Grasping the Affordances, Understanding the Reasoning: Toward a Dialectical Theory of Human Tool Use

François Osiurak, Christophe Jarry, and Didier Le Gall
University of Angers and University Hospital of Angers

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 humans perceive not 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. It is precisely at this point that technical reasoning occurs. However, 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.

Keywords: action, anthropology, apraxia, perception, technology

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 behavior (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 are 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 indirectly1 into appropriate motor outputs (grasping, hammering). J. J. Gibson’s ecological approach to perception falls into the latter category. For J. J. Gibson (1979), humans 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 behavior, 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 nonhumans 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 to spontaneously and almost systematically use tools so as to modify their way of interacting with the world, a feature that characterizes humans of all cultures through the ages (Leroi-Gourhan, 1971, 1973). For instance, humans use horses, bicycles, cars, boats, or airplanes to move. Likewise, they use spears, traps, guns, and bows to hunt, or rucksacks, baskets, jags, cans, and heavy-goods vehicles to transport things. In fact, the relationship existing between humans and the environment is constantly changing, a specificity that is much

1 In analogy with the dual-route models of reading (see Coltheart, 2005), most cognitive models of action encompass two main processing components, namely, (a) an indirect, lexical route that recruits stored semantic knowledge about object function and (b) a direct route linking the perceptual representation of an actually seen object to the stored action programs (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.
more visible at the species level through 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, etc.), 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 of why humans spontaneously use tools (referred to hereafter as the why issue).

The purpose of this article is threefold. First, we address two tricky epistemological issues concerning tool use. The first one is what a tool is. Most articles on the topic do not define precisely what they mean by tool use, probably because they view tool behavior as something obvious. Through this work, we wish to emphasize that tool behavior is anything but obvious, however. The second is what it means to consider two behaviors 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 what extent tool use by humans and nonhumans 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 article. Briefly, the thesis we defend here is that humans have the ability to view body action as a problem to be solved. It is precisely at this point that technical reasoning occurs. However, 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 by 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 on 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, this set of features is organized around the central idea that tools are extensions of the upper limbs.

A noteworthy aspect of this definition is that it applies to both human and nonhuman actions. Anthropologists once considered tool use to be a highly characteristic feature of genus Homo (Oakley, 1949). Reports of tool use in nonhumans, 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, see Baber, 2003; Beck, 1980; van Schaik, Deaner, & Merrill, 1999), and it is now largely accepted that tool behavior is not peculiar to humans. In this article, we do not intend to challenge the view that some animals can also exhibit tool behaviors. After all, humans are not alone in having the biological equipment appropriate for manipulating things. 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 behavior can be observed in nonhumans. However, beyond the question of whether some animals are tool users, a more interesting question is whether animals exhibit tool behavior 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 20 of an estimated 8,600 known species of birds have been reported to use tools. 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 behavior, 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 behavior displayed by nonhumans (e.g., nest building) as well as by humans. The viewpoint adopted by some of the authors who have largely contributed to the study of tool behavior is somehow more subtle. Beck (1980) himself thought that it would be a mistake to see tool use as biologically distinct from construction behavior, 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 behavior is to show how surprisingly difficult it is to recognize what is the tool in some tool behavior, 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. Amant 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
### Definitions of Tool/Tool Use

<table>
<thead>
<tr>
<th>Field</th>
<th>Author</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive neurosciences</td>
<td>Johnson-Frey (2007, p. 368)</td>
<td>“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., motor-to-mechanical transformations).”</td>
</tr>
<tr>
<td>Computer science</td>
<td>St Amant &amp; Horton (2008, p. 1203)</td>
<td>“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.”</td>
</tr>
<tr>
<td>Ergonomics</td>
<td>Baber (2003, p. 8)</td>
<td>“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.”</td>
</tr>
<tr>
<td>Ethology</td>
<td>Beck (1980, p. 10)</td>
<td>“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.”</td>
</tr>
<tr>
<td>Neuropsychology</td>
<td>Ochipa, Rothi, &amp; Heilman (1992, p. 1063)</td>
<td>“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.”</td>
</tr>
<tr>
<td>Primatology</td>
<td>van Lawick-Goodall (1970, p. 195)</td>
<td>“[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.”</td>
</tr>
<tr>
<td>Psychology</td>
<td>J. J. Gibson (1979, p. 41)</td>
<td>“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.”</td>
</tr>
</tbody>
</table>

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 criticized 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 & 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. However, 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 an 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, 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 labeling behavior as tool use may appear to be relatively easy and obvious, recognizing what the tool is, paradoxically, is something difficult and nonobvious. Therefore, the viewpoint adopted in the present article 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 behavior.

### What Does It Mean to Consider Two Behaviors to Be Analogous?

The idea of a psychological continuity among species is deeply ingrained in the minds of comparative psychologists and neuroscientists alike (Penn, Holyoak, & Povinelli, 2008; Povinelli, Bering, & Giambrone, 2000). This hypothesis was 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 beh-
behavior 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 of nonhuman 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 behaviors can be considered analogous. There are at least three ways to answer this question.

The first is to compare the behaviors at an action level. Imagine, for instance, a chimpanzee using a twig to fish for 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 a fish on the hook). This is the level of analysis that is generally preferred, leading to highlighting similarities between humans and nonhumans (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 behaviors at an individual level, involving the observation time being extended to the lifetime of the individual. At this level, things drastically change. It has been extensively reported that in nonhuman 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 of life. Also, 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 nonhumans.

Differences become even more visible when attention shifts from the individual to the species level (the third level). Only humans are able to transcend their natural abilities and to radically alter their 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 behavioral 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 behaviors seemingly analogous to human ones.

In broad terms, considering two behaviors 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 behavior is fundamental to understanding how individuals guide their own behaviors (the how issue) and, as a result, to determining what is common in tool use between humans and nonhumans. But it is not because two behaviors are seemingly analogous that the underlying mental mechanisms are analogous too (Penn et al., 2008). Studies on tool use by nonhumans provide support for this view (see below). Moreover, what renders a piece of behavior 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 behavior. 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 humans spontaneously use tools (the why issue). An attempt to answer this question is made explicitly in the last sections of this article. 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 Nonsemantic Route Hypothesis

Until very recently, scientists’ understanding of the processes involved in using tools came exclusively from studies of brain-damaged patients, particularly those who experienced difficulties in using tools (De Renzi & Lucchelli, 1988; De Renzi, Piec zoom, & Vignolo, 1968). For instance, when asked to light a candle, such a 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 of 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, Daumiller, Delta Sala, & Goldenberg, 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, & Rumiani, 2007; Osiurak, Aubin, Allain, Jarry, Richard, & Le Gall, 2008; Osiurak et al., 2009; Silveri & Ciccarelli, 2009).

Hence, growing attention has been paid to the possibility of a nonsemantic 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; Rumaiati & 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—that is, 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 (Craigiero, Fadiga, Rizzolatti, & Umiltà, 1999; Ellis & Tucker, 2000; Tucker & Ellis, 1998, 2001). In their seminal work, Tucker and Ellis (1998) asked participants to make pushbutton responses with the left or right hand depending on whether a tool was upright or inverted. The orientation of the tool’s 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 nongraspable 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—that is, 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 detecting 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 pantomimizing the use of objects (to verbal or visual command) suffer from lesions in the left inferior parietal region (Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005; Buxbaum, Kyle, Grossman, & Coslett, 2007; Buxbaum, Kyle, & Menon, 2005; Buxbaum, Sirigu, Schwartz, & Klatsky, 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, Goldberg (2009) nevertheless concluded that the impact of parietal lobe damage on pantomiming 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—that is, object–object complementarities.

Experimental. Rumaiati 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 or mixed errors in comparison to naming. Rumaiati and Humphreys 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 as 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, and recognizing that a real object is a hammer. This is certainly true if the intended aim is to describe the world with words, but it appears to be far less true for tool use.

Indeed, it is not because one names a toy hammer that one can use it to pound a nail (e.g., a small plastic toy hammer). Likewise, it is not because one recognizes a hammer drawn on a sheet of paper that one will use the sheet of paper to pound a nail (see Foucault & Howard, 1976). If one uses a hammer to pound a nail, it is because one is able to extract from the physical attributes of the hammer the information relevant to the action *pounding a nail*. Yet, to pound a nail, one may also use any other object that 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 ways of interpreting the world: one that leads to describing the world with words and, as a result, to giving the same name to objects whose use differs considerably (e.g., hand hammer, small plastic toy hammer, a picture or drawing of a hammer) and another that leads to specifying the use of tools and, thereby, to determining 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 relevant to directly activating 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 that translates the information contained in the drawing into a representation of the real object, a possibility that 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 naming it, regardless of whether it is the real object or a 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 the sight of objects they are unable to name. It has been suggested that this reflects impaired access to a supramodal semantic system from vision and that the preserved ability to gesture to visually presented objects reflects the operation of a nonsemantic 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 behavior is based either on declarative knowledge or on procedural knowledge (e.g., Anderson, 1983; Tulving, 1985), thereby involving the idea that the preserved ability to use tools in the presence of deficits of semantic memory necessarily involves the recruitment of procedural knowledge. However, 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 that 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 that is relevant to directly activating 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 nontool objects or things that are placed in the position in which people usually see them (the sun above a mountain, a man on a horse) with performance for nontool 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 nonsemantic 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, Aubin, Allain, Jarry, Etcherry-Bouyx, et al., 2008). 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 or away from 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 vs. away from the patient). We found that only one patient selected inappropriate grips. More interestingly, out of the 15 patients who performed appropriate grips, four patients showed difficulties in using objects correctly. These results challenge the hypothesis of a direct route between vision and action, the hypothesis of a direct tactile route for object use has strongly similar to the idea of a direct route between vision and action by showing that during tool use, the ability to plan appropriate postures for use does not necessarily lead to using tools correctly.²

In sum, it appears that (a) seeing graspable stimuli automatically activates grasping movements; (b) these priming effects can be related to a specific neural network, as evidenced by neuroimaging studies; and (c) a somewhat similar neural substrate devoted to the same purpose also exists in other primates. Yet, 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 kinesthetic 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, & Humphries, 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 reported a significant improvement in pantomiming when apraxic patients were allowed to grasp a neutral object during their performance (Graham et al., 1999; Wada et al., 1999).

Research for the past 2 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 temperature, and pressing to explore hardness of an object. Invariants based on 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 (Carell, Thuot, Anderson, & Turvey, 1999; Carell & Turvey, 2000; Turvey, 1996). Evidence for the existence of the exploratory procedures has also been provided by neuropsychological studies of tactile apraxia (Binkofski, Kunesh, Classen, Sieitz, & 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 nontool 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 in the work of Graham et al. (1999) and Wada et al. (1999) that 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, corrects the movement executed by the patients, particularly by forcing them to adopt an appropriate hand posture, a feature that is often used to assess pantomime (e.g., Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005; Buxbaum et al., 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 kinesthetic 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. Yet the computational hypothesis also suffers from theoretical shortcomings that, 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 receiving 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 that extracts sensory information about object properties (e.g., color, rigidity, texture, size, shape, etc.). All cognitive models of tool use posit the existence of such a system (e.g., Buxbaum, 2001; Roth et al., 1991; Roy & Square, 1985; Yoon et al., 2002). Two fundamental questions nevertheless arise: What is a property? How does this modular system extract this property?

² It is also noteworthy that these findings demonstrate that brain damage can impair affordance perception and technical reasoning independently of each other. We discuss this point in more detail below.
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. Yet what does “a wooden pencil is light” mean? The pencil 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 humans ascribe to things are always relative to the actions humans 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 intention.3

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 paradoxical reasoning (see Figure 1).4

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; Rumiai & Humphreys, 1998). Yet how many times in one’s life has one been confronted with this kind of situation? Very few, probably. In fact, these experimental situations do not reflect the relationships people 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 people do not systematically recognize the usual use of tools but, rather, extract information from tools to fulfill their intentions.

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 that 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 that 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 in the text.

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).

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” (Humphreys, 2001, p. 408). He gave the example of an instrument for removing the 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 recognizing it as an instrument for removing a stone from an olive. However, this object may also be used for a wide range of other actions according to what one intends to do: poking, hammering, reaching, cracking, crushing, and so on.
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 one is 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 demonstrate not 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. This would suggest that the structural description system is able to extract essential properties that are inherent in the human manufacture. However, as James (1890/2007b) stressed, “There is no property absolutely essential to any thing” (p. 333). 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, Aubin, Allain, Jarry, Richard, & Le Gall, 2008; Osiurak et al., 2009). 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, Aubin, Allain, Jarry, Richard, & Le Gall, 2008; Osiurak et al., 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. However, there is no clear evidence supporting this hypothesis. 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 that perform specific behavior in response to a given stimulation. Put differently, it may be particularly useful for modeling systems that have only one way of interacting with the world, namely, according to the purpose for which they have been built. Yet humans are different. As James (1890/2007b) and J. J. Gibson (1979) claimed, people do not perceive the world without any intention. It is certainly this intention that enables people 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 “How do humans recognize the use of tools?” to the question “Why do humans spontaneously use tools?”

The Ecological View of 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: Humans do not perceive the properties of objects (e.g., stone is heavy) but their properties in relation to humans themselves, that is, in terms of what they afford humans (a small and light object is graspable). 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, Grososfsky, 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 favor 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, and also by organisms of the same species or by the same organism at different times.

For J. J. Gibson (1979), affordances were 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 effectivities for (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, even if the concept of affordance is still in development, all ecological psychologists agree that (a) affordances are animal-relative properties of the environment and (b) 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), humans have the propensity to fail to notice that, when they are engaged in the analysis of what they are perceiving, they typically do not analyze what they are perceiving but the outcome of the analysis. James called this error psycho-
gist’s fallacy, an error that 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 that chases a mouse in a park. This park is enclosed by a 2-m 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 jumpable. Imagine now that the cat is chased by a dog. The same wall may be perceived as perchable by the cat.

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, 1981; Stoffregen, 2003; Turvey, 1992.) To answer 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 jumpable (affordance) when attempting to catch the mouse to feed (goal), it perceives the wall as perchable (affordance) when attempting to escape from the dog to protect its life (goal). Interestingly, this does not imply that the wall is seen as jumpable by the cat only when it chases the mouse to feed. If this cat is a male, it may also see the wall as jumpable (affordance) when attempting to get to a female cat that is at the other side of the wall 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 that 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, which primarily has dealt 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 people perceive when they look at detached objects—that is, tools—are not their qualities (e.g., color, rigidity, texture, size, shape, etc.) but their affordances, that is, invariant combinations of variables that satisfy a goal. For instance, an elongated object of moderate size and weight affords wielding. However, 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-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 wieldable 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 that are too large for a termite nest. Likewise, birds can manipulate a great number of things with their beaks, but only some of these things are suitable for building nests. This is even more significant for humans. For instance, humans are able to determine that an airplane is heavy enough to crush a car or that a tree trunk is long enough to be used as a bridge linking the two banks of a river, while they 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 behavior, 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 guiding the selection of the most appropriate objects to perform the task. However, 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 construction,6 is determined. A 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

---

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 behavior: How are the relationships between the different components of a construction determined by an organism?
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 that were supposed to be hammered and poked. This study provides strong support for the proposal that once the idea of a 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). However, 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 poking. In sum, this study tells us nothing about the psychological mechanisms that 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 relationship, 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 dispositional significance to animal activity. There are significant dispositional 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 for 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 that support them (Chemerio, 2003).

J. J. Gibson (1979) supported a view somewhat similar to that of Turvey (1992) by considering that the theory of affordances also applies to the perception of the function of tools, namely, the relationship between tools and objects. However, this view is contradictory to 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 that are detected by the organism in the 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. The question remains open as to how an organism’s possibilities for action can constrain to perceive that Object α is heavy enough to afford hammering with Object β but not Object γ or that Object π is friable and dark enough to afford writing with Object σ but not Object μ. So, the theory of affordances needs to be extended and modified to include new hypotheses about the psychological mechanisms supporting tool use. 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: It also requires determining a dual relationship between the tool and the object. As Drills (1963) suggested, a tool (a) must be able to perform the function for which it is intended (relationship between the tool and the object) and (b) 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 of an animal to detect relationships between its body and the environment (Point 2 of Drills, 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 understanding what is so special about human tool use since it is certainly at this level that humans differ from nonhuman animals.

The aim of the ecological doctrine of necessary specificity is the search for the laws of the ecological scale—the scale at which animals and environment are defined—that make cognition possi-

7 This situation is the same as when an individual engages in construction behavior. For example, an individual who 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.
ble. Consistent with this, we are firmly convinced that the way in which humans and nonhumans alike interact 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. However, as mentioned above, when one shifts one’s attention to other levels of analysis (individual, species), things change dramatically, with only humans spontaneously and constantly using tools. So, although the ecological approach allows us to formulate laws that explain how organisms perceive possibilities for action, the challenge remains to formulate an additional principle that 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 Nonhuman Minds

There is a growing body of evidence indicating that tool use is not a characteristic feature of genus *Homo* (for reviews, see 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: What is the nature of the mental mechanisms underlying tool use? Are these the same mechanisms in humans and nonhumans?

A series of studies has revealed serious limitations on the ability of nonhuman 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 the ability of 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 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 nonhuman 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 behavior 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. First, they indicate that it is not because some animals exhibit behavior seemingly analogous to human ones that the underlying mental mechanisms are analogous too. After all, the similarity between human and nonhuman tool behavior 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 behavior. So, it seems necessary to escape the argument by analogy 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).

Second, 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 behavior. One plausible account is that tool-using behavior in nonhumans 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 behavior in nonhumans 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 nonhuman animals to execute a sequence of tool behaviors 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 spearlike 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 & Bertolani, 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 do not appear to use tools in the wild, are able to solve a complex tool-use problem, consisting in raising the level of water in 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, nonhuman animals, tool users and non–tool users alike, 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 in-
stance, 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, when it becomes again a tool. It can also be used for cutting the throat of a sheep, and it becomes a tool. Yet, 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, and 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, etc.; for a discussion on this point, see Osiurak, Aubin, Allain, Jarry, Richard, & Le Gall, 2008; Osiurak et al., 2009; Osiurak, Jarry, & Le Gall, in press).

Things are different in nonhumans. 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 nonhuman 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 that is deeply ingrained in the minds of psychologists and neurologists alike, that is, that 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 of as a set of learned behavioral 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 nondeclarative 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 humans are able to form a declarative representation of each of the underlying generative mechanisms they understand. Humans probably learn the lever principle or the tracing principle well before being able to specify them with precise concepts. Still, it is not because humans are not able to form such representations that their 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" (p. 333; 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), and 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, Aubin, Allain, Jarry, Richard, & Le Gall, 2008; Osiurak et al., 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 that is inspired by the computational approach and that 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 of tracing: An object that is friable and either darker or clearer than another object that is porous affords tracing.8 An individual acquiring the principle of tracing will be able to determine that this action can be performed by using a pencil with a sheet of paper or with a white wall, by using white chalk with a blackboard 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 do 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 to the idea that the perception of affordances involves a close relationship between object properties and the capacities of

---

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 people understand laws about how objects behave that they 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. Yet Newton’s law of gravity offered humans a better way to explain why this phenomenon occurs. In broad terms, the understanding humans have of technical laws are far more complex than what they can say about it (for discussion on this point, see White, 1990, 2006; see also Shaw, 2003).
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 had 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 (see 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). 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 nonhuman 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 behavior. However, the process of trial-and-error learning is highly context dependent—or, rather, tool dependent—and, as a result, does not allow to users to understand the physical principles involved. The corollary is that in animals, tool behavior is supposed to take place only when certain favorable environmental conditions are satisfied, corroborating for instance the literature on nonhuman 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 behavior is guided during tool use cannot be supported merely by the perception of affordances associated with a trial-and-error learning process (see 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 for explaining 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 behavior in the 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 (see 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 (see 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 to interact with the environment accordingly.

The Paradox of Human Tool Use

To understand why humans spontaneously use tools, it is fundamental to wonder first, What benefit do humans 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 stressing that this feeling does not stem from the fact that tools are ineffective for the intended purposes. They are inevitably inappropriate 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 in the use of any tool, namely, while human tools give people the illusion of constantly doing less (e.g., TV remote control), they are still forced to use body action to operate them (pushing buttons with the fingers). After all, even though an electrical knife enables one to cut without having to gesticulate too much, it is not the ultimate 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 ultimate solution. One must drive it and stay inside it throughout the journey. Typewriters and computers are also not the ultimate solution, since they require staying in front of them during use and they do not work unless one strikes 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 human bodies 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. It is precisely at this point that technical reasoning occurs. However, 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 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). All of these are only the product of technical reasoning, and the physical constraints of the body force people 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 being handled. Likewise, a car cannot be driven without a steering wheel. Even if an individual designs a car that can be driven from a distance, he or she still needs a remote-control device to steer the car. Interestingly, it is precisely because humans can never be free from the necessity to perform body action to interact with the environment and, as a result, to operate their tools that they always have technical problems to be solved.

Another important feature of the principle of dialectic does not 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 nonhuman animals can exhibit tool behavior in a manner similar to humans. Therefore, humans think not only 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 a problem: having to walk to get from Point A to Point B. The problem is essentially the same for elevators, bridges, roads, and even TV monitors, which solve the problem of going out to watch movies, shows, and sports or to get information. In fact, even the mere fact of having to stay at a place without having nothing to do may be viewed as a problem to be solved because it also requires body action. Think, for instance, of 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 artifacts that surround

![Figure 3](attachment:image.png)
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 shelves (see Figure 4). Although the number of solutions is very large, we consider only 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 that are at the top of the column 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 desires 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?

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, proposing new ways of interacting with the environment. For instance, the bookseller may think about the technical law of support: An object that is denser and larger than another object affords support. Technical reasoning aims at finding out new ways of interacting with the environment. Yet 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 that formed the original ecosystem (see Shaw, 2003). Therefore, he will not seek an object that is denser and larger than another one but something that 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 titles of the 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 to interact with the environment again and, as a result, to perceive affordances (see 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, reason 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 that offers solutions to the problems it raises. 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 equipment (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 that are regulated by indirect communication between individuals. Grasse (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 a 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 attractiveness 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...
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 Configuration A with Action A and responds to Configuration B with Action B. Interestingly, the execution of Action B can transform Configuration B into Configuration A, leading to the execution of Action A, which can also transform Configuration A into 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 idiosynchratic characteristics of individual behavior. 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 his or her society (e.g., stone tools to cut meat) and, therefore, imagine other ways of acting (knives). Yet 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, similar to 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 Järvi-lehto, 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 about 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 behavior (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 behavior of a patient, MJC, who showed a severe semantic impairment (Osiurak, Aubin, Allain, Jarry, Richard, & Le Gall, 2008). She encountered difficulties in demonstrating the use of tools in isolation (e.g., using a screwdriver without the screw). Nevertheless, MJC used the desk almost systematically 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 scraping 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 the performance considerably (e.g., using a screwdriver with the screw). She also performed normally on 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 the object’s usual purpose (in which context it is used, with which kind of objects) 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 herpes 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 nonimmediate 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 surrounding him 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 was originally formulated in the context of the computational approach (Tulving, 1985), a theoretical orientation that 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 purposes 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, Aubin, Allain, Jarry, Richard, & Le Gall, 2008; Osiurak et al., 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 this article has been to examine the potential of the computational view and the ecological view to account for human tool use. In our discussion, we have highlighted several theoretical and empirical limitations inherent in the computational approach, emphasizing its capacity to resolve the how issue. By considering that the human cognitive system contains a structural description system that 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 concentrating 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 does one wonder, What is that object? People generally ask themselves this question when they intend to describe the environment that surrounds them. When they interact with the environment, they first intend to achieve a purpose and then determine what the potential of the objects surrounding them is—or is not (see the discussion on the role of semantic memory just above)—for the intended purpose. Moreover, this approach represents the drawback of focusing on the action level, inevitably leading to formulating models explaining how an individual performs a given behavior 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 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 objects is entirely inherent in 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, p. 333). Unfortunately, this approach fails to account for how humans determine the dual relationships between tools and objects, which is particularly crucial to understanding what is so special about human tool use since it is certainly at this level that humans differ from nonhuman 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 nonhuman animals, this ability, associated with an associative learning process, could support tool use (Penn et al., 2008;
Penn & Povinelli, 2007; Tebbich & Bshary, 2004; Tomasello & Call, 1997). In humans, this hypothesis cannot be supported: Besides the ability to easily solve tool-use situations—which appear to be considerably difficult for nonhumans—humans 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). However, the originality of the present theory is in accounting 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 the principles behind the self-organization of human societies are.

The following lines summarize the key points of the present theory. (a) Any definition of tool use is one of convenience rather than psychological distinctness (Beck, 1980; Hansell & Ruxton, 2008). (b) It is not because other species exhibit behavior similar to our own that similar psychological causes are at work (Povinelli et al., 2000). (c) What happens at the species level inevitably reflects the psychological functioning of each individual (Wundt, 1912). (d) There is no property absolutely essential to any one thing (James, 1890/2007b). (e) Perception is designed for action (J. J. Gibson, 1979). (f) Humans alone are able to acquire a technique to reach a specific goal and to transfer it to reach another goal (Leroy-Gourhan, 1971, 1973), that is, to do analogical reasoning (Penn et al., 2008). (g) 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). (h) Humans are unique because of their dialectical functioning: Humans raise the problems they have to solve (Gagnepain, 1990). (i) The regulation of societies results from idiosyncratic features of individual behavior (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? How are they reified into affordances? How is 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 interesting new directions for future research in psychology and the 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 instead being paid to the nature of the cognitive deficit. By contrast, it is also well known that patients with severe dementia tend to directly use 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 of the right hemisphere (De Ajuriaiguerra, 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 impair not only the use of manipulable objects but also the use of nonmanipulable objects such as clothes. Therefore, 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 leftdamaged 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 so as to create another has been suggested to necessitate a high degree of cognitive sophistication, so it might distinguish humans from nonhuman 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 spearelike tools during hunting (Pruetz & Bertolani, 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 behaviors 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 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 by 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 to find out solutions, such as the use of a shovel, and so on (qualitative stigmergy). Interestingly, the shovel is here a tool that 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 conditions 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 behaviors and actions and the theories that explain them must be quite unlike to those that govern animal behaviors 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 (1739/1798), who suggested that the resemblance of the external actions of animals to those we perform demonstrates that their internal actions resemble ours and, as a result, that the causes from which they derived must also be resembling (see Massey, 1993). In a way, Hume (1739/1798) formulated the idea of a psychological continuity based on the argument by analogy,10 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 specter of Cartesian dualism. We conclude by explaining why this 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 by the ecological approach by assuming that affordance perception is the key principle enabling organisms to interact with the word, thereby permitting 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, p. 95), 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 the idea 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 specter of Cartesian dualism.

References


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).


Foucault, M., & Howard, R. (1976). Ceci n’est pas une pipe [This is not a pipe]. *October, 1,* 6–21.


faculty of language: What is it, who has it, and how did it evolve? Science, 298, 1569–1579.


TOWARD A DIALECTICAL THEORY OF HUMAN TOOL USE


Received May 12, 2009
Revision received December 11, 2009
Accepted December 21, 2009

---

**E-Mail Notification of Your Latest Issue Online!**

Would you like to know when the next issue of your favorite APA journal will be available online? This service is now available to you. Sign up at http://notify.apa.org/ and you will be notified by e-mail when issues of interest to you become available!