelves” problem which can be summed up as follows: Why do people use a set of shelves? A good way to address this problem, we think, is to imagine how a bookseller would keep many books tidy without it (Figure 4). Although the number of solutions is very large, we only consider two of them here: Grouping books either into columns or into rows. Whatever the solution chosen by the bookseller may be, both require a certain set of actions from him: Walking from column/row to column/row, bending down to better read the title of books,

moving the books which are at the top of the column in order to reach the desired one, picking up/grasping the book, and so forth. Moreover, the piles of books may also waste so much space that the bookseller may be required to store DVDs behind the books, forcing him to move the books when he decides to reach a DVD. Regardless of the amount of body action necessary to find the desired book, all actions performed are effective because they allow the bookseller to achieve his goal and, there would be no reason that either of these two ways of storing books would be abandoned. So, why use a set of shelves?

[INSERT FIGURE 4 ABOUT HERE]

We posit that the first movement of the dialectic (from affordance perception to technical reasoning) corresponds to the ability to view body action as a problem to be solved, regardless of the affordances perceived by the individual. It is precisely at this point that technical reasoning occurs, to propose new ways of interacting with the environment. For instance, the bookseller may think about the technical law “support”: An object which is denser and larger than another object affords support. Technical reasoning aims at finding out new ways of interacting with the environment. But, the product of the reasoning is abstract and, if the bookseller wants to apply it, he must translate, reify it into the real world by taking into consideration the existing physical constraints: His body and the books, that is, the two components which formed the original *ecosystem* (see Shaw, 2003). Therefore, he will not seek *an object* which is denser and larger than *another one*, but *something* which is denser and larger than *a pile of books* (e.g., a wooden board). Likewise, the height at which the support will be placed must fit his height, since otherwise he could not read the title of books. In broad terms, while the first movement of the dialectic allows humans to escape egocentric relationships, which directly link them to the environment, the second movement of the dialectic (from technical reasoning to affordance perception) forces them to reify the reasoning into the real world in order to interact with the environment again and, as a result,

to perceive affordances (Figure 3).

With regard to our example, the obvious question arises: Must the bookseller hold the set of shelves himself at the appropriate height? Although this is a solution, everyone agrees that it is very inconvenient. So, according to the principle of dialectic, the bookseller could consider that holding the set of shelves is a problem to be solved and, as a result, reasons about other ways of holding the set of shelves at the appropriate height without having to do it himself (an instance of qualitative stigmergy, see below). In sum, the dialectical process is an ongoing mechanism which offers solutions to the problems it raises⁹. As Gagnepain (1990) claimed, “humans dig the ditches they have to pass over”.

DIALECTIC AND SELF-ORGANIZATION

A key organizational feature of all human societies lies in the desire to constantly innovate and move away from previous technical equipments (Leroi-Gourhan, 1971, 1973). This is made possible by the existence of an indirect cooperation between human individuals, which consists in continuing the work of others at whatever stage of its development (e.g., the evolution of cutting techniques from stone tools to electrical knives). Any society can be seen as an “organism”, that is, a complex, definitely coordinated and therefore individualized system of activities (Wheeler, 1911). Nevertheless, the individuals that make it up do not possess the laws of organization of this system and behave as if they were alone. So, even if the present theory in line with the ideas of folk psychology (Wundt, 1912) assumes that what happens at the level of the society inevitably reflects the psychological functioning of each individual, it remains to understand how the connection between the level of the individual and the level of the society is made.

Indirect cooperation is not unique to humans. Social insect colonies also present highly structured organizations which are regulated by indirect communication between individuals. Grassé (1959) introduced the term *stigmergy* to describe this phenomenon of self-

organization. Nest building in termites is the typical example of stigmergy. Termite workers use soil pellets, which they impregnate with pheromone. The existence of an initial deposit of soil pellets stimulates the same worker or any other worker in the colony to accumulate more material. The accumulation of material reinforces the attractivity of deposits through the diffusing pheromone emitted by the pellets, and pillars can emerge. However, if the density of workers is too small, the phenomenon disappears between two successive passages by the builders, and the amplification mechanism cannot work. In broad terms, the coordination and regulation of building activities in social insects do not depend on the workers themselves but are achieved by the structure they build.

Two different forms of stigmergy have been identified (Theraulaz & Bonabeau, 1999). With *quantitative* stigmergy, the environmental configuration does not differ qualitatively, and only modifies the probability for the individuals to interact with this configuration. The construction of pillars in termites provides a good illustration of quantitative stigmergy. With *qualitative* stigmergy, qualitatively different environmental configurations result in different actions. Put simply, an insect responds to a configuration *A* with action *A* and responds to configuration *B* with action *B*. Interestingly, the execution of action *B* can transform the configuration *B* into the configuration *A*, leading to the execution of action *A*, which can also transform the configuration *A* into the configuration *B*. A good example of qualitative stigmergy is comb building in social wasps (Theraulaz & Bonabeau, 1999; see also Bonabeau, Theraulaz, Deneubourg, Aron, & Camazine, 1997).

By integrating the principles of stigmergy and dialectic into a single coherent framework, the present theory offers an effective way of addressing the issue of how the indirect cooperation underlying human technical evolution can result from idiosyncratic characteristics of individual behaviour. The principle of dialectic assumes that each human individual is able to view as problematic the body action associated with the use of the tools

available in its society (e.g., stone tools to cut meat) and, therefore, imagine other ways of acting (knives). But, this new way of acting always requires body action. The consequence is that the use of the new technique can also be viewed as problematic by the same individual or any other human individual, again leading to the creation of a new technique (electrical knives). This is an instance of qualitative stigmergy: Configuration *A* (use of technique *A*) triggers Action *A* (creation of technique *B*); Creation of technique *B* transforms Configuration *A* into Configuration *B* (use of technique *B*) that triggers Action *B* (creation of technique *C*). Moreover, whereas in some cases, the product of technical reasoning leads to the creation of new techniques, in other cases, similarly as for nest building by termites some factors can prevent the creation and/or the propagation of the new technique (e.g., the social status of the individual, the availability of the material resources). This is an instance of quantitative stigmergy. In sum, the organization of human societies can be conceived as an activity of the whole organism-environment system that is governed by laws of self-organization (see Järvillehto, 1998), thus explaining how and why human societies can accomplish complex tasks that far exceed the capacities of a single individual (e.g., walk on the Moon, fly in the air).

THE ROLE OF SEMANTIC MEMORY IN TOOL USE

As mentioned above, a significant body of literature has shown that conceptual knowledge about object function and the ability to use tools can be impaired independently from each other. Despite these findings, many works continue to assume that conceptual knowledge about object function can be used in tool behaviour (e.g., Bozeat et al., 2002). This is certainly another consequence of the “multiple-routes” hypothesis. Although in the present theory we posit that conceptual/semantic knowledge is not directly involved in tool use, we do not think, however, that “semantic memory” does not play any role.

Recently, we described the behaviour of a patient, MJC, who showed a severe semantic

impairment (Osiurak et al., 2008b). She encountered difficulties in demonstrating the use of tools in isolation (e.g., using a screwdriver without the screw). Nevertheless, MJC used almost systematically the desk to show the use of objects, as if she attempted to bring out mechanical relationships from the tools and the desk. For instance, when given a key, she used it for scrapping the chamfered edge of the wooden desk. In a way, the ability to do technical reasoning was relatively intact. This hypothesis was supported by the fact that the presence of corresponding objects improved considerably the performance (e.g., using a screwdriver with the screw). She also performed normally the Unusual Use of Objects Test, which demands unusual applications of tools to achieve a goal for which the usually applied object is not provided (e.g., screwing a screw with a knife). We interpreted the difficulties encountered by MJC in using tools in isolation as a selective semantic impairment. Indeed, demonstrating the use of an isolated object requires conceptual knowledge to specify its usual purpose (in which context it is used, with which kind of objects) in order to, subsequently, reason about the technical means it provides. By contrast, the role played by conceptual knowledge would be considerably reduced as soon as the entire “mechanical device” is given, such as in the context of the use of objects with their corresponding objects. In this case, technical reasoning could be sufficient to support the utilization.

Support for this view also comes from the work of Sirigu, Duhamel, and Poncet (1991) who reported a somewhat similar strategy in a patient (FB) with bitemporal lobe lesions caused by herpetic encephalitis. FB was unable to recognize many common objects but could nevertheless describe how they could be manipulated. When asked to identify a nail clipper, for instance, he said: “It can attach several sheets of paper together. You turn the piece on the top and tip it back (makes the precise movement sequence). You press and it maintains them” (Sirigu et al., 1991, p. 2566). Like MJC, FB could show a potential utilization by using contextual cues such as a stack of sheets of paper on a desk, but could not determine the usual

purpose by retrieving conceptual knowledge (for similar reports, see also Dumont, Ska, & Schiavetto, 1999; Hayakawa, Yamadori, Fujii, Suzuki, & Tobita, 2000).

We propose that semantic memory might be particularly useful for tool use by allowing humans to reify the product of technical reasoning into non-immediate environments. This is fully consistent with the idea that semantic memory enables people to think about things that are not here now (Tulving, 1985). To illustrate this point, let us come back to the set-of-shelves problem. We assume that, if the bookseller was only able to do technical reasoning, he would have no other choice than to probe the environment which surrounds him in order to reify the product of the reasoning. However, because he has access to semantic information, he is able to represent and mentally operate on situations that are not present to his senses. Therefore, he can represent his house, his garage or even the home improvement superstore to which he usually goes, and mentally search for an appropriate object such as a wooden board.

The semantic memory hypothesis has been originally formulated in the context of the computational approach (Tulving, 1985), a theoretical orientation which differs from the present theory. Of course, we do not assume that tool use is supported by the ability to extract object properties (structural description system) and to store knowledge about object function (semantic memory). Nevertheless, we cannot dispute the idea that humans are able to remember in which context a word like “scalpel” is used, where cactus is a common plant or for which purpose a computer is usually used. Put simply, we cannot dispute the idea that humans are able to save the *usage* of words, names, objects, places, and so on. Therefore, even if the connection we propose here between the dialectical theory of human tool use and the semantic memory hypothesis may appear awkward because of the theoretical discrepancy, we assume that the understanding of why and how humans save the usage of tools (for which purpose a given tool is usually used) can only be achieved through the marriage of the two approaches (see Osiurak et al., 2008b, in press). This constitutes an interesting challenge for

future research.

SUMMARY AND NEW DIRECTIONS FROM THE DIALECTICAL THEORY OF HUMAN TOOL USE

SUMMARY

One of the purposes of the present paper was to examine the potential of the computational view and the ecological view to account for human tool use. From our discussion, we have highlighted several theoretical and empirical limitations inherent to the computational approach, emphasizing its capacity to resolve the HOW issue. By considering that the human cognitive system contains a structural description system which extracts object properties in a modular fashion, the computational approach commits the mistake of focusing on the outcome of the analysis of what humans perceive instead of on the analysis of what humans perceive, an error called “psychologist’s fallacy” by James (1890/2007a). Moreover, this view leads to concentrate on “how humans recognize the use of tools”, which is an epistemological obstacle to the understanding of human tool use. After all, how many times in a day do we wonder: What is that object? We generally ask ourselves this question when we intend to describe the environment that surrounds us. But, when we interact with the environment, we first intend to achieve a purpose and then we determine what is the potential of the objects surrounding us – or not (see the discussion on the role of semantic memory just above) – for the intended purpose. Moreover, this approach presents the drawback of focusing on the action level, inevitably leading to formulate models explaining how an individual performs a given behaviour in response to a given stimulation, but not why humans spontaneously engage in object-object manipulations (K. R. Gibson, 1991).

The major contribution of the ecological approach is to bypass the problem of the modularity by stressing that organisms do not perceive the world without any intention. As J. J. Gibson (1979) claimed, perception is designed for action, implying that the meaning of the objects is entirely inherent to the organism’s possibilities for action. In a way, the ecological

approach emphasizes the important idea that “there is no property absolutely essential to any one thing” (James, 1890/2007b). But, unfortunately, this approach fails to account for how humans determine the dual relationships between tools and objects, which is particularly tricky to understand what is so special about human tool use since it is certainly at this level that humans differ from non-human animals. Nevertheless, the theory of affordances provides an appropriate account of the perception of the relationships between the organism and the environment (Heft, 2003; Michaels, 2003).

In response, we offer an original theoretical framework based on the idea that affordance perception and technical reasoning work together in a dialectical way. This theory is inspired by the theory of affordances (J. J. Gibson, 1979) as well as the work of Gagnepain (1990) on the dialectical functioning of the human mind. In line with J. J. Gibson (1979), the present theory holds that organisms interact with the environment through the perception of affordances, which are action-referential properties of the environment. In non-human animals, this ability, associated with an associative learning process, could support tool use (Penn & Povinelli, 2007; Penn et al., 2008; Tebbish & Bshary, 2004; Tomasello & Call, 1997). In humans, this hypothesis cannot be supported: Besides the ability to solve easily tool use situations – which appear to be considerably difficult for non-humans –, we engage spontaneously in object-object manipulations and possess a vast repertoire of tool use skills. To account for this, we propose that in humans, there is an additional process, the ability to do technical reasoning. A somewhat similar view has already been expressed (Johnson-Frey, 2003; Povinelli, 2000, 2004, Wolpert, 2003). But, the originality of the present theory is to account for how affordances and technical reasoning are linked together, via a principle of dialectic. This principle describes more than a simple mutual relationship between affordance perception and technical reasoning. It accounts for how the idea of using a tool spontaneously emerges in humans. Moreover, the integration of the principles of dialectic and stigmergy into

a single coherent framework provides an effective way of addressing the issue of what are the principles behind the self-organization of human societies?

The following lines summarize the key points of the present theory. (1) Any definition of tool use is one of convenience rather than psychological distinctness (Beck, 1980; Hansell & Ruxton, 2008). (2) It is not because other species exhibit behaviour similar to our own that similar psychological causes are at work (Povinelli et al., 2000). (3) What happens at the species level inevitably reflects the psychological functioning of each individual (Wundt, 1912). (4) There is no property absolutely essential to any one thing (James, 1890/2007b). (5) Perception is designed for action (J. J. Gibson, 1979). (6) Humans alone are able to acquire a technique to reach a specific goal and to transfer it to reach another goal (Leroi-Gourhan, 1971, 1973), that is, to do analogical reasoning (Penn et al., 2008). (7) The ability to use tools gives humans the illusion of constantly doing less, but they are still forced to use body action to operate the tools (Gagnepain, 1990). (8) Humans are unique because of their dialectical functioning: Humans raise the problems they have to solve (Gagnepain, 1990). (9) The regulation of societies results from idiosyncratic features of individual behaviour (Grassé, 1959).

NEW DIRECTIONS

Obviously, we are aware that the dialectical theory of human tool use raises a certain number of issues to which we have no satisfactory answers at this time. What is the precise nature of the technical laws? And how are they reified into affordances? How does the understanding of these technical laws change with age? Is it possible to envisage that some human pathologies result from the inability to view body action as problematic? (The first movement of the dialectic) Nevertheless, we are convinced that the present theory sheds a new light on the issue of human tool use, and provides new interesting directions for future research in psychology and neurosciences.

By assigning well-defined and distinct roles to affordances and technical reasoning, the present theory is based on the principle of economy which might renew the question of tool use impairment. For example, it is well known that brain-lesioned patients continue to demonstrate how to use tools, even when they have difficulties in using them (De Renzi & Lucchelli, 1988; De Renzi et al., 1968; Le Gall, 1998; Osiurak et al., 2009). This aspect has been totally ignored, attention being paid to the nature of the cognitive deficit. By contrast, it is also well known that patients with severe dementia tend to use directly the hands to interact with the environment. This may provide evidence that, while some brain damage impairs the ability to do technical reasoning without disturbing the process of dialectic, more severe damage can impair the dialectical process (Osiurak et al., 2009).

A second example can be given in the field of apraxia. Dressing apraxia, a severe difficulty in putting on an article of clothing or even an inability to dress, may occur after damage to the left or right hemisphere (De Ajuriaguerra, Hécaen, & Angelergues, 1960). This disorder rarely appears in isolation and, as a result, it has been speculated that it is simply the manifestation of an underlying problem, such as unilateral neglect, spatial disorientation and perceptual deficits (Walker & Walker, 2001). The present theory leads to the formulation of several testable predictions, one of which is that inability to do technical reasoning should not only impair the use of manipulable objects, but also the use of non-manipulable objects such as clothes. Therefore, and without ignoring that dressing apraxia may be caused by other neurological disorders, it can be suggested that left-damaged patients with dressing apraxia should encounter more difficulties than left-damaged patients without dressing apraxia in tasks requiring technical reasoning such as the Novel Tool Test (Goldenberg & Hagmann, 1998) or the Unusual Use of Objects test (Osiurak et al., 2009).

The ability to make one tool in order to create another has been suggested to necessitate a high degree of cognitive sophistication, so it might distinguish humans from non-human

animals (K. R. Gibson, 1993; Johnson-Frey, 2007; Napier, 1980; Oakley, 1949; Wolpert, 2003). This view has been recently challenged by evidence from tool-making activities by animals. For instance, chimpanzees have been shown to be capable of completing four or more steps to manufacture spear-like tools during hunting (Pruetz & Bertoni, 2007). The sequence of steps is hierarchically organized, with some steps that can be repeated and others that can be omitted, demonstrating the flexibility involved in an otherwise structured process. Likewise, crows have been reported to manufacture stepped tools for probing insects (Hunt, 1996). It has also been noted that tool manufacture activity by crows is far from stereotyped because defective tools are promptly discarded (Hunt & Gray, 2004). Taken together, these data strongly support the conclusion that the human ability to use a tool to make another cannot be distinguished from animal tool making because it involves more “hierarchical mental constructional skills” (K. R. Gibson, 1993). Of course, this is not to deny that most human tool manufacture involves a far greater degree of transformation of the raw material than is characterized by the behaviours reported above. However, it seems that this apparent greater complexity does necessarily mean more efficient “planning” skills.

By assuming that humans are unique because they can view body action as a problem to be solved, the present theory provides an original account of the ability to use a tool to create another one, without positing any additional mechanism (principle of theoretical economy). Let us illustrate this with the example of an individual who intends to catch a rabbit to eat it. If this individual is human, the present theory assumes that he or she may spontaneously regard the running action as a problem to be solved and do technical reasoning in order to find out solutions. One solution may be to use a trap, or more precisely, a hole into which the rabbit may fall. So the initial sequence of actions consisting in running after the rabbit and catching it is now replaced “making a hole and waiting for the rabbit to fall into it”. However, given that making a hole requires body action, such as digging with the hands or with the feet,

again the individual may spontaneously view it as a problem to be solved and do technical reasoning in order to find out solutions, such as the use of a shovel. And so on (qualitative stigmergy). Interestingly, the shovel is here a tool which is used to create another one (the hole), suggesting that the principle of dialectic can explain how and why humans use a tool to create another one.

CONCLUSION

One of the chief aims of anthropology is the study of the human mind under the varying condition of environment and culture. Whether the human mind is unique in some aspects has always engendered heated debate among scholars (e.g., Darwin, 1871/1981; Hauser, Chomsky, & Fitch, 2002; Lévi-Strauss, 1962; Penn et al., 2008; Watson, 1913). René Descartes, the high-priest of scientific quasi-Creationists, believed that the laws that govern human behaviours and actions and the theories that explain them must be quite unlike to those that govern animal behaviours and actions (see Massey, 1993). Indeed, unlike animals, humans have free choice, that is, they are able to act contrary to the dictates of their nature. Mind is uniquely human. The antithesis of this doctrine was stated by Hume (1739/1978), who suggested that the resemblance of the external actions of animals to those we perform demonstrate that their internal actions resemble ours and, as a result, the causes from which they derived must also be resembling (see Massey, 1993). In a way, Hume (1739/1978) formulated the idea of a psychological continuity based on the argument by analogy¹⁰, which is also called “Hume’s touchstone” (see Turvey & Shaw, 1999). The dialectical theory of human tool use is not true to Hume’s touchstone, raising the question as to whether it does not risk reviving the spectre of Cartesian dualism. We conclude by explaining why it is not so.

Unlike some psychological theories that have focused on the specificity of human mind in different aspects of cognition (e.g., Hauser et al., 2002; Penn et al., 2008; Tomasello & Call, 1997), the present theory is largely inspired from the ecological approach by assuming that

affordance perception is the key principle which enables organisms to interact with the world, thereby permitting to escape from two harmful forms of dualism: The dualism of mind and body and the dualism of animal and environment (see Turvey & Shaw, 1995, 1999). In other words, the present theory does not ignore that humans are organisms and that they interact with the environment with the same laws.

However, if there are “phenomena that can be shown unequivocally to be particular to humans” (Turvey & Shaw, 1999), an interesting challenge is to formulate a theory that allows us to account for the specificity of human tool use without violating the key principle of affordances. This is precisely what the dialectical theory does by assuming that technical reasoning is based on abstract, technical laws. Indeed, each technical law involves a close relationship between object properties and a technique in a manner similar that the perception of affordances involves a close relationship between object properties and the capacities of an organism. In sum, the present theory proposes an original way of solving the long-standing issue of the dualism of mind and body (see Gagnepain, 1990), without reviving the spectre of Cartesian dualism.

ACKNOWLEDGEMENTS

We are grateful to Georg Goldenberg and two anonymous reviewers for their many helpful comments and suggestions on earlier versions of the manuscript.

REFERENCES

- Anderson, J. R. (1983). *The architecture of cognition*. Cambridge: Harvard University Press.
- Baber, C. (2003). *Cognition and tool use: Forms of engagement in human and animal use of tools*. London: Talyor & Francis.
- Barnett, S. A. (1998). Instinct. In G. Greenberg, & M. M. Haraway (Eds.), *Comparative psychology: A handbook* (pp. 138–149). New York: Galland Press.
- Bartolo, A., Daumüller, M., Della Sala, S., & Goldenberg, G. (2007). Relationship between object-related gestures and the fractionated object knowledge system. *Behavioural*

Neurology, 18, 143–147.

Beck, B. B. (1980). *Animal tool use behavior: The use and manufacture of tools by animals*. New York: Garland STPM Press.

Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, 94, 115–147.

Binkofski, F., Kunesch, E., Classen, J., Seitz, R. J., & Freund, H. -J. (2001). Tactile apraxia. Unimodal disorder of tactile object exploration associated with parietal lesions. *Brain*, 124, 132–144.

Bird, C. D., & Emery, N. J. (2009). Rooks use stones to raise the water level to reach a floating worm. *Current Biology*, 19, 1410–1414.

Bonabeau, E., Theraulaz, G., Deneubourg, J. -L., Aron, S., & Camazine, S. (1997). Self-organization in social insects. *Trends in Ecology and Evolution*, 12, 188–193.

Boswall, J. (1977). Tool using by birds and related behaviour. *Aviculture Magazine*, 83, 88–97.

Bozeat, S., Lambon Ralph, M. A., Patterson, K., & Hodges, J. R. (2002). When objects lose their meaning: What happens to their use? *Cognitive, Affective and Behavioral Neurosciences*, 2, 236–251.

Breuer, T., Ndoundou-Hockemba, M., & Fishlock, V. (2005). First observation of tool use in wild gorillas. *PLoS Biology*, 3, 2041–2043.

Buxbaum, L. J. (2001). Ideomotor Apraxia: A call to action. *Neurocase*, 7, 445–448.

Buxbaum, L. J., Johnson-Frey, S. H., & Bartlett-Williams, M. (2005a). Deficient internal models for planning hand-object interactions in apraxia. *Neuropsychologia*, 43, 917–929.

Buxbaum, L. J., Kyle, K. M, Grossman, M., & Coslett, H. B. (2007). Left inferior parietal representations for skilled hand-object interactions: Evidence from stroke and corticobasal degeneration. *Cortex*, 43, 411–423.

- Buxbaum, L. J., Kyle, K. M., & Menon, R. (2005b). On beyond mirror neurons: Internal representations subserving imitation and recognition of skilled object-related actions in humans. *Cognitive Brain Research*, *25*, 226–239.
- Buxbaum, L. J., Schwartz, M. F., & Carew, T. G. (1997). The role of memory in object use. *Cognitive Neuropsychology*, *14*, 219–254.
- Buxbaum, L. J., Sirigu, A., Schwartz, M. F., & Klatzky, R. (2003). Cognitive representations of hand posture in ideomotor apraxia. *Neuropsychologia*, *41*, 1091–1113.
- Byrne, R. W. (2004). The manual skills and cognition that lie behind hominid tool use. In A. E. Russon & D. R. Begun (Eds.), *The evolution of thought* (pp. 31–44). Cambridge: University Press.
- Carello, C., Groszofsky, A., Reichel, F. D., Solomon, H. Y., & Turvey, M. T. (1989). Visually perceiving what is reachable. *Ecological Psychology*, *1*, 27–54.
- Carello, C., Thuot, S., Anderson, K. L., & Turvey, M. T. (1999). Perceiving the sweet spot. *Perception*, *28*, 307–320.
- Carello, C., & Turvey, M. T. (2000). Rotational dynamics and dynamic touch. In M. Heller (Ed.), *Touch, representation and blindness* (pp. 27–66). Oxford: Oxford University Press.
- Cesari, P., & Newell, K. M. (2002). Scaling the components of prehension. *Motor Control*, *6*, 347–365.
- Chainay, H., Louarn, C., & Humphreys, G. W. (2006). Ideational action impairments in Alzheimer's disease. *Brain and Cognition*, *62*, 198–205.
- Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *NeuroImage*, *12*, 478–484.
- Chappell, J., & Kacelnik, A. (2002). Tool selectivity in a non-primate, the New Caledonian crow (*Corvus moneduloides*). *Animal Cognition*, *5*, 71–78.
- Chemero, A. (2003). An outline of a theory of affordances. *Ecological Psychology*, *15*, 181–

195.

- Chemero, A., Klein, C., & Cordeiro, W. (2003). Events as changes in the layout of affordances. *Ecological Psychology, 15*, 19–28.
- Clark, M. A., Merians, A. S., Kothari, A., Poizner, H., Macauley, B., Rothi, L. J. G., & Heilman, K. M. (1994). Spatial planning deficits in limb apraxia. *Brain, 117*, 1093–1106.
- Coltheart, M. (2005). Modelling reading: The dual-route approach. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 6–23). Malden: Blackwell.
- Craighero, L., Fadiga, L., Rizzolatti, G., & Umiltà, C. A. (1999). Action for perception: A motor-visual attention effect. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1673–1692.
- Cubelli, R., Marchetti, C., Boscolo, G., & Della Sala, S. (2000). Cognition in action: Testing a model of limb apraxia. *Brain and Cognition, 44*, 144–165.
- Darwin, C. (1981). *The descent of man and selection in relation to sex*. Chichester: Princeton University Press. (Original work published 1871)
- De Ajuriaguerra, J., Hécaen, H., & Angelergues, R. (1960). Les apraxies: Variétés cliniques et latéralisation lésionnelle. *Revue Neurologique, 102*, 566–633.
- De Renzi, E. (1989). Apraxia. In F. Boller, & J. Grafman (Eds.), *Handbook of Neuropsychology* (pp. 245–263). Amsterdam: Elsevier.
- De Renzi, E., Faglioni, P., & Sorgato, P. (1982). Modality-specific and supramodal mechanisms of apraxia. *Brain, 101*, 301–312.
- De Renzi, E., & Lucchelli, F. (1988). Ideational apraxia. *Brain, 111*, 1173–1185.
- De Renzi, E., Pieczuro, A., & Vignolo, L. A. (1968). Ideational apraxia: A quantitative study. *Neuropsychologia, 6*, 41–52.
- Drillis, R. J. (1963). Folk norms and biomechanics. *Human Factors, 5*, 427–441.
- Dumont, C., Ska, B., & Schiavetto, A. (1999). Selective impairment of transitive gestures: An

- unusual case of apraxia. *Neurocase*, 5, 447–458.
- Ellis, R., & Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British Journal of Psychology*, 91, 451–471.
- Fodor, J. (1983). *The modularity of mind*. Cambridge: MIT Press.
- Forde, E. M. E., & Humphreys, G. W. (2000). The role of semantic knowledge and working memory in everyday tasks. *Brain and Cognition*, 44, 214–252.
- Foucault, M., & Howard, R. (1976). Ceci n'est pas une pipe. *October*, 1, 6–21.
- Fujita, K., Kuroshima, H., & Asai, S. (2003). How do tufted capuchin monkeys (*Cebus apella*) understand causality involved in tool use? *Journal of Experimental Psychology: Animal Behavior Processes*, 19, 233–242.
- Gagnepain, J. (1990). *Du vouloir dire: Du signe, de l'outil*. Bruxelles: De Boeck Université.
- Geschwind, N. (1965). Disconnection syndrome in animal and man. *Brain*, 88, 585–644.
- Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston: Houghton-Mifflin Co.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton-Mifflin Co.
- Gibson, K. R. (1991). Tools, language and intelligence. Evolutionary implications. *Man*, 26, 255–264.
- Gibson, K. R. (1993). Generative interplay between technical capacities, social relations, imitation and cognition. In K. R. Gibson & T. Ingold (Eds.), *Tools, language and cognition in human evolution* (pp. 131–137). New York: Cambridge University Press.
- Goldenberg, G. (2003). Pantomime of object use: A challenge to cerebral localization of cognitive function. *NeuroImage*, 20, 101–106.
- Goldenberg, G. (2008). Apraxia and the parietal lobes. *Neuropsychologia*, 47, 1449–1559.
- Goldenberg, G., & Hagmann, S. (1998). Tool use and mechanical problem solving in apraxia.

Neuropsychologia, 36, 581–589.

Goldenberg, G., Hentze, S., & Hermsdörfer, J. (2004). The effect of tactile feedback on pantomime of tool use in apraxia. *Neurology*, 63, 1863–1867.

Goldenberg, G., & Iriki, A. (2007). From sticks to coffee-maker: Mastery of tools and technology by human and non-human primates. *Cortex*, 43, 285–288.

Goldenberg, G., & Spatt, J. (2009). The neural basis of tool use. *Brain*, 132, 1645–1655.

Grafton, S. T., Fadiga, L., Arbib, M. A., & Rizzolatti, G. (1997). Premotor cortex activation during observation and naming of familiar tools. *NeuroImage*, 6, 231–236.

Graham, N. L., Zeman, A., Young, A. W., Patterson, K., & Hodges, J. R. (1999). Dyspraxia in a patient with corticobasal degeneration: The role of visual and tactile inputs to action. *Journal of Neurology, Neurosurgery and Psychiatry*, 67, 334–344.

Grassé, P. P. (1959). La reconstruction du nid et les coordinations interindividuelles chez *bellicositermes natalensis* et *cubitermes* sp. La théorie de la stigmergie: Essai d'interprétation du comportement des termites constructeurs. *Insectes Sociaux*, 6, 41–81.

Greeno, J. G. (1994). Gibson's affordances. *Psychological Review*, 101, 336–342.

Grèzes, J., & Decety, J. (2002). Does visual perception of object afford action? Evidence from neuroimaging study. *Neuropsychologia*, 40, 212–222.

Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience*, 17, 2735–2740.

Hansell, M. (1987). What's so special about using tools? *New Scientist*, 1542, 54–56.

Hansell, M., & Ruxton, G. D. (2008). Setting tool use within the context of animal construction behaviour. *Trends in Ecology and Evolution*, 23, 73–78.

Hart, B. L., Hart, L. A., McCoy, M., & Sarath, C. R. (2001). Cognitive behaviour in Asian elephants: Use and modification of branches for fly switching. *Animal Behaviour*, 62, 839–

847.

- Hartmann, K., Goldenberg, G., Daumüller, M., & Hermsdörfer, J. (2005). It takes the whole brain to make a cup of coffee: The neuropsychology of naturalistic actions involving technical devices. *Neuropsychologia*, *43*, 625–627.
- Hauser, M. D., Chomsky, N., & Fitch, T. (2002). The faculty of language: What is it, who has it, and how did it evolve? *Science*, *298*, 1569–1579.
- Hayakawa, Y., Yamadori, A., Fujii, T., Suzuki, K., & Tobita, M. (2000). Apraxia of single tool use. *European Neurology*, *43*, 76–81.
- Heft, H. (2003). Affordances, dynamic experience, and the challenge of reification. *Ecological Psychology*, *15*, 149–180.
- Heilman, K. M., Rothi, L. J., & Valenstein, E. (1982). Two forms of ideomotor apraxia. *Neurology*, *32*, 342–346.
- Hermsdörfer, J., Hentze, S., & Goldenberg, G. (2006). Spatial and kinematic features of apraxic movement depend on the mode of execution. *Neuropsychologia*, *44*, 1642–1652.
- Hodges, J. R., Bozeat, S., Lambon Ralph, M. A., Patterson, K., & Spatt, J. (2000). The role of knowledge in object use: Evidence from semantic dementia. *Brain*, *123*, 1913–1925.
- Hodges, J. R., Spatt, J., & Patterson, K. (1999). “What” and “how”: Evidence for the dissociation of object knowledge and mechanical problem-solving skills in the human brain. *Proceeding of the National Academy of Sciences of the United States of America*, *96*, 9444–9448.
- Hume, D. (1978). *A treatise of human nature*. Oxford: Oxford University Press. (Original work published 1739)
- Humphreys, G. W. (2001). Objects, affordances, action. *The Psychologist*, *14*, 408–412.
- Humphreys, G. W., Riddoch, J., Forti, S., & Ackroyd, K. (2004). Action influences spatial perception: Neuropsychological evidence. *Visual Cognition*, *11*, 401–427.

- Hunt, G. R. (1996). Manufacture and use of hook tools by New Caledonian crows. *Nature*, 379, 249–251.
- Hunt, G. R., & Gray, R. D. (2004). The crafting of hook tools by wild New Caledonian crows. *Proceedings of the Royal Society of London*, 271B, S88–S90.
- James, W. (2007a). *The principles of psychology, Vol. 1*. New York: Cosimo Classics. (Original work published 1890)
- James, W. (2007b). *The principles of psychology, Vol. 2*. New York: Cosimo Classics. (Original work published 1890)
- Järvilehto, T. (1998). The theory of the organism-environment system. I. Description of the theory. *Integrative Physiological and Behavioural Science*, 33, 335–342.
- Jeannerod, M., Arbib, M. A., Rizzolatti, G., & Sakata, H. (1995). Grasping objects: The cortical mechanisms of visuomotor transformation. *Trends in Neurosciences*, 18, 314–320.
- Johnson-Frey, S. H. (2003). What’s so special about human tool use? *Neuron*, 39, 201–204.
- Johnson-Frey, S. H. (2004). The neural bases of complex tool use in humans. *Trends in Cognitive Sciences*, 8, 71–78.
- Johnson-Frey, S. H. (2007). What puts the how in where? Tool use and the divided visual streams hypothesis. *Cortex*, 43, 368–375.
- Johnson-Frey, S. H., & Grafton, S. T. (2003). From “acting on” to “acting with”: The functional anatomy of action representation, In C. Prablanc, D. Pélisson, & Y. Rossetti (Eds.), *Progress in brain research* (pp. 127–139). New York: Elsevier.
- Klatzky, R. L., & Lederman, S. J. (2002). Touch. In A. F. Healy, & R. W. Proctor (Eds.), *Experimental Psychology* (pp. 147–176). New York: Wiley.
- Lauro-Grotto, R. Piccini, C., & Shallice, T. (1997). Modality-specific operations in semantic dementia. *Cortex*, 33, 593–622.

- Le Gall, D. (1992). Apraxies idéo-motrice et idéatoire: Revue critique de la littérature. *Revue de Neuropsychologie*, 2, 325–371.
- Le Gall, D. (1998). *Des apraxies aux atechnies: Propositions pour une ergologie clinique*. Bruxelles: De Boeck Université.
- Lefebvre, L., Nicolakakis, N., & Boire, D. (2002). Tools and brains in birds. *Behaviour*, 139, 939–973.
- Leroi-Gourhan, A. (1971). *L'Homme et la matière*. Paris: Albin Michel.
- Leroi-Gourhan, A. (1973). *Milieu et techniques*. Paris: Albin Michel.
- Lévi-Strauss, C. (1962). *La pensée sauvage*. Paris: Plon.
- Limongelli, L., Boysen, S. T., & Visalberghi, E. (1995). Comprehension of cause-effect relations in a tool-using task by chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology*, 109, 18–26.
- Marr, D., & Nishihara, H. K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proceedings of the Royal Society of London*, 200B, 269–294.
- Martin, A., Wiggs, C. L., Ungerleider, L. G., & Haxby, J. V. (1996). Neural correlates of category-specific knowledge. *Nature*, 379, 649–652.
- Massey, G. (1993). Mind-body problems. *Journal of Sport and Exercise Psychology*, 15, S97–S115.
- Matsuzawa, T. (2001). Primate foundations of human intelligence: A view of tool use in nonhuman primates and fossil hominids. In T. Matsuzawa (Ed.), *Primate origins of human cognition and behavior* (pp. 1–25). New York: Springer-Verlag.
- McCloskey, M. (1983). Intuitive physics. *Scientific American*, 248, 395–400.
- McFarland, D. (1982). *The Oxford companion to animal behavior*. Oxford: Oxford University Press.

- McGrew, W. C. (1992). *Chimpanzee material culture: Implications for human evolution*. Cambridge: Cambridge University Press.
- Michaels, C. F. (2003). Affordances: Four points of debate. *Ecological Psychology, 15*, 135–148.
- Michaels, C. F., & Carello, C. (1981). *Direct perception*. New York: Appleton-Century-Crofts.
- Napier, J. R. (1980). *Hands*. New York: Pantheon.
- Negri, G. A., Lunardelli, A., Reverberi, C., Gigli, G. L., & Rumiati, R. I. (2007). Degraded semantic knowledge and accurate object use. *Cortex, 43*, 376–388.
- Oakley, K. P. (1949). *Man the toolmaker*. London: British Museum.
- Ochipa, C., Rothi, L. J. G., & Heilman, K. M. (1989). Ideational apraxia: A deficit in tool selection and use. *Annals of Neurology, 25*, 190–193.
- Ochipa, C., Rothi, L. J. G., & Heilman, K. M. (1992). Conceptual apraxia in Alzheimer's disease. *Brain, 115*, 1061–1071.
- Osiurak, F., Aubin, G., Allain, P., Jarry, C., Etcharry-Bouyx, F., Richard, I., & Le Gall, D. (2008a). Different constraints on grip selection in brain-damaged patients. Object use versus object transport. *Neuropsychologia, 46*, 2431–2434.
- Osiurak, F., Aubin, G., Allain, P., Jarry, C., Richard, I., & Le Gall, D. (2008b). Object usage and object utilization. A single-case study. *Neurocase, 14*, 169–183.
- Osiurak, F., Jarry, C., Allain, P., Aubin, G., Etcharry-Bouyx, F., Richard, I., Bernard, I., & Le Gall, D. (2009). Unusual use of objects after unilateral brain damage. The technical reasoning model. *Cortex, 45*, 769–783.
- Osiurak, F., Jarry, C., & Le Gall, D. (in press). De l'ouvrage à l'usage. Réflexion sur les concepts d'improvisation et de pérennité. *Tétralogiques*.
- Parker, S. T., & Gibson, K. R. (1977). Object manipulation, tool use and sensori-motor

- intelligence as feeding adaptations in cebus monkeys and great apes. *Journal of Human Evolution*, 6, 623–641.
- Penn, D. C., Holyoak, K. J., & Povinelli, D. J. (2008). Darwin's mistake: Explaining the discontinuity between human and nonhuman minds. *Behavioral and Brain Sciences*, 31, 109–130.
- Penn, D. C., & Povinelli, D. J. (2007). Causal cognition in human and nonhuman animals: A comparative, critical review. *Annual Review of Psychology*, 58, 97–118.
- Pilgrim, E., & Humphreys, G. W. (1991). Impairment of action to visual objects in a case of ideomotor apraxia. *Cognitive Neuropsychology*, 8, 459–473.
- Povinelli, D. J. (2000). *Folk physics for apes*. New York: Oxford University Press.
- Povinelli, D. J. (2004). Behind the ape's appearance: Escaping anthropocentrism in the study of other minds. *Daedalus*, 133, 29–41.
- Povinelli, D. J., Bering, J. M., & Giambrone, S. (2000). Toward a science of other minds: Escaping the argument by analogy. *Cognitive Science*, 24, 509–541.
- Pruetz, J. D., & Bertolani, P. (2007). Savannah chimpanzees *Pan troglodytes* hunt with tools. *Current Biology*, 17, 1–6.
- Reed, E. S. (1996). *Encountering the world*. New York: Oxford University Press.
- Riddoch, M. J., & Humphreys, G. W. (1987). Visual object processing in a case of optic aphasia: A case of semantic access agnosia. *Cognitive Neuropsychology*, 4, 131–185.
- Riddoch, M. J., Humphreys, G. W., Edwards, S., Baker, T., & Willson, K. (2003). Seeing the action: Neuropsychological evidence for action-based effects on object selection. *Nature Neuroscience*, 6, 82–89.
- Riddoch, M. J., Humphreys, G. W., & Price, C. J. (1989). Route to action: Evidence from apraxia. *Cognitive Neuropsychology*, 6, 137–454.
- Rizzolatti, G., Camarda, R., Fogasi, L., Gentilucci, M., Luppino, G., & Matelli, M. (1988).

- Functional organization of inferior area 6 in the macaque monkey. *Experimental Brain Research*, 71, 491–507.
- Rizzolatti, G., & Matelli, M. (2003). Two different streams form the dorsal visual system: Anatomy and functions. *Experimental Brain Research*, 153, 146–157.
- Romanes, G. J. (1883). *Mental evolution in animals*. New York: Appleton.
- Rothi, L. J. G., Ochipa, C., & Heilman, K. M. (1991). A cognitive neuropsychological model of limb praxis. *Cognitive Neuropsychology*, 8, 443–458.
- Roy, E. A., & Square, P. A. (1985). Common considerations in the study of limb, verbal and oral apraxia. In E. A. Roy (Ed.), *Neuropsychological studies of apraxia and related disorders* (pp. 111–161). Amsterdam: Elsevier.
- Rumiati, R. I., & Humphreys, G. W. (1998). Recognition by action: Dissociating visual and semantic routes to action in normal observers. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 631–647.
- Santos, L. R., Pearson, H. M., Spaepen, G. M., Tsao, F., & Hauser, M. (2006). Probing the limits of tool competence: Experiments with two non-tool-using species (*Cercopithecus aethiops* and *Saguinus oedipus*). *Animal Cognition*, 9, 94–109.
- Seed, A. M., Tebbich, S., Emery, N. J., & Clayton, N. S. (2006). Investigating physical cognition in rooks (*Corvus frugilegus*). *Current Biology*, 16, 697–701.
- Shaw, R. (2003). The agent-environment interface: Simon's indirect or Gibson's direct coupling. *Ecological Psychology*, 15, 37–106.
- Shaw, R., Turvey, M. T., & Mace, W. (1982). Ecological psychology: The consequence of a commitment to realism. In W. Weimer, & D. Palermo (Eds.), *Cognition and the symbolic process* (pp. 159–226). Hillsdale: Lawrence Erlbaum Associates.
- Shettleworth, S. J. (1998). *Cognition, evolution and behavior*. New York: Oxford University Press.

- Shockley, K., Carello, C., & Turvey, M. T. (2004). Metamers in the haptic perception of heaviness and moveableness. *Perception and Psychophysics*, *66*, 731–742.
- Silveri, M. C., & Ciccarelli, N. (2009). Semantic memory in object use. *Neuropsychologia*, *47*, 2634–2641.
- Sirigu, A., Duhamel, J. -R., & Poncet, M. (1991). The role of sensorimotor experience in object recognition. *Brain*, *114*, 2555–2573.
- Spatt, J., Bak, T., Bozeat, S., Patterson, K., & Hodges, J. R. (2002). Apraxia, mechanical problem solving and semantic knowledge: Contributions to object usage in corticobasal degeneration. *Journal of Neurology*, *249*, 601–608.
- Squire, L. R. (1987). *Memory and Brain*. New York: Oxford University Press.
- St Amant, R., & Horton, T. E. (2008). Revisiting the definition of animal tool use. *Animal Behaviour*, *75*, 1199–1208.
- Stoffregen, T. A. (2003). Affordances as properties of the animal-environment system. *Ecological Psychology*, *15*, 115–134.
- Taira, M., Mine, S., Georgopoulos, A. P., Murata, A., & Sakata, H. (1990). Parietal cortex neurons of the monkey related to the visual guidance of hand movement. *Experimental Brain Research*, *83*, 29–36.
- Tebbich, S., & Bshary, R. (2004). Cognitive abilities related to tool use in the woodpecker finch, *Cactospiza pallida*. *Animal behaviour*, *67*, 689–697.
- Tebbich, S., Seed, A., Emery, N. J., & Clayton, N. S. (2007). Non-tool-using rooks *Corvus frugilegus* solve the trap-tube task. *Animal Cognition*, *10*, 225–231.
- Theraulaz, G., & Bonabeau, E. (1999). A brief history of stigmergy. *Artificial Life*, *5*, 97–116.
- Tomasello, M., & Call, J. (1997). *Primate cognition*. New York: Oxford University Press.
- Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and*

Performance, 24, 830–846.

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition*, 8, 769–800.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology*, 25, 1–12.

Turvey, M. T. (1992). Affordances and prospective control: An outline of the ontology. *Ecological Psychology*, 4, 173–187.

Turvey, M. T. (1996). *Dynamic Touch*. *American Psychologist*, 51, 1134–1152.

Turvey, M. T., & Shaw, R. E. (1995). Toward an ecological physics and an physical psychology. In R. L. Solso, & D. Massaro (Eds.), *The science of the mind: 2001 and beyond* (pp. 144–172). Oxford: Oxford University Press.

Turvey, M. T., & Shaw, R. E. (1999). Ecological foundations of cognition. I. Symmetry and specificity of animal-environment systems. *Journal of Consciousness Studies*, 6, 95–110.

Turvey, M. T., Shaw, R. E., Reed, E. S., & Mace, W. M. (1981). Ecological laws of perceiving and acting: In reply to Fodor and Pylyshyn (1981). *Cognition*, 9, 237–304.

Valenza, N., Patk, R., Zimine, I., Badan, M., Lazeyras, R., Schnider, A. (2001). Dissociated active and passive tactile shape recognition: A case study of pure tactile apraxia. *Brain*, 124, 2287–2298.

van Lawick-Goodall, J. (1970). Tool-using in primates and other vertebrates. In D. Lehrman, R. Hinde, & E. Shaw (Eds.), *Advances in the Study of Behavior* (pp. 195–249). New York: Academic Press.

van Leeuwen, L., Smitsman, A., & van Leeuwen, C. (1994). Affordances, perceptual complexity, and development. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 174–191.

van Schaik, C. P., Deaner, R. O., & Merrill, M. Y. (1999). The conditions for tool use in primates: Implications for the evolution of material culture. *Journal of Human Evolution*,

36, 719–741.

van Schaik, C. P., Fox, E. A., & Fechtman, L. T. (2003). Individual variation in the rate of use of tree-hole tools among wild orang-utans: Implications for hominin evolution. *Journal of Human Evolution*, *44*, 11–23.

Vauclair, J. (1997). *Animal cognition: An introduction to modern comparative psychology*. Cambridge: Harvard University Press.

Vera, A. H., & Simon, H. A. (1993). Situated action: A symbolic interpretation. *Cognitive Science*, *17*, 7–48.

Vingerhoets, G., Vandamme, K., & Vercammen, A. (2009). Conceptual and physical object qualities contribute differently to motor affordances. *Brain and Cognition*, *69*, 481–489.

Visalberghi, E., & Limongelli, L. (1994). Lack of comprehension of cause-effect relations in tool-using capuchin monkeys (*Cebus apella*). *Journal of Comparative Psychology*, *108*, 15–22.

Visalberghi, E., & Tomasello, M. (1998). Primate causal understanding in the physical and psychological domains. *Behavioral Processes*, *42*, 189–203.

Visalberghi, E., & Trinca, L. (1989). Tool use in capuchin monkeys: Distinguishing between performing and understanding. *Primates*, *30*, 511–521.

Vonk, J., & Povinelli, D. J. (2006). Similarity and difference in the conceptual systems of primates: The unobservability hypothesis. In T. Zentall, & E.A. Wasserman (Eds.), *Comparative cognition* (pp. 363–387). Oxford: Oxford University Press.

Wada, Y., Nakagawa, Y., Nishikawa, T., Aso, N., Inokowa, M., Kashiwagi, A., Tanabe, H., & Takeda, M. (1999). Role of somatosensory feedback from tools in realizing movements by patients with ideomotor apraxia. *European Neurology*, *41*, 73–78.

Wagman, J. B., & Carello, C. (2001). Affordances and inertial constraints on tool use. *Ecological Psychology*, *13*, 173–195.

- Wagman, J. B., & Carello, C. (2003). Haptically creating affordances: The user-tool interface. *Journal of Experimental Psychology: Applied*, *9*, 175–186.
- Walker, C. M., & Walker, M. F. (2001). Dressing ability after stroke: A review of the literature. *British Journal of Occupational Therapy*, *64*, 449–454.
- Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 683–703.
- Warren, W. H., & Whang, S. (1987). Visual guidance of walking through apertures: Body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance*, *13*, 371–383.
- Watson, J. B. (1913). Psychology as the behaviorist views it. *Psychological Review*, *20*, 158–177.
- Westwood, D. A., Schweitzer, T. A., Heath, M. D., Roy, E. A., Dixon, M. J., & Black, S. E. (2001). Transitive gesture production in apraxia: Visual and nonvisual sensory contributions. *Brain and Cognition*, *46*, 300–304.
- Wheeler, W. M. (1911). The ant colony as an organism. *Journal of Morphology*, *22*, 307–325.
- White, P. A. (1990). Ideas about causation in philosophy and psychology. *Psychological Bulletin*, *108*, 3–18.
- White, P. A. (2006). The causal asymmetry. *Psychological Review*, *113*, 132–147.
- Wolpert, L. (2003). Causal belief and the origins of technology. *Philosophical Transactions of the Royal Society of London*, *361A*, 1709–1719.
- Wundt, W. (1912). *Elements of folk psychology. Outline of a psychological history of the development of mankind*. New York: MacMillan.
- Yoon, E. Y., Heinke, D., & Humphreys, G. W. (2002). Modelling direct perceptual constraints on action selection: The naming and action model. *Visual Cognition*, *9*, 615–661.

FOOTNOTE 1

In analogy with the dual-route models of reading (see Coltheart, 2005), most cognitive models of action encompass two main processing components, namely, (i) an indirect, lexical route that recruits stored semantic knowledge about object function and (ii) a direct route linking the perceptual representation of an actually seen object to the stored action programmes (e.g., Pilgrim & Humphreys, 1991; Rothi et al., 1991). This view of directness has however to be distinguished from the notion of directness founded on the notions of laws and symmetries, as employed in the ecological approach (see Michaels & Carello, 1981; Turvey & Shaw, 1995; Turvey, Shaw, Reed, & Mace, 1981). We return to these matters later.

FOOTNOTE 2

It is also noteworthy that these findings demonstrate that brain damage can impair affordance perception and technical reasoning independently from each other. We discuss this point in more detail below.

FOOTNOTE 3

Shaw, Turvey, and Mace (1982) held the same view by arguing that in a given situation (being in the kitchen, noticing the table and its contents), the *intentional object*, which is that object whose affordance structure receives the highest *attensity* (e.g., the *edibility* of the pie receives greater attensity than the *readability* of the newspaper), can vary according to the occasion, that is, the person's psychological attitude (being a hungry person).

FOOTNOTE 4

The way in which Humphreys (2001) illustrated his concept of affordance provides a good example of this paradoxical reasoning. What Humphreys meant by the term affordance is “some direct link between the perceived visual properties of an object and an action that may be performed with it”. He gave the example of an instrument to remove a stone from an olive,

an object very unfamiliar to many people, and argued that “the top arm of the object...constrains the arm so that it may only be pushed down, and the hole in the lower part of the object can be filled by vertical section of the top arm...these visual properties may directly signal the action of pushing the top arm down” (Humphreys, 2001; p. 408). By describing the visual properties of this instrument in this way, Humphreys implicitly inferred that the properties of the object naturally lead to recognize it as an instrument to remove a stone from an olive. However, this object may also be used for a wide range of other actions according to what we intend to do: Poking, hammering, reaching, cracking, crushing, and so on.

FOOTNOTE 5

One important question concerns the properties of animals relevant to the perception of affordances. It has been suggested that body scale could be a possible candidate (Warren, 1984; Warren & Whang, 1987). Nevertheless, most authors think that the animal-side counterparts of affordances are effectivities, stressing that body scale is just an easily quantifiable stand-in for ability (Cesari & Newell, 2002; Chemero, 2003; Chemero, Klein, & Cordeiro, 2003; Heft, 2003; Reed, 1996; Stoffregen, 2003; Turvey, 1992).

FOOTNOTE 6

As mentioned above, we assume that any definition of tool use is one of convenience rather than psychological distinctness. Therefore, even if for the sake of clarity we continue our discussion with the question of how the dual relationship between a tool and an object is determined by an organism, we actually think that this question can be posed in the same terms for construction behaviour: How the relationships between the different components of a construction are determined by an organism?

FOOTNOTE 7

This situation is the same as when an individual engages in “construction” behaviour. For example, an individual that intends to make fire will first select the relevant “objects”, according to their combustibility. Then, among the relevant objects, it is likely that he or she selects only those that are the easiest to be transported, without considering nevertheless that the other pieces of wood, less easy to be transported, will be inappropriate to make fire. In a way, this example illustrates the problem of reification of the product of technical reasoning through affordance perception. We return to this matter in the next part of the article.

FOOTNOTE 8

Please note the lack of precision with which we define the technique of tracing. This may appear a little surprising since like the majority of people living on the Earth we master this technique and use it very intuitively. In fact, this lack of precision just illustrates the idea that it is not because we understand laws about how objects behave that we can specify them in very precise terms. After all, humans did not wait until Newton’s law of gravity to understand that things fall down, that is, the principle of support. But, Newton’s law of gravity offered humans a better way to explain why this phenomenon occurs. In broad terms, the understanding we have of technical laws are far more complex than what we can say about it (for discussion on this point, see White, 1990; 2006; see also Shaw, 2003).

FOOTNOTE 9

It is noteworthy that the principle of dialectic must not be viewed as a mental structure through which humans take decision about the achievement of goals. Put simply, the principle of dialectic describes what incites humans to use tools spontaneously, but not the process which enables them to take the decisions about whether or not to use tools. To illustrate this point, let us come back to the set-of-shelves problem. As mentioned, the bookseller can spontaneously view all the actions he performed to find a desired book as a problem to be

solved, and envisage to use the principle of support to solve it. Imagine that, unfortunately, there is no wooden board within reach, implying that he has to get one from the home equipment store. Although his reasoning enabled him to envisage other ways of keeping books tidy, he may choose not to get a wooden board because he considers the home equipment store too far or because his bookstore is famous for its original manner of storing books. In other words, it is not because we reason about other ways of acting, that we systematically apply the outcome of the reasoning.

FOOTNOTE 10

Without denying the need to escape from any form of dualism, it can be emphasized that the argument by analogy on which Hume's touchstone is based is highly debatable (see above).

TABLE 1

Table 1.

Definitions of tool/tool use

Field	Author	Definition
Cognitive neurosciences	Johnson-Frey (2007, p. 368)	Tools...[are] manipulable objects that are used to transform an actor's motor output into predictable mechanical actions for purposes of attaining specific goals (i.e., <i>motor-to-mechanical transformations</i>).
Computer science	St Amand and Horton (2008, p. 1203)	Tool use is the exertion of control over a freely manipulable external object (the tool) with the goal of (1) altering the physical properties of another object, substance, surface or medium (the target, which may be the tool user or another organism) via a dynamic mechanical interaction, or (2) mediating the flow of information between the tool user and the environment or other organisms in the environment.
Ergonomics	Baber (2003, p. 8)	A tool is a physical object that is manipulated by users in such a manner as to both affect change in some aspect of the environment and also to represent an extension of the users themselves. The manipulation is directed towards a specific goal or purpose, and the associated activity requires a degree of control and coordination.
Ethology	Beck (1980, p. 10)	Tool use is the external employment of an unattached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself when the user holds or carries the tool during or just prior to use and is responsible for the proper and effective orientation of the tool.
Neuro-psychology	Ochipa, Rothi, and Heilman (1992, p. 1063)	A tool was defined as an implement for performing or facilitating mechanical operations, such as a screwdriver. An object was defined as a thing to which mechanical action is directed, such as a screw.
Primatology	van Lawick-Goodall (1970, p. 195)	[Tool use is] the use of an external object as a functional extension of mouth or beak, hand or claw, in the attainment of an immediate goal.
Psychology	J. J. Gibson (1979; p. 41)	When in use, a tool is a sort of extension of the hand, almost an attachment to it or a part of the user's own body, and thus is no longer a part of the environment of the user. But when not in use, the tool is simply a detached object of the environment, graspable and portable, to be sure, but nevertheless external to the observer.

FIGURE LEGENDS

Figure 1 The paradoxical reasoning of the computational approach. In the left part of the figure is shown a representative example of a cognitive model of object recognition (inspired by Humphreys, 2001; Yoon et al., 2002). The model consists of two separate, modular systems that are supposed to work autonomously (Fodor, 1983). That is, the processing performed by the structural description system is not “guided” by the processing performed by the action selection level. In the right part of the figure is shown the implicit reasoning which has led to the formulation of the model. Interestingly, the reasoning appears to be reversed since it is the outcome of the processing performed by the action selection system which guides the processing performed by the structural description system. Therefore, by formulating the model in this way, the computationalist overrides the principle of modularity in that the properties extracted by the structural description system are necessarily guided by the outcome of the processing performed by the action selection system. By doing this, computationalists commit a mistake, called “psychologist’s fallacy”. We return to this point later.

Figure 2 The multiple-route hypothesis. Explanations are given in the text.

Figure 3 The principle of dialectic. Explanations are given in the text.

Figure 4 The set-of-shelves problem. Explanations are given in the text.

FIGURE 1

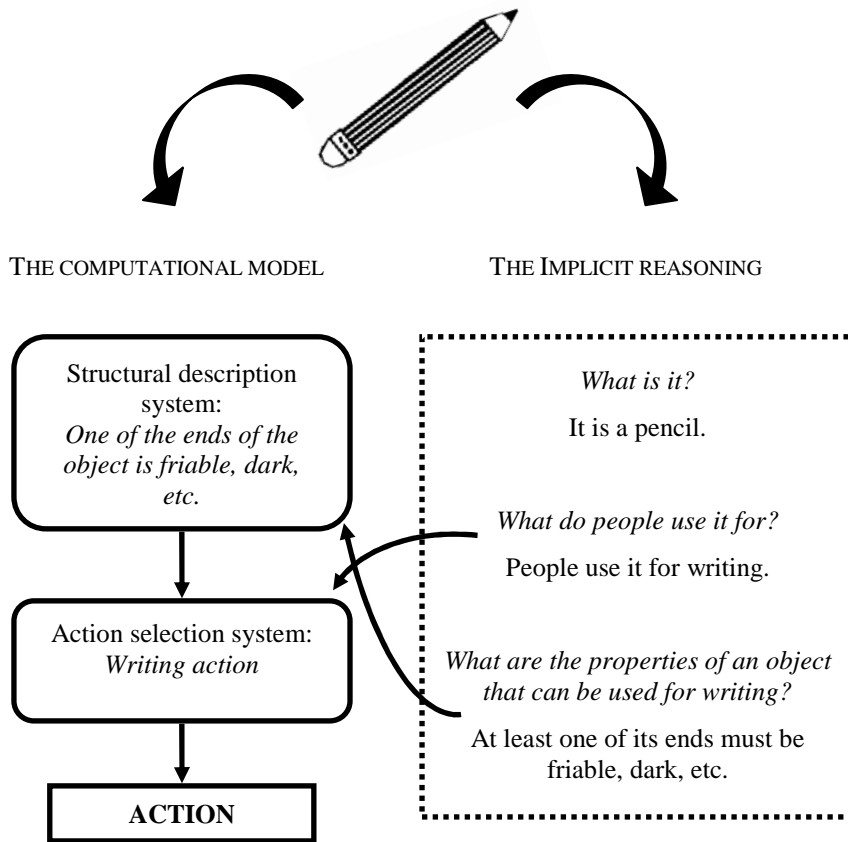


FIGURE 2

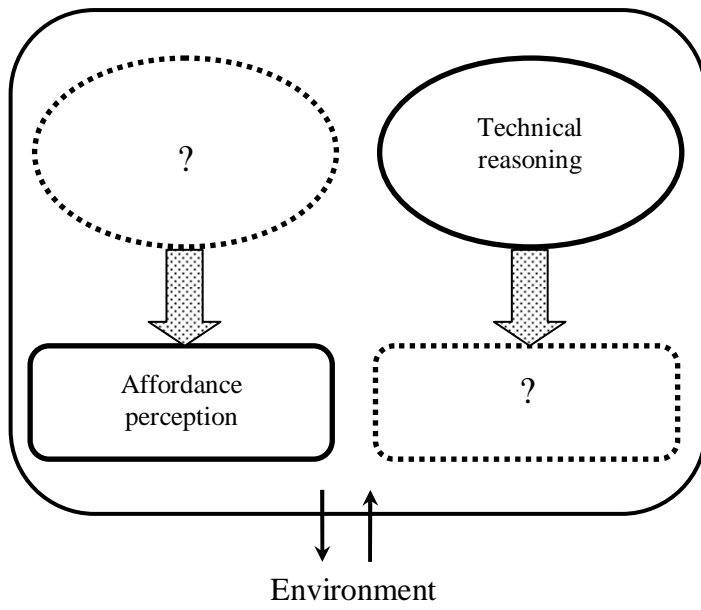


FIGURE 3

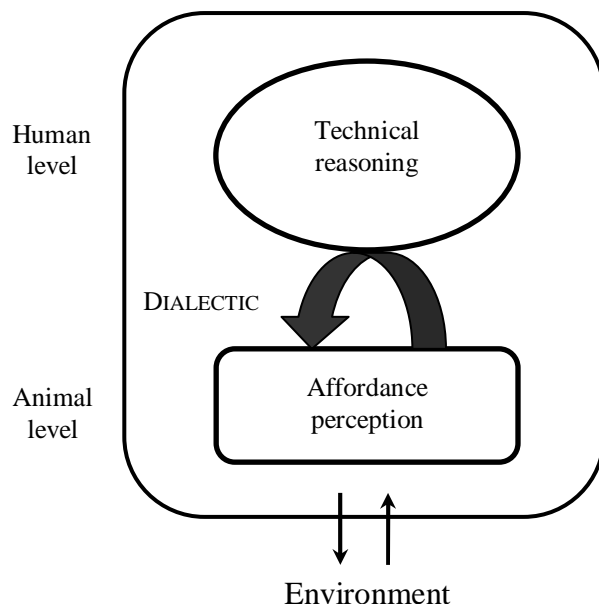


FIGURE 4

