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What Is the Future for Tool-Specific Generalized Motor Programs?

François Osiurak

Laboratoire d'Etude des Mécanismes Cognitifs (EA 3082), Université de Lyon, France
Institut Universitaire de France, Paris, France

Correspondence

François Osiurak, Laboratoire d'Etude des Mécanismes Cognitifs (EA 3082), Institut de Psychologie, 5, avenue Pierre Mendès-France, 69676 Bron Cedex, France.

Email: Francois.Osiurak@univ-lyon2.fr

Tel: +33 (0) 4 78 77 43 95

Fax: + 33 (0) 4 78 77 43 35

RUNNING HEAD: TOOL-SPECIFIC GENERALIZED MOTOR PROGRAMS

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Abstract

A key issue in cognitive sciences is to understand the cognitive bases of human tool use. Answers have been provided by two competing approaches. The manipulation-based approach assumes that humans can use tools because of the ability to store sensorimotor knowledge about how to manipulate tools. By contrast, for the reasoning-based approach, human tool use is based on the ability to reason about physical object properties. Recently, Caruana and Cuccio proposed a kind of reconciliation, based on the distinction between three types of abductive inference, involving a different contribution of motor and cognitive elements: Automatic abduction (motor+ and cognitive-), abduction by selection (motor± and cognitive±) and creative abduction (motor- and cognitive+). This perspective offers new interesting avenues. Nevertheless, it is also subject to several theoretical and epistemological limitations, which make it in its present form inappropriate for the study of the cognitive bases of human tool use. This article aims to discuss these limitations.

Keywords: Generalized Motor Program; Manipulation Knowledge; Technical Reasoning; Tool Use

1. Introduction

Humans are not alone in using tools. However, only humans are able to show very specific tool-use behaviors such as the use of one tool to create another (Gibson 1993) or cumulative technological culture (Tomasello et al. 1993). So, a fundamental issue in cognitive sciences is to understand the cognitive bases of human tool use. Some answers have been provided by two competing approaches, namely, the manipulation-based approach and the reasoning-based approach. The former assumes that, to use tools, people need to store sensorimotor knowledge about how to manipulate tools. The latter considers that tool use is supported by the ability to reason about the physical properties of tools and objects, based on abstract, mechanical knowledge. Recently, Caruana and Cuccio (hereafter called C&C; Caruana and Cuccio this issue) stressed that neither of these approaches, considered in itself, is sufficient to explain human tool use. They proposed a kind of reconciliation based on the distinction between three types of abductive inference, involving a different contribution of motor and cognitive elements: Automatic abduction (motor+ and cognitive-), abduction by selection (motor± and cognitive±) and creative abduction (motor- and cognitive+). This model – hereafter called the C&C model – has the merit to be the first to suggest such reconciliation and, as a result, offers new interesting avenues. However, it is also subject to a certain number of theoretical and epistemological limitations, which make it in its present form inappropriate for the study of the cognitive bases of human tool use. This article aims to discuss these limitations.

2. From manipulation knowledge to generalized motor programs

The manipulation-based approach is based on the core idea that people store sensorimotor/motor knowledge about how to manipulate tools, also called

manipulation knowledge (Buxbaum 2001; Buxbaum and Kalénine 2010; Heilman et al. 1982; Rothi et al. 1991; van Elk et al. 2014). This motor knowledge is thought to contain “the features of gestures which are invariant and critical in distinguishing a given gesture from others. For hammering movement, for example, a broad oscillation from the elbow joint is critical, as is a clenched hand posture, and these and other similar gestural features are construed as forming the “core” of the gesture representation” (Buxbaum 2001; p. 452). This knowledge can be viewed as based on egocentric coordinates in that it contains information about the action made by the hand with the tool (e.g., a hammer), but not by the tool with the object (e.g., a nail). It is supposed to be stored in the left inferior parietal lobe (IPL). So, damage to this brain area can induce tool use disorders because of impaired manipulation knowledge.

As suggested by C&C, an important limitation of the manipulation-based approach concerns the rigid nature of manipulation knowledge in that they are supposed to contain very specific information about the different parameters of the action (e.g., amplitude and velocity of the effectors). However, as stressed by Goldenberg (Goldenberg 2013), even the most familiar tool action such as screwing can be carried out in a multitude of different contexts, leading to a great variability as to the motor action performed (e.g., screwing with both hands instead of one hand; see also Caruana and Cuccio this issue; Osiurak et al. 2011).

To resolve this issue, C&C proposed that humans do not store manipulation knowledge, but rather tool-specific generalized motor programs (for a somewhat similar proposal, see Hermsdörfer et al. 2012; see also Schmidt 1982). These programs contain information about the “body action” without specifying the effector or the joint involved. They are supported by an IPL sub-region, namely, the left anterior supramarginal gyrus (aSMG; see also Orban and Caruana 2014; Orban and Rizzolatti, 2012; Peeters et al.

2009). In a way, these programs correspond to the sensorimotor/motor element of tool use.

3. Three types of abduction

In the C&C model, tool-specific generalized motor programs might be deeply involved in what they call “automatic abduction”, by being “immediately and automatically retrieved” as soon as we identify the expected result (e.g., “nail in the wall”)¹. In this case, they are sufficient to select the appropriate tool (e.g., a hammer): “The retrieval of a habit of action, determining the automatic activation of the motor program for tool use, leads us to select the tool and to automatically generate use behaviour” (Caruana and Cuccio this issue). However, if we realize “that no hammer is available, we will start looking for something else to use in its stead... We need, then, to select the right habit of action/motor program in consideration of the objects available and of our biological constraints and we need to adjust it to the present situation” (Caruana and Cuccio this issue). In other words, when the tool usually used to perform a given action is not available, abduction by selection is required. Finally, these programs are not involved in creative abduction because, in this last case, the motor program is new. In the following lines, I will mainly discuss the theoretical validity of the distinction between automatic abduction and abduction by selection.

¹ According the C&C model, the notion of automatic abduction involves that tool-specific generalized motor programs are not simply recruited, but integrated with the current situation. Said differently, even if this process is quick, automatic and implicit, this involves reasoning, and not the mere activation of learnt knowledge. Regardless, for C&C, this automatic abduction is based on motor knowledge. So, the key issue is whether motor knowledge can be involved even in tool use situations that may appear relatively simple at first glance as suggested by C&C (e.g., a situation where a hammer is already available). This issue shall be discussed in detail below.

4. Idealistic situations

For the C&C model, tool-specific generalized motor programs could lead people to automatically use the appropriate tools when available (i.e., automatic abduction). However, the situation discussed by C&C can be viewed as “idealistic”. After all, when we intend to hang up a painting on a wall, nothing is present except the painting and the wall. So, we need to reason about how we can achieve this goal, leading us to think about the potential tools and objects that can be used to do so. The corollary is that given that neither the hammer nor the nails are directly available, we need to go get them. The issue is also how to select the appropriate hammer and nails while being in the garage. This necessarily implies that we are still thinking about the properties of the wall and the painting in order to select what is suitable to reach our goal. So, even if we go back from the garage with all the tools and objects needed and we begin to pound the nail with the hammer, it is difficult to consider that motor programs guide us to select the hammer, without any reasoning. If the hammer is available, this is because we previously selected it. Note however that this can lead us to have the feeling that we automatically select the hammer when prepared to pound the nail, because all the reasoning steps have already been completed and, as a result, all the tools and objects needed are now available. At an epistemological level, this can explain why C&C assumed that in situations where the familiar tool usually used is available, the nature of cognitive process involved is automatic.

5. The issue of selection

Imagine now a more realistic situation, where you intend to cut a slice of bread. You are in your kitchen, and many knives are available (e.g., butter knife, bread knife). According to the C&C model, this situation may require automatic abduction, leading

you to automatically retrieve the generalized motor program associated with the knife. The issue, however, is how to select the most appropriate knife. Perhaps the motor program “cutting” can inform you about the body movement – regardless of the effector involved – needed to cut something. The problem is that both the butter knife and bread knife can be selected on this basis, thereby suggesting that these motor programs cannot support the selection. An alternative is that abduction by selection is required. In this case, not only motor programs but also “conceptual knowledge” could be required. However, for the C&C model, abduction by selection only applies to situations where the appropriate tool is not available, leaving open the issue of how to select the appropriate tool when this tool is accompanied by other tools.

6. The dynamic of the use

Imagine now that you intend to pound a nail into a wall but the hammer selected is eventually ineffective. This can lead you to use another hammer or, if you do not have other hammers, you can look for something else that can replace it. You can also simply modify the orientation of the hammer or grasp the handle at its basis in order to increase the percussion force. All these scenarios suggest that even during the use, a certain number of technical problems can occur, which needs to rethink the use by reasoning about the physical properties of the tools and objects involved in the tool-use action. These scenarios are not taken into account by the C&C model – except the use of a non-conventional tool. Yet, these scenarios stress that people are not passive when using tools, and this cannot be reduced to the mere activation of tool-specific generalized motor programs. Moreover, if reasoning is involved (1) not only when people have to select the appropriate conventional tool, but also (2) when they encounter technical difficulties during the use or (3) when the appropriate tool is

eventually ineffective, this leads to the conclusion that the distinction between automatic abduction and abduction by selection is not valid, because based on idealistic situations that do not correspond to everyday situations.

7. What is the future for tool-specific generalized motor programs?

To my opinion, the idea behind the use of the notion of generalized motor programs in the context of tool use may have a future, provided some refinement. Particularly, the issue is, if these programs do not store any specific motor information, what do they store? The C&C model seems to be in line with the manipulation-based approach by considering that these programs contain motor information, although it is generalized. An interesting alternative is to assume that these programs are not stored but rather generated, ruling out the hypothesis of motor routine (Goldenberg 2013; Osiurak 2014). This assumption has been developed in several models of the reasoning-based approach, including the four constraints theory² (4CT; Osiurak 2014; see also Goldenberg and Hagmann 1998; Goldenberg and Spatt 2009; Osiurak 2013; Osiurak and Badets in press; Osiurak et al. 2010, 2011). 4CT assumes that any tool use activity is a problem situation, requiring not only to reason about the physical properties of tools and objects (i.e., technical reasoning) but also to determine how to get them (Osiurak et al. 2008; for a detailed discussion on this aspect, see Osiurak 2014). Technical reasoning is critical to determine how in a given situation the tool has to be used with the object. The outcome of this reasoning process is the simulation of the expected motion of the

² The reasoning-based approach is based on two main assumptions (see Osiurak 2014; see also Reynaud et al. 2016). The first is that tool use is not based on sensorimotor knowledge about manipulation, but rather on abstract, non-declarative mechanical knowledge. The second is that, during the use, motor programs are not stored, but generated (see the discussion after). Importantly, this approach strongly contrasts with the manipulation/embodied cognition approach, according to which knowledge is constituted by information represented within the motor and sensory systems (Barsalou 1999; Buxbaum and Kalénine 2010; Thill et al. 2013). In a way, the reasoning-based approach is closer to more classical cognitive approaches (for a somewhat similar view, see Penn et al., 2008).

tool relatively to the object (e.g., a broad oscillation of a hammer relatively to a nail). This simulation is based on allocentric coordinates in that it does not involve the body. However, to actually perform the tool-use action, an additional system is required (i.e., the production system) to select the appropriate movement executed by the effectors in function of the action simulated (see also Bril et al. 2010; Nonaka 2013). In other words, the action generated by technical reasoning guides the selection of affordances in a fashion similar to the tool-specific generalized motor programs guides the selection of affordances, as suggested by C&C.

Importantly, 4CT does not assume that technical reasoning is necessarily required during all the use. Once the action is generated/simulated by technical reasoning, it can be kept in mind temporarily (i.e., working memory) in order to guide the production system to execute the appropriate motor movements. The fact that reasoning is no longer involved at this point can trigger the feeling that the motor program is automatically retrieved. Again, this can explain at an epistemological level why C&C suggested the notion of automatic abduction. However, if a technical problem occurs, technical reasoning is needed, perhaps to select a more appropriate tool. In this case, we can have the feeling that more controlled processes are at work, as suggested by the notion of abduction by selection. Nevertheless, even if you select a non-conventional tool (e.g., a shoe) to pound the nail, you will have to generate the potential action via technical reasoning, and this will be this simulation that will guide your motor execution. If the shoe appears to be suited for the task, the feeling of automaticity could come back.

8. The reasoning-based approach: Potential theoretical limitations?

C&C stressed four potential theoretical limitations of the reasoning-based approach that deserve some discussion. The first one is the idea that the reasoning-based approach would posit that the cognitive mechanisms involved in familiar versus novel tool use are *very different*. To my opinion, this is a misinterpretation of this approach. As suggested above, technical reasoning skills are considered as critical to carry out mechanical actions both in familiar and novel tool use situations (Osiurak 2014; Osiurak and Badets in press; Osiurak et al. 2010). For this approach, the only difference between these two kinds of situations is that people can use semantic knowledge to determine what familiar tools are usually used in the context of use (e.g., cooking) as well as where to go get them (e.g., kitchen; see Osiurak 2014; Osiurak et al. 2008; Reynaud et al. 2016). Nevertheless, the ability to reason about the mechanical actions only depends on technical reasoning skills so that familiar tool use is not *as different* from novel tool use as C&C suggested.

The second limitation is that the reasoning-based approach does not address the novelty problem. Unfortunately, C&C did not detail why. For C&C, “every action is, at least in part, a new one”. The reasoning-based approach is fully consistent with this proposal, by assuming that tool use is not based on automatic activation of manipulation knowledge but rather on reasoning skills. As suggested above, “any tool use activity is a problem situation”. Therefore, to solve tool use situations, people have to use technical principles learnt from experience (i.e. mechanical knowledge). For instance, imagine you intend to hang up a painting on a wall but you never experience this problem situation before, you may use the principle of “perforation” so that you may determine that a support for the painting can be inserted into the wall. Nevertheless, if you never learnt

this principle, you would have to find another technical solution based on your mechanical knowledge. In sum, the strength of the reasoning-based approach is precisely to overcome the so-called theoretical distinction between novel and familiar tool use, by considering that any tool use activity is a problem situation.

The third and fourth limitations are that the reasoning-based approach specifies neither the number of physical principles that could exist (numerical problem), nor what is the maximal capacity of the system (storage problem). Actually, the numerical problem is not really a problem for cognitive psychologists, but rather for physicians or mathematicians. The storage problem, however, is a matter of cognitive science. More specifically, the issue is how many physical/technical principles someone can understand and store (i.e., mechanical knowledge). It is true that this aspect has never been directly addressed by proponents of the reasoning-based approach. To the extent that mechanical knowledge can be viewed as long-term knowledge or technical vocabulary, the more likely answer is that this storage has no apparent limit, as for language.

9. Conclusion

To sum up, the C&C model offers the opportunity to debate the cognitive origins of human tool use. The notion of tool-specific generalized motor programs is attractive and could be useful to attempt to reconcile the manipulation-based and reasoning-based approaches. However the C&C model in its present form is deeply inspired by the manipulation-based approach, notably by considering that these programs are motor routines. Here, I propose a refinement of this model, by suggesting that these programs are (1) not motor but rather cognitive and (2) generated rather stored. For me, this refinement is essential to propose a model reconciling the two approaches. Otherwise

the risk is that the C&C model becomes just another version of the models developed within the manipulation-based approach, where the role of reasoning is considered as limited in most of tool use situations.

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