Cognition 130 (2014) 66–73

Contents lists available at ScienceDirect

Cognition

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

Pliers, not fingers: Tool-action effect in a motor intention paradigm

François Osiurak[a,*], Arnaud Badets[b]

[a] Laboratoire d'Etude des Mécanismes Cognitifs (EA 3082), Université Lyon 2, France
[b] Centre de Recherche sur la Cognition et l'Apprentissage UMR 7295, Centre National de la Recherche Scientifique, France

ARTICLE INFO

Article history:
Received 23 January 2013
Revised 8 July 2013
Accepted 22 September 2013
Available online 29 October 2013

Keywords:
Tool use
Motor intention
Sensorimotor representations
Compatibility effect

ABSTRACT

Tool-use representations have been suggested to be supported by the representation of hand actions and/or by the representation of tool actions. A major issue is to know which one of these two representations is preferentially activated when people intend to use a tool. To address this issue, we developed a paradigm in which, in 20% of trials, participants had to press a button and actually use pliers to move an object in response to a predefined target symbol. Importantly, two masks hiding the symbols performed "opening" or "closing" actions before symbols appeared. In Experiment 1, participants used normal pliers: Hand's opening actions induced pliers' opening actions and vice versa for hands' closing actions. Results indicated a compatibility effect between masks' actions and pliers' actions. Participants were faster to press the button in response to the target symbol when opening and closing actions of the masks were congruent with the corresponding actions of the hand. In Experiment 2 participants used inverse pliers: Hand's opening actions involved pliers' closing actions and vice versa. In this situation, results showed that the congruency of masks' actions occurred with pliers' actions and not hand's actions. Altogether, these findings demonstrate that intention of use is preferentially based on the representation of tool actions, and have important implications for the domain of neuropsychology of tool use and the theories of goal-directed behavior.

1. Introduction

Different animal species use tools but humans are unique because they use tools frequently (Osiurak, Jarry, & Le Gall, 2010, 2011). So, a fundamental issue is to understand the psychological basis of human tool use. Tool-use representations have been suggested to contain two types of information, namely, information about the manipulation (e.g., Buxbaum, 2001) and the mechanical action of the tool (e.g., Goldenberg & Hagmann, 1998; Osiurak et al., 2010). For instance, when using pliers to grasp and move an object, manipulation-centered representations correspond with the hand's closing/opening action (hand-action effect) and mechanical-action-centered representations with the pliers' closing/opening action (tool-action effect). The aim of the present study is to explore which one of these representations is activated when people intend to use a tool.

According to the embodied cognition view, conceptual knowledge about tool use is grounded in sensorimotor representations (e.g., Barsalou, 1999; see also Binkofski & Buxbaum, in press). Evidence for this view comes from neuroimaging (e.g., Chao & Martin, 2000; Grèzes, Tucker, Armony, Ellis, & Passingham, 2003) as well as experimental studies showing that the mere observation of a tool is sufficient to activate motor representations of how to grasp and use them (Tipper, Paul, & Hayes, 2006; Tucker & Ellis, 1998). This view has found resonance in neuropsychology, wherein difficulties met by left brain-damaged patients with apraxia of tool use have been described as resulting from damage to stored representations about

* Corresponding author. Address: Laboratoire d'Etude des Mécanismes Cognitifs (EA 3082), Institut de Psychologie, 5, avenue Pierre Mendès-France, 69676 Bron Cedex, France. Tel.: +33 0478774395.

E-mail address: Francois.Osiurak@univ-lyon2.fr (F. Osiurak).

0010-0277/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.cognition.2013.09.005

how to manipulate tools (Binkofski & Buxbaum, in press; Buxbaum, 2001; Rothi, Ochipa, & Heilman, 1991). In a way, these studies stress the role of hand-action effect representations in tool use.

An alternative theoretical position assumes that although there is a significant interaction between sensorimotor and conceptual representations, they are also dissociable (e.g., Chatterjee, 2010; Mahon & Caramazza, 2005, 2008). Retrieving conceptual knowledge about tool function (knowing the tool's usual function/mechanical action) may activate representations about manipulation, but the retrieval of conceptual knowledge does not necessarily imply the prior activation of those representations (e.g., Negri et al., 2007). In line with this, Garcea and Mahon (2012) demonstrated that participants presented with pictures of familiar tools were faster to make mechanical action/function judgments than manipulation judgments. Interestingly, apraxia of tool use has also been explained as resulting not from impaired representations about manipulation but rather from impairment at a conceptual level and, more particularly, to understand mechanical actions (Goldenberg, 2009; Goldenberg & Hagmann, 1998; Goldenberg & Spatt, 2009; Jarry et al., 2013; Osiurak, Jarry, Lesourd, Baumard, & Le Gall, 2013; Osiurak et al., 2008, 2009, 2010, 2011). In broad terms, these studies emphasize the role of tool-action effect representations.

When engaged in everyday life activities such as working odd jobs (e.g., to set up a shelf), we generally anticipate the future tool actions to perform (e.g., turning a screw with a screwdriver). In a way, the activation of the representations of these future tool actions forms the intention of use. So, as long as the relevant situation or event does not occur (e.g., the wooden board correctly placed) we maintain this intention (see Badets, Albinet, & Blandin, 2012, for a complete description of this event-based task of delayed motor intention). To better understand the psychological basis of human tool use, it appears interesting to determine whether this intention of use is preferentially based on hand-action effect or tool-action effect representations.

The aim of the present study was to address this issue. Generally used experimental paradigms do not allow us to do so because participants are commonly asked to form a covert intention of the use action and to directly execute the overt action. To bypass this methodological issue, we developed a motor intention paradigm wherein participants had to form an intention of use all along an ongoing task but to execute the overt action infrequently during the ongoing task and only in response to a specific stimulus (Badets et al., 2012; see also Einstein & McDaniel, 2005 for a review on this event-based task in the domain of prospective memory). More particularly, participants were instructed that they would use pliers to grasp and move an object. To know when they had to use the pliers, participants performed a computerized task wherein pairs of symbols were presented. In 20% of trials, a target symbol appeared indicating that they had to press a key and use pliers to move an object. We called these trials the action trials. When no target were presented, they had to respond whether the two symbols were similar or not (80% of trials; judgment trials). Two masks hid the symbols before their presentation. Those masks performed either an "opening" or a "closing" action before symbols appeared.

In Experiment 1, participants had to use normal pliers to move an object either by opening or closing the pliers to move the object (between-subjects condition). For these pliers, the hand action (opening/closing) was analogous to the tool action (opening/closing). As found in other paradigms (e.g., Tucker & Ellis, 1998), we expected to obtain in the action trials a compatibility effect between the hand/tool-action and the irrelevant masks' action. More specifically, we hypothesized that participants who made an opening hand/tool-action with the pliers responded faster to target symbols when preceded by opening than closing masks' actions. The opposite pattern was expected for the participants who made a closing hand/tool action with the pliers. We thought that for a closing hand/tool-action, for example, participants would form an intention of use based on the abstract code "closing". Thus, the congruency of this code with the masks' action would prepare the participants to overtly execute the use action, improving the detection of the target symbol. Given that the actions made by both the hand and the tool were analogous, we could not determine whether the intention of use was based on hand-action effect or tool-action effect representations. Therefore, in Experiment 2, participants had to use inverse pliers to move an object either by opening or closing the pliers to move the object (between-subjects condition). Importantly, for these pliers, the hand action effect was opposite to the tool action effect. So, as suggested by the manipulation hypothesis (Binkofski & Buxbaum, in press; Buxbaum, 2001; Rothi et al., 1991), if the intention of use was based on hand-action effect representations, a compatibility effect should be found between the hand action and the masks' action. By contrast, as suggested by the tool function hypothesis (Goldenberg & Spatt, 2009; Osiurak et al., 2010, 2011), a compatibility effect between the tool action and the masks' action should be observed if the intention was based on tool-action effect representations.

Finally, it is noteworthy that the use of two different pliers making different actions (opening vs. closing) is inspired from the study of Umiltà et al. (2008). They observed in monkeys trained to use tools that cortical motor neurons, active during hand grasping, also became active during grasping with pliers, as if the pliers were the fingers. This study showed that motor embodiment could occur after training. With regard to the study of Umiltà et al. (2008), the originality of the present study was to examine whether, without any training, people form an intention of use based on the abstract code linked to the action of the tool. In other words, the originality of the present study was also to extend the results of Umiltà et al. (2008) to human subjects.

2. Experiment 1

2.1. Method

2.1.1. Participants

Twenty-four undergraduate students from the University of Lyon took part in Experiment 1 (16 women; $M_{age} = 19.38$, $SD_{age} = 0.82$). All participants were right-handed (Edinburgh Score > 70) and had normal or corrected-to-normal visual acuity. Informed consent was obtained from the participants. The study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

2.1.2. Materials and procedure

A schematic representation of the apparatus is presented in Fig. 1. Participants were seated at a table in front of a monitor and a keyboard (monitor size: 32 × 50 cm; distance participant–monitor: 75 cm; distance participant–keyboard: 30 cm). The pliers and the object to be moved were located to the right of the participant (distance participant–pliers: 45 cm). The pliers were placed at 10 cm from the edge of the table. Two rectangles were drawn on the table (20 × 6 cm) and corresponded with two locations, namely, the far and the near location at 70 cm and 55 cm from the edge of the table, respectively (“A” and “B” in Fig. 1). The object was initially placed at the far location. The pliers were 35-cm long and were relatively standard in that fingers’ closing movements led to a pliers’ closing action, and vice versa. The object to be moved was a “trident” (width: 15 cm; depth: 3 cm; height: 9 cm; width of each “branch”: 2.5 cm; distance between two branches: 3.75 cm). After inserting the pliers between the branches, the object could be grasped either by opening the pliers and pressing the two lateral branches or by closing the pliers and pressing the middle branch (between-subjects condition).

Participants were first instructed that they would have to perform a computerized task but at some moments they would have to stop the task to use pliers to grasp and move an object. Each use had to be performed as follows: Grasping the pliers, inserting the pliers between the object’s branches, grasping the object by opening/closing the pliers (Fig. 2), moving the object from one location to the other (far to near or near to far), and putting the pliers on the table. The experimenter performed one demonstration by moving the object from the far to the near location. Then, the participant carried out the use action by moving the object from the near to the far location. During the experiment, participants had to move the object only from one location to another so that the first use consisted in moving the object from the far to the near location, the second use, from the near to the far location, and so on.

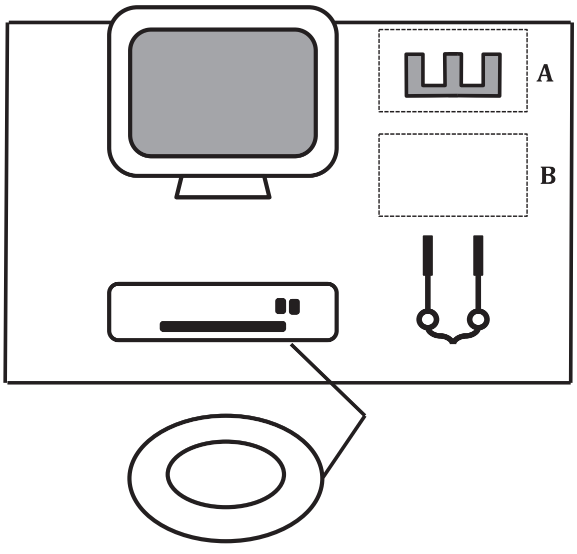

Fig. 1. Schematic representation of the apparatus used in the present study. Only the normal pliers used in Experiment 1 are illustrated. A and B refer to the far and the near location, respectively.

After this demonstration, participants were informed that they would have to perform a computerized task wherein they would be presented pairs of symbols (Fig. 3). When a target symbol appeared (joker), either with another symbol or doubly, they had to press the spacebar with the right thumb and carried out the use action described above (action trials). The term “action” appeared on the screen. After each use, they had to press again the spacebar with the right thumb to make disappear the term “action” and to resume the computerized task. If the participant pressed erroneously one of the two other keys instead of the spacebar, the term “forgetting” appeared on the screen. In this case, the participant had nevertheless to press the spacebar (the term “action” appeared) and to carry out the use action. When no joker appeared, they had to perform the similarity task (judgment trials). In this task, they had to decide whether the two symbols (heart, clover, diamond or spade) were similar or not by pressing the right key (“*l*”) with the right middle finger or the left key (“*k*”) with the right index finger. An 800-ms feedback was given for incorrect responses. The experimenter stressed the importance of being particularly fast for the action trials and of keeping the fingers in contact with the keys during the computerized task. Finally, participants were informed that the use actions were videotaped. Videotape recording allowed us to verify that all the participants performed the use actions correctly.

As shown in Fig. 3, two masks hid the stimuli. After 500 ms, the two masks started an opening/closing action during 660 ms, with an acceleration phase and a deceleration phase. Then, the two masks remained immobile during 200 ms and the symbols appeared. The inter-stimulus interval was 1000 ms. Twenty percent of the trials were action trials ($n = 48$) and 80% were judgment trials ($n = 192$), totaling 240 trials. In half of the trials, symbols were similar and in the other half they were different. Likewise, in half of the trials, masks performed an opening action and in the other half a closing action. The experiment was divided into blocks of 120 trials (24 action trials and 96 judgment trials). In each block, trials were fully randomized. In one block, participants had to press the right key for “similar” and the left key for “different” and vice versa for the other block. The order of block was counterbalanced between participants. Participants performed eight training trials before each block (2 action trials and 6 judgment trials). Half of the participants had to carry out an opening action with the pliers and the other half a closing action.

2.1.3. Data analysis

Response times were collected for action and judgment trials. We also recorded the use time, that is, the time needed to use the pliers corresponding with the time

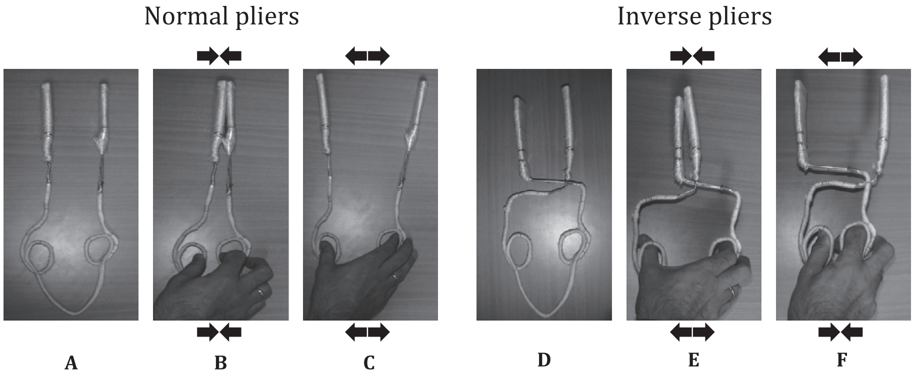

Fig. 2. Normal and inverse pliers used in Experiments 1 and 2, respectively. Both pliers (a and d) could be used by performing a closing (b and e) or an opening action (c and f). Whereas closing and opening actions of the normal pliers could be made by performing similar fingers' movement (b and c), closing and opening actions of the inverse pliers required opposite fingers' movement (e and f).

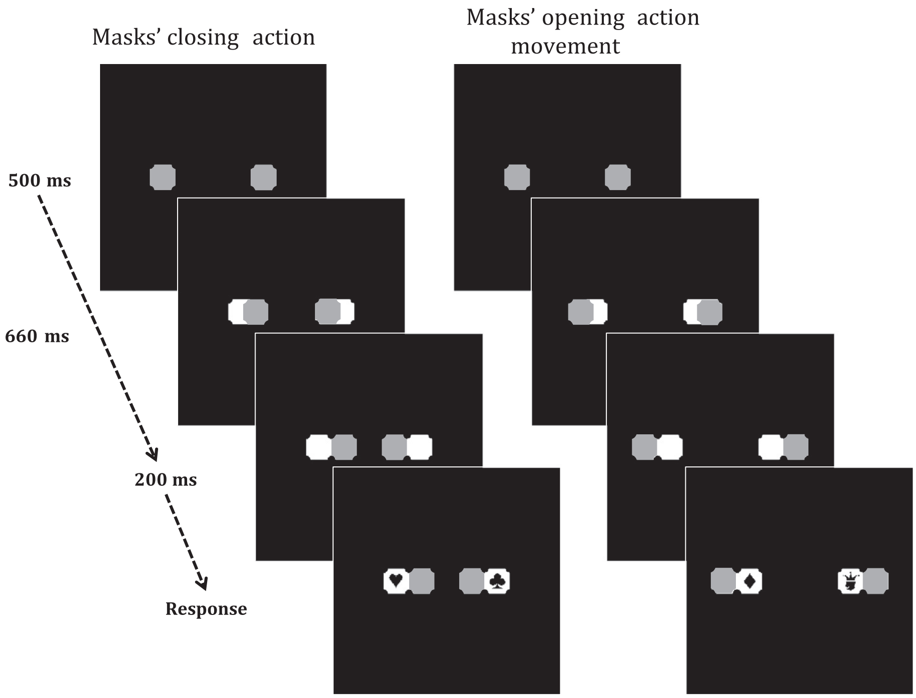

Fig. 3. Examples of action and judgment trials. The two types of masks' actions are shown. Note that the example of closing action presented here led to a judgment trial (response: different). By contrast, the example of opening movement led to an action trial, requiring the pressing of the spacebar because of the appearance of the joker and the subsequent use of the pliers.

between the pressing of the spacebar when a joker appeared and the pressing of the spacebar to resume the computerized task.

2.2. Results

Responses times for action and judgment trials and use times below or above two standard deviations from the mean were removed (1.92% of the data).

2.2.1. Response times for action trials

Mean response times were analyzed by means of a two-way ANOVA with Masks' action (opening vs. closing) as within-subjects factor and Pliers' action (opening vs. closing) as between-subjects factor. No significant effect was found for Masks' action, $F < 1$, nor was there a significant effect for Pliers' action, $F < 1$ (Fig. 4a). The two-way interaction was however significant, $F(1,22) = 11.38$, $P < 0.01$, $\eta^2 = 0.34$. Post hoc comparisons (Fisher's LSD tests) were conducted to examine the interaction. This analysis revealed that participants who made closing pliers' actions were faster to respond after a closing than an opening action of the masks, $P < 0.05$, and vice versa for participants making opening pliers actions, $P < 0.02$.

2.2.2. Response times for judgment trials

Mean response times were analyzed with a two-way ANOVA with Masks' action (opening vs. closing) as within-subjects factor and Pliers' action (opening vs. closing) as between-subjects factor. As can be seen in Table 1, a significant main effect was found for Masks' action, $F(1,22) = 5.15$, $P < 0.04$, $\eta^2 = 0.19$, suggesting that participants were faster to make similarity judgments after a closing ($M = 718$) than an opening action of the masks ($M = 732$). Neither the main effect for Pliers' action, $F < 1$, nor the interaction, $F(1,22) = 1.73$, $P = 0.20$, was significant.

2.2.3. Number of errors for judgment trials

As participants made very few errors in action trials ($N = 14$) no data analysis was performed on the number of errors for action trials. The number of errors for judgment trials was analyzed with a two-way ANOVA with Masks' action (opening vs. closing) as within-subjects factor and Pliers' action (opening vs. closing) as between-subjects factor. No significant effect was found for Masks' action, $F < 1$, nor for Pliers' action, $F < 1$ (Table 2). The interaction did not reach significance, $F(1,22) = 1.07$, $P = 0.31$.

2.2.4. Use times

To examine the learning of the use of pliers, we divided the 48 use trials into four blocks of 12 use trials (Table 3). Mean use times were analyzed with a three-way ANOVA with Masks' action (opening vs. closing) and Blocks (1–12 vs. 13–24 vs. 25–36 vs. 37–48) as within-subjects factors and Pliers' action (opening vs. closing) as between-subjects factor. No significant effect was found for Pliers' action, $F < 1$, nor for Masks' action, $F < 1$. A significant effect for blocks was however found, $F(3,66) = 12.93$, $P < 0.001$, $\eta^2 = 0.37$, indicating a progressive decrease of use times across blocks. None of the interactions was significant, $Fs < 1$.

2.3. Discussion

Our results indicated that in action trials participants were faster to respond when the masks' action was congruent with the hand/tool-action, confirming that our paradigm could be sensitive to a compatibility effect. More particularly, our findings seem to indicate that for a closing hand/tool action, for instance, participants formed an intention of use centered on the abstract code "closing". Therefore, the congruency of this code with the masks' action prepared them to overtly execute the use action, facilitating the detection of the target symbol. Importantly, this compatibility effect only occurred for action trials and not judgment trials. In broad terms, these results indicate that the compatibility effect was only found for stimuli that were specifically linked to the motor intention.

Table 1
Response times (in ms) for judgment trials of Experiment 1 (normal pliers) and Experiment 2 (inverse pliers).

		Masks' action	
		Closing	Opening
Experiment 1 (normal pliers)			
Pliers' action	Closing	718 (22)	724 (27)
	Opening	717 (26)	739 (28)
Experiment 2 (inverse pliers)			
Pliers' action	Closing	730 (26)	743 (28)
	Opening	742 (27)	740 (25)

Values in brackets are standard errors to the means.

Table 2
Number of errors for judgment trials of Experiment 1 (normal pliers) and Experiment 2 (inverse pliers).

		Masks' action	
		Closing	Opening
Experiment 1 (normal pliers)			
Pliers' action	Closing	3.58 (0.81)	2.75 (0.55)
	Opening	3.42 (0.78)	3.75 (0.59)
Experiment 2 (inverse pliers)			
Pliers' action	Closing	3.92 (0.82)	4.83 (0.87)
	Opening	3.08 (0.82)	2.75 (0.75)

3. Experiment 2

In Experiment 1, both the tool and the hand-action were analogous in terms of movement effects, so we could not determine whether the intention of use was based on

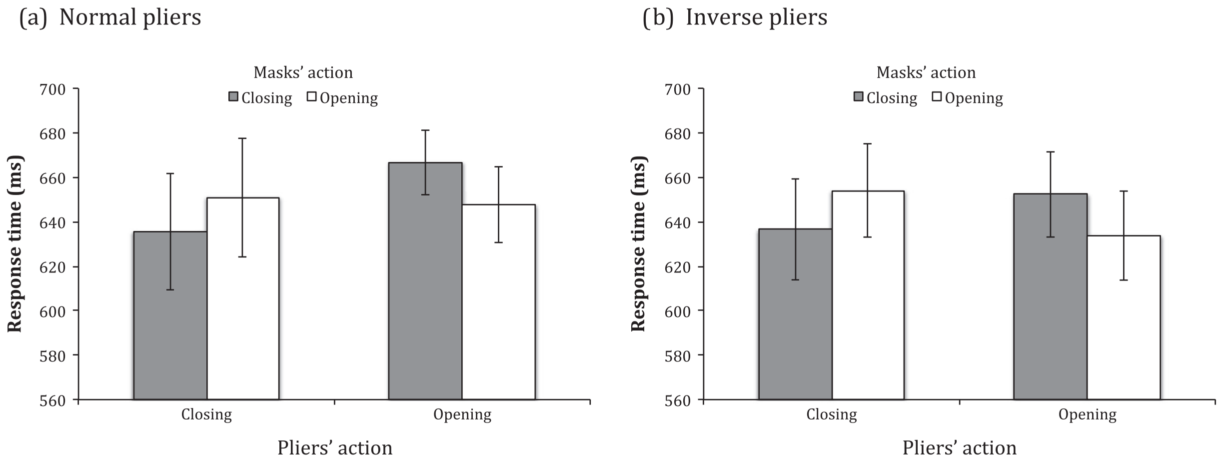

Fig. 4. Response times (in ms) for action trials of Experiment 1 (a; normal pliers) and Experiment 2 (b; inverse pliers). Error bars indicate standard errors to the means.

Table 3
Use times (in ms) in Experiment 1 (normal pliers) and Experiment 2 (inverse pliers).

		Blocks			
		1–12	13–24	25–36	37–48
Experiment 1 (normal pliers)					
Pliers' action	Closing	6628 (503)	6398 (425)	5947 (416)	5811 (433)
	Opening	6228 (471)	6110 (520)	5713 (481)	5655 (484)
Experiment 2 (inverse pliers)					
Pliers' action	Closing	8046 (696)	6812 (517)	6122 (311)	5659 (193)
	Opening	7877 (376)	7195 (329)	6552 (319)	6175 (337)

hand-action effect or tool-action effect representations. In Experiment 2, we replicated Experiment 1 except that participants had to use inverse pliers involving opposite hand and tool-actions. Consequently, if the intention of use was centered on hand-action effect representations, a compatibility effect was expected between the hand action and the masks' action. By contrast, a compatibility effect between the tool action and the masks' action should be found if the intention was based on tool-action effect representations.

3.1. Method

3.1.1. Participants

Twenty-four right-handed (Edinburgh Score > 70) undergraduate students from the University of Lyon participated in Experiment 2 (15 women; $M_{age} = 18.86$, $SD_{age} = 0.99$). None of them took part in Experiment 1. All participants had normal or corrected-to-normal visual acuity. Informed consent was obtained from the participants. The study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki.

3.1.2. Materials and procedure

The method was similar to that of Experiment 1, except that participants had to use inverse pliers in that fingers' closing movements involved a pliers' opening action and fingers' opening movements a pliers' closing action (Fig. 2). Half of the participants had to make a pliers' closing action to move the object and the other a pliers' opening action.

3.2. Results

Responses times for action and judgment trials and use times below or above two standard deviations from the mean were removed (2.16% of the data).

3.2.1. Response times for action trials

Mean response times were submitted to a two-way ANOVA with Masks' action (opening vs. closing) as within-subjects factor and Pliers' action (opening vs. closing) as between-subjects factor. No significant effect was found for Masks' action, $F < 1$, nor for Pliers' action, $F < 1$ (Fig. 4b). The two-way interaction was however significant, $F(1,22) = 8.98$, $P < 0.01$, $\eta^2 = 0.29$. Post hoc comparisons (Fisher's LSD test) indicated that participants who made pliers' closing actions were faster to respond after closing than opening actions of the masks, $P < 0.04$. The opposite pattern was observed for participants making pliers' opening actions, $P < 0.04$.

3.2.2. Response times for judgment trials

Mean response times were subjected to a two-way ANOVA with Masks' action (opening vs. closing) as within-subjects factor and Pliers' action (opening vs. closing) as between-subjects factor. No significant effect was found for Masks' action, $F < 1$, nor for Pliers' action, $F < 1$ (Table 1). The interaction did not reach significance, $F(1,22) = 1.54$, $P = 0.23$.

3.2.3. Number of errors for judgment trials

As participants made very few errors in action trials ($N = 10$) no data analysis was performed on the number of errors for these trials. The number of errors for judgment trials was analyzed with a two-way ANOVA with Masks' action (opening vs. closing) as within-subjects factor and Pliers' action (opening vs. closing) as between-subjects factor. No significant effect was found for Masks' action, $F < 1$, nor for Pliers' action, $F(1,22) = 2.56$, $P = 0.12$ (Table 2). The interaction did not reach significance, $F(1,22) = 1.69$, $P = 0.21$.

3.2.4. Use times

Mean use times were analyzed with a three-way ANOVA with Masks' action (opening vs. closing) and Blocks (1–12 vs. 13–24 vs. 25–36 vs. 37–48) as within-subjects factors and Pliers' action (opening vs. closing) as between-subjects factor (Table 3). No significant effect was found for Pliers' action, $F < 1$, nor for Masks' action, $F < 1$. A significant effect for blocks was however found, $F(3, 66) = 32.25$, $P < 0.001$, $\eta^2 = 0.59$, indicating that, as in Experiment 1, there was a progressive decrease of use times across blocks. None of the interactions was significant, $Fs < 1$.

3.3. Discussion

Results of Experiment 2 were highly similar to those of Experiment 1. However, we observed a compatibility effect between the pliers' action and the masks' action. Note that if the intention of use was based on hand-action effect representations, we should have obtained the opposite pattern, namely, a compatibility effect between the hand action and the masks' action. Therefore, our findings indicate that the intention of use might be centered on tool-action effect representations.

4. General discussion

To sum up, results of Experiment 1 demonstrated that a compatibility effect could be obtained between the irrelevant masks' action and the hand/tool-action. These findings show that when people form an intention of use, they create an abstract code (e.g., closing) that can interact with the features shared with another task (i.e., masks' action). Thus, the congruency of this code with the processing of environmental stimulus features prepares them to overtly execute the use action, facilitating the detection of a target linked to the intended use action. Importantly, the congruency effect between the mask' actions and the pressing of the space bar is apparent well before the actual action with the tool. This effect confirms that important features of the intended action with the tool are kept in mind for future enactment. The originality of Experiment 1 was to demonstrate that a compatibility effect could be observed in a motor intention paradigm. More importantly, results of Experiment 2 indicated that this compatibility effect occurred with the pliers' action, and not the hand's action. At least two interpretations can be given to the findings of Experiment 2.

The first is that when people intend to use a tool they preferentially form a tool-action effect representation. Then, when they have to actually execute the action, they activate hand-action effect representations to manipulate the tool in line with the tool-action effect representation. The corollary is that, in Experiment 2, the congruency only occurred between the masks' action and the pliers' action effect because hand-action effect representations were activated after participants had pressed the key, that is, when they were actually engaged in the execution of the use action. This interpretation is consistent with recent evidence showing that people presented with pictures of familiar tools are faster to make mechanical action/function than manipulation judgments (Garcea & Mahon, 2012). This is also in line with some neuropsychological studies suggesting that apraxia of tool use mainly results from impaired tool-action effect representations (Goldenberg, 2009; Goldenberg & Spatt, 2009; Osiurak et al., 2010, 2011). Note that somewhat similar results were found in an imitation-based task wherein participants had to observe another person (i.e., the model) carrying out a tool-action (touching a target by making a lever action) before doing an action by themselves (Massen & Prinz, 2007a,b, 2009; see also Beisert, Massen, & Prinz, 2010 for a switching paradigm that use pliers). In these studies, the action performed by the model could be congruent with that of the observer in two ways: Either the action made by the lever or the movement made by the user. The results showed that participants were faster and committed fewer errors when the action made by the lever was congruent. This finding suggests that the representation formed during the observation was rather centered on the tool-action effect than on the hand-action effect.

More globally, our results are also consistent with the ideomotor approach of action control that predicts that actions are strongly linked to their distal expected sensory consequences (Greenwald, 1970; see Hommel, Müsseler, Aschersleben, & Prinz, 2001 for this distal hypothesis). The core mechanism of the ideomotor theory is that actions are represented in terms of expected sensory consequences they aim to produce in the environment (e.g., Prinz, 1997; see Koch, Keller, & Prinz, 2004; Shin, Proctor, & Capaldi, 2010 for reviews). Crucially, the association suggests that merely thinking about the expected sensory effects can prime efficiently the associated action (Hommel et al., 2001). A similar interpretation has been suggested in favor for the dominance of a distal action effect of tool use during manipulations (Sutter, Ladwig, Oehl, & Müsseler, 2012). For Sutter and colleagues, the most important expected sensory consequence in controlling a tool is the distal effect of the tool and not the proximal effect of the hand. In the same vein, Mechsner, Kerzel, Knoblich, and Prinz (2001) proposed that "voluntary movements are, in general, organized by way of a simple representation of the perceptual goals, whereas the corresponding motor activity of, sometimes extreme, formal complexity is spontaneously tuned in" (p. 72). Adapted for tool use, the final goal on the distal environment might represent the main representation whatever the actions that produce this goal. More empirical data to a behavioral and neurophysiological level are needed in order to confirm this assumption.

The second interpretation is that when people intend to use a tool they activate both hand-action effect and tool-action effect representations, but the intention of use would be preferentially based on the latter. This interpretation cannot be ruled out from our results alone and future research is needed to address this issue. Nevertheless, even if our data cannot invalidate the idea that hand-action effect representations are activated when people intend to use a tool, they challenge the centrality of hand-action effect representations as assumed by some cognitive models (Binkofski & Buxbaum, in press; Buxbaum, 2001; Rothi et al., 1991).

As explained in introduction, the difficulties met by left brain-damaged patients with apraxia of tool use can be described as resulting either from damage to stored representations about how to manipulate tools (e.g., Binkofski & Buxbaum, in press) or from damage to representations about the mechanical actions of tools (e.g., Osiurak et al., 2013). An important issue in this field is to know whether these two interpretations are exclusive or not. Particularly, some left-brain damaged patients have been shown to present a selective impairment when asked to match tools on the basis of similar manipulation (Buxbaum & Saffran, 2002). Those patients generally do not have difficulties to actually use tools, but rather to demonstrate the corresponding pantomime (Buxbaum, 2001). This deficit has been labeled "ideomotor apraxia" and differs from "ideational apraxia" (inability to actually use tools), which occurs after impairment of representations about the mechanical actions of tools (see Osiurak et al., 2011). The compatibility effect observed in the present study might be useful to examine the distinction usually made between these two forms of apraxia. As explained above, the compatibility effect observed here may demonstrate that the intention of use is based on the representations about the mechanical actions of the tool. Therefore, if patients with ideomotor apraxia have a selective impairment of representations about tool manipulation, then the same compatibility effect should be found in these patients.

To conclude, it is interesting to discuss the present findings in the light of those obtained by Umiltà et al. (2008). After training macaque monkeys to use normal and inverse pliers during 6–8 months (closing pliers' action only), they tested neurons of areas F5 and F1 (primary motor cortex) during grasping performed by using the two types of pliers. All of these neurons were selected because they discharged in association with hand grasping movements. They found that F5 and F1 neurons discharged during grasping done with normal and reverse pliers. In other words, neurons that discharged when the hand was closing with the normal pliers also discharged when the hand was opening with the inverse pliers. The conclusion was that the capacity to use tools is based on goal-centered organization of primate cortical motor areas. In a way, the present study extends these results in humans even if our participants were not trained at all to use the pliers. This is interesting because this might suggest that humans can very rapidly form a representation of the tool's goal, which might be subsequently the basis of the intention of use. Such an interpretation differs somewhat from that of Umiltà et al. (2008), who stressed the idea of a progressive incorporation of the tool into the body schema, especially for hand movements. Future research in neuroimaging might be particularly interesting to determine whether analogous cortical areas are involved in humans, even when no training is provided as in the present study.

Acknowledgments

This work was performed within the framework of the LABEX CORTEX (ANR-11-LABX-0042) of Université de Lyon (F. Osiurak), within the program ''Investissements d'Avenir'' (ANR-11-IDEX-0007) operated by the French National Research Agency (ANR).

References

Badets, A., Albinet, C. T., & Blandin, Y. (2012). Sensory-based mechanism for delayed motor intention. *Acta Psychologica, 141*, 205–213.
Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences, 22*, 577–660.
Beisert, M., Massen, C., & Prinz, W. (2010). Embodied rules in tool use: A tool-switching study. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 359–372.
Binkofski, F., & Buxbaum, L. J. (in press). Two action systems in the human brain. *Brain and Language*.
Buxbaum, L. J. (2001). Ideomotor apraxia: A call to action. *Neurocase, 7*, 445–448.
Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language, 82*, 179–199.
Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *NeuroImage, 12*, 478–484.
Chatterjee, A. (2010). Disembodying cognition. *Language and Cognition, 2*, 79–116.
Einstein, G. O., & McDaniel, M. A. (2005). Prospective memory: Multiple retrieval processes. *Current Directions in Psychological Science, 14*, 286–290.
Garcea, F. E., & Mahon, B. Z. (2012). What is in a tool concept? Dissociating manipulation knowledge from function knowledge. *Memory & Cognition, 40*, 1303–1313.
Goldenberg, G. (2009). Apraxia and the parietal lobes. *Neuropsychologia, 47*, 1449–1559.
Goldenberg, G., & Hagmann, S. (1998). Tool use and mechanical problem solving in apraxia. *Neuropsychologia, 36*, 581–589.
Goldenberg, G., & Spatt, J. (2009). The neural basis of tool use. *Brain, 132*, 1645–1655.
Greenwald, A. G. (1970). Sensory feedback mechanisms in performance control: With special reference to the ideomotor mechanism. *Psychological Review, 77*, 73–99.
Grèzes, J., Tucker, M., Armony, J., Ellis, R., & Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience, 17*, 2735–2740.
Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences, 24*, 849–878.
Jarry, C., Osiurak, F., Delafuys, D., Chauviré, V., Etcharry-Bouyx, F., & Le Gall, D. (2013). Apraxia of tool use: More evidence for the technical reasoning hypothesis. *Cortex, 49*, 2322–2333.
Koch, I., Keller, P., & Prinz, W. (2004). The ideomotor approach to action control: Implications for skilled performance. *International Journal of Sport and Exercise Psychology, 2*, 362–375.
Mahon, B. Z., & Caramazza, A. (2005). The orchestration of the sensory-motor systems: Clues from neuropsychology. *Cognitive Neuropsychology, 22*, 480–494.
Mahon, B. Z., & Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology, 102*, 59–70.
Massen, C., & Prinz, W. (2007a). Programming tool-use actions. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 692–704.
Massen, C., & Prinz, W. (2007b). Activation of actions rules in action observation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 1118–1130.
Massen, C., & Prinz, W. (2009). Movements, actions and tool-use actions: An ideomotor approach to imitation. *Philosophical Transactions of the Royal Society of London, Series B, 364*, 2349–2358.
Mechsner, F., Kerzel, D., Knoblich, G., & Prinz, W. (2001). Perceptual basis of bimanual coordination. *Nature, 414*, 69–73.
Negri, G. A. L., Rumiati, R. I., Zadini, A., Ukmar, M., Mahon, B. Z., & Caramazza, A. (2007). What is the role of motor stimulation in action and object recognition? Evidence from apraxia. *Cognitive Neuropsychology, 24*, 795–816.
Osiurak, F., Aubin, G., Allain, P., Jarry, C., Richard, I., & Le Gall, D. (2008). Object usage and object utilization. A single-case study. *Neurocase, 14*, 169–183.
Osiurak, F., Jarry, C., Allain, P., Aubin, G., Etcharry-Bouyx, F., Richard, I., et al. (2009). Unusual use of objects after unilateral brain damage. The technical reasoning model. *Cortex, 45*, 769–783.
Osiurak, F., Jarry, C., & Le Gall, D. (2010). Grasping the affordances, understanding the reasoning. Toward a dialectical theory of human tool use. *Psychological Review, 117*, 517–540.
Osiurak, F., Jarry, C., & Le Gall, D. (2011). Re-examining the gesture engram hypothesis: New perspectives on apraxia of tool use. *Neuropsychologia, 49*, 299–312.
Osiurak, F., Jarry, C., Lesourd, M., Baumard, J., & Le Gall, D. (2013). Mechanical problem-solving strategies in left-brain damage patients and apraxia of tool use. *Neuropsychologia, 51*, 1964–1972.
Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9*, 129–154.
Rothi, L. J. G., Ochipa, C., & Heilman, K. M. (1991). A cognitive neuropsychological model of limb praxis. *Cognitive Neuropsychology, 8*, 443–458.
Shin, Y. K., Proctor, R. W., & Capaldi, E. J. (2010). A review of contemporary ideomotor theory. *Psychological Bulletin, 136*, 943–974.
Sutter, C., Ladwig, S., Oehl, M., & Müsseler, J. (2012). Age effects on controlling tools with sensorimotor transformations. *Frontiers in Psychology, 3*, 573.
Tipper, S. P., Paul, M. A., & Hayes, P. E. (2006). Vision-for-action: The effects of object property discrimination and action state on affordance compatibility effects. *Psychonomic Bulletin & Review, 13*, 493–498.
Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 830–846.
Umiltà, M., Escola, L., Intskirveli, I., Grammont, F., Rochat, M., Caruana, F., et al. (2008). How pliers become fingers in the monkey motor system. *Proceedings of the National Academy of Science, 105*, 2209–2213.