New Ideas in Psychology 31 (2013) 239–246

Contents lists available at SciVerse ScienceDirect

New Ideas in Psychology

journal homepage: www.elsevier.com/locate/newideapsych

# Cognitive representations of tool-use interactions

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*Keywords:*
Tool use
Sensorimotor transformation
Action planning
Movement planning
Stimulus–response mapping
Visuo-motor mapping

A B S T R A C T

Tools are important mediators between our bodies and the world surrounding us. They can substantially change the usual relationship between our body movements and the effects that ensue in the environment. Given the ease with which we learn to apply new tools, the question arises how our motor system flexibly adapts to specific tool transformations. There are two basic possibilities. One consists of incorporating the tool into one's body by updating one's body schema. Movement planning can then proceed in the same manner as it did without the tool. In the present paper I argue for a second view, that tool use involves representations of the tool-specific mappings between body movements and environmental effects at a central level. I present evidence for this view from several research areas including stimulus–response compatibility, bimanual coordination, and action observation. Finally, I discuss the degree of abstractness of these central representations of tool-use interactions.



## 1. Introduction

It has often been claimed that language and tool use are universal and defining characteristics of the human species (e.g., Gibson & Ingold, 1995). As might be expected, the topic of language has attracted considerable scientific research interest, generating a huge and still growing body of literature. Somewhat surprisingly, much less attention has been devoted to human tool use, in either philosophy or cognitive psychology (Preston, 1998). However, in recent years this situation has begun to change: an increasing number of scientific studies in cognitive psychology and in the neurosciences have been devoted to the mechanisms and functional architecture of human tool use (e.g. Baber, 2003, 2006; Johnson-Frey, 2004; Osiurak, Jarry, & Le Gall, 2010).

In order to successfully use a tool, the user needs two basic skill components. First, an appropriate tool has to be selected for the task at hand. This means that information has to be retrieved from semantic memory, specifying which kind of tool has been used in the past to carry out the task. If no such information is available, the structure of the task has to be analyzed in order to determine what physical properties of a potential tool will exert the desired effect on the goal object or environment. For instance, if a nail has to be driven into a wooden board and a hammer is not available, the actor has to recognize that something dense and heavy is required for the task and consequently should prefer a stone over an apple to accomplish the task. Second, the user has to be able to compute the sensorimotor transformations needed for using the tool. Each tool alters the usual relationship between one's limb movements and the effects generated by these limb movements in external space, producing a dissociation between the spatial locations to which the body movements are directed and the locations at which the effects of the movements will actually occur. A fundamental question is whether tools must be considered as entities separate from the human body, belonging to the environment, or whether they should rather be treated as parts or extensions of the human body. While some evidence suggests that functional reorganization of visuotactile limb representations is possible in tool use (e.g. Berti & Frassinetti, 2000; Iriki, Tanaka, & Iwamura, 1996), the question is whether and how such representations can be used to 1) select an appropriate tool

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http://dx.doi.org/10.1016/j.newideapsych.2012.12.002

from the environment and 2) program and execute movements with the tool.

Both selecting and adequately using a tool often rely on past experiences of tool use, which are stored in semantic or procedural memory. Research in neuropsychology has focused on problems in the use of these representations as a consequence of brain injury and has introduced a fundamental distinction between the brain systems responsible for schematic, conceptual knowledge about tools and those responsible for the procedural skills necessary for their dexterous use (e.g., Johnson-Frey, 2004; Morlaas, 1928). Evidence for this distinction comes from studies of patients who have trouble assigning the appropriate action to a tool, trying, for instance, to brush their teeth with a comb. These patients have no difficulty with the tool-use skill itself (e.g., they know how to brush their teeth when given a toothbrush). The conclusion has been that the representations responsible for performing tool-use skills are separable from semantic knowledge about tools and their associated functions (e.g., Ochipa, Rothi, & Heilman, 1989). The reverse pattern of deficits also exists: patients with ideomotor apraxia retain knowledge about tools' functions but do poorly when asked to pantomime how familiar tools are used, especially when they are given only a visual or verbal cue for the action.

In the following, I focus on the procedural aspect of tool use; that is, on how movements with tools are planned and executed. In the first part, I outline two principal ways that movement planning with tools might proceed. The first is that tools are incorporated in the body schema and thus do not change the planning of the movement in external space. The second is that tools are treated as separate from the human body, with central representations of the mapping between body movements and tool movements guiding planning of the movement in external space.

In the second part, I present evidence from experimental studies of human tool use. These studies speak in favor of tool representations at a central level enabling preparation and planning of the movement in advance.

The third part addresses whether central representations for guiding a tool-use action are abstract—containing only the abstract mapping between body movements and associated tool movements/effects, with no further information about the tool's physical properties—or whether they are mental models of the concrete tool at hand, with information about the tool's physical properties and its mechanics to guide the action.

## 2. Movement planning with tools

Recent research in neuroscience and neuropsychology has suggested that tools are incorporated into the body schema and can change the representation of the space surrounding our body. This could lead to the assumption that early movement planning with tools can proceed as if the tool had no separate existence and only the body representation had changed. On the other hand, tool representations have often been conceptualized as distinct action schemata that specify the movements and associated environmental effects accomplished through their application (e.g., Baber, 2006; Norman & Shallice, 1986). In the following, I outline these different views before discussing evidence for a central representation of tools, operating at early stages of movement planning.

According to Willingham's (1998) neuropsychological theory of motor skill learning, several basic stages can be distinguished in movement control and motor skill learning. First, an environmental goal for the action has to be identified (e.g., a strawberry to be grasped). Second, the target for the movement has to be selected (in our example, the spatial position of the strawberry). Sometimes a sequence of targets has to be selected to reach the environmental goal. The third process translates the spatial target into patterns of muscle activity that result in the appropriate movement.

There are (at least) two possible ways that a tool can be considered in this sequence of stages (cf. Rieger, Massen & Verwey, 2008; Verwey & Heuer, 2007). Let's consider the example of someone picking up a strawberry with a fork. In this case the environmental goal is still the strawberry. On the one hand, the tool could have already altered the process of selecting the movement target, which would now be the spatial endpoint of the hand movement, rather than the spatial location of the strawberry. The other stages of movement planning could then proceed as they would have without the tool. On the other hand, the tool could leave the initial stages of movement planning unchanged, with the selection of the position of the strawberry as the spatial target of the action. The tool would then have to be taken into account later, when the spatial target position is translated into the required patterns of muscle activity. Hence, the usual relationship between target positions in space and the muscle activity to move a limb there would have to be changed, as though the limb itself had changed its properties (e.g., as its length changes over time with growth).

In the first case, the tool is treated as something separate from the human body, and requires a central representation of the mapping between goal locations for the tool and the corresponding spatial positions to which the bodily effector (most often the hand) has to be moved. The second possibility seems to be more in line with the view that tools are incorporated into the body schema, extending peripersonal space to include the tool. In particular, there seems to be no need to distinguish between external goal locations to which the tool has to be moved, and the locations to which the bodily effector has to be moved.

According to Willingham (1998), a fundamental distinction between the first two states of movement planning and the third is the awareness an actor can have of the representations at each stage. It is assumed that humans are always aware of the environmental goals they pursue, and can sometimes be aware of the movement targets they select, but that they are never aware of the representations that support the translation from spatial targets into the firing of particular muscle groups. As a consequence, human beings can strategically select an environmental goal, and they can also consciously select certain targets for movement (although they do not usually do so). However, the third and last stage of movement planning is not susceptible to conscious, strategic influences.