Tool use, semantic processing and prospective cognition

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Tool-number interaction during a prospective memory task

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Abstract

Theoretical views suggest that tool-use and numerical magnitude processing can interact during prospective actions. For example, if a person intends to make a meal for several persons the next week, she/he will have to keep in mind during the homework-week large dish and large food-portions for this event. Here, the magnitude 'large' can influence the future choice for large dishes and other related large tools. This study presents the first empirical evidence supporting this hypothesis. During a prospective memory task that implied to keep in mind a future action, participants were required to use a tool after processing Arabic numbers. Small (less than 5) and large (more than 5) magnitudes were employed as cues for the initiation of the tool-use task, which required participants to use inverse pliers with a small or a large object, but only for some prospective trials. The inverse pliers were used to dissociate the hand action from the tool action with the object (for example, opening the hand produced the closing action of the tool). The results revealed that during prospective trials, number processing interacted only with the tool action toward the object and not with the hand action. Specifically, after the processing of large magnitudes, the initiation of the closing action of the tool (i.e., the opening action of the hand) was reduced. This finding is discussed in light of theories on the emergence of semantics through tool actions.

Key words:

Prospective memory, numerical cognition, tool use

Introduction

Tools for future use are critical for survival. For example, we keep shovels and rakes for the new winter in order to manage bad weather. More broadly, nations improve weapons in order to handle future possible national and international conflicts. In this respect, the tool emergence 3.3 million years ago (Harmand et al. 2015), and the capacity to communicate verbally and non-verbally about their constructs and use for anticipated survival behaviour has possibly constituted the core of human brain evolution (Badets & Osiurak, 2017; Suddendorf & Corballis, 2007). Indeed, planning and enacting our future tool actions at appropriate times and places is critical for a safe life. In contrast, failing to remember relevant tool behaviour from prior intentions can be fatal for people and is considered a pervasive human error (Reason, 1990). Therefore, a fundamental issue is the understanding cognitive basis of tool use during a paradigm that engages participants in prospective behaviour.

To explore the link between prospective cognition and tool use, Osiurak and Badets (2014) developed an event-based task (see Anderson, Strube & McDaniel, 2019; Einstein & McDaniel, 1990; 2005, for reviews and theories about these double-task paradigms), during which the participant was required to perform a tool-use task after processing a pre-instructed stimulus (called a prospective stimulus) while engaging in another different, ongoing task. In this study, the pre-instructed stimulus was a picture of a joker, which was presented for only 15% of the trials (85% of trial for the ongoing task). The appearance of the joker prompted participants to stop the ongoing task to perform the tool-use task (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009). For the ongoing task, participants had to decide whether two symbols presented on a screen were identical or different. Crucially, these two symbols were shown to the participants as masks performing an opening or a closing action. For the tool-use task, participants were asked to use inverse pliers. The inverse pliers enabled the dissociation of the hand action from the tool action in relation to the object. More specifically, closing the hand led to the opening action of the tool. The results revealed a compatibility effect between the action of the tool and the action of the masks, regardless of the action of the hand. Specifically, participants were faster to initiate the closing or opening action of the tool after the closing or opening action of the masks, respectively. This finding suggests that, during the ongoing task, when a person intends to use a tool in the far future (for only 15% of the trials), the cognitive representation of this action is based on the action of the tool more than on the action of the hand, drawing a close link between prospective memory and tool use (for theoretical development, see Badets & Osiurak, 2017; Osiurak & Badets, 2016, 2017).

In another area, it has also been suggested that tool-use skills and semantic processing could interact from an evolutionary point of view too. For example, Larsson (2015) suggested that human communication and tool use have evolved in a mutual way, starting approximately 2 million years ago. Indeed, we need a complex communication system to make tools and transfer tool-use skills to others (for a somewhat similar view, see also Gergely & Csibra 2006). Like hand actions (Corballis, 2018; Rizzolatti & Arbib, 1998), tool actions can also constitute a cognitive basis for human communication. For example, producing and perceiving events such as sounds generated by tool use could have played a role in the emergence of semantics and communication in humans. In this view, the sound of tools can have the same utility as visual information for communicative abilities. Physical dimensions can also be relevant for such a mechanism. For example, a small dish can contain a small piece of food, but a large dish can contain a larger one. Here, the tool (i.e., the dish) and the object (i.e., the piece of food) share a physical dimension for “small” and “large” magnitudes.

Although attractive, this magnitude dimension received no empirical evidence in the context of tool use until a recent study by Badets et al. (2017). This work followed the well-known finger/number interaction that has been found in the numerical cognition domain (Andres, Ostry, Nicol, & Paus, 2008; Namdar, Tzelgov, Algom, & Ganel, 2014; Ranzini et al. 2011). To summarize this interaction, studies have generally found that the processing of small or large magnitude numbers can improve the selection or the execution of small or large aperture of fingers movements, respectively. Therefore, the main hypothesis of Badets et al.’ study was that tools could also afford a numerical magnitude dimension, which is shared with symbols such as Arabic numbers. To test this hypothesis, participants in this study were required to use inverse pliers after processing Arabic number stimuli. These stimuli represented either a small (2 or 3) or a large magnitude (8 or 9). The semantic hypothesis predicted that the quantity representation associated with Arabic numbers should interact with the action of the tool toward the object, not with the action of the hand. The results confirmed this hypothesis: Large numbers interacted with the action of the tool, such that participants were longer to perform the closing action with the tool—and, as a result, the opening action with the hand—after the processing of large numbers. Here, the processing of the number magnitude of “large” interfered with the processing of the tool magnitude of “small” to grasp the small object. Conversely, no interference was detected between the processing of small numbers and the closing/opening actions of the tool. To interpret this lack of interference, authors suggested that grasping a large object with pliers is largely unfamiliar and therefore did not favor the processing of the tool magnitude of "large" to grasp a large object (see also Badets & Pesenti, 2010, 2011 for similar discussion). Regardless of the interpretation, the main finding is that tool use can interact with abstract symbols such as Arabic numbers. This preliminary finding provides the first evidence in favor of the abstract physical dimension account in tool use.

The two main theoretical accounts developed in the present paper can be summed up as follows. On one hand, it has been shown that the cognitive representation of tool use for a future action is kept in mind throughout the tool action toward the environment and not the hand action toward the tool. Indeed, Osiurak and Badets (2014) found an interaction between the tool actions (opening and closing action) and the masks movements (opening and closing action) during a prospective memory task. On the other hand, tool use can also interact with semantic dimensions like magnitude information afforded by Arabic numbers (Badets et al. 2017). However, it is unknown whether semantic dimensions can also have an influence on tool use during a prospective task. We could speculate for such hypothesis. Indeed, if an individual intends to plant a big tree in the garden the next weekend, she/he will have to keep in mind that strong and large tools will be needed in order to perform such a task. Here, the concepts "strong" and "large" can be seen as semantic dimension that will help the individual to retrieve the appropriate tools in order to perform the appropriate action.

Specifically, the working hypothesis of the present study was that during a prospective task (i.e., an event-based task) an interaction should be found between the semantic processing of Arabic numbers and tool use. In this perspective, we combined the two paradigms described above to explore the tool-semantic account (Badets et al. 2017) and the prospective-tool account (Osiurak & Badets, 2014). As in Osiurak and Badets (2014), we used an event-based task that primarily involved the capacity to envision the future use of a tool. However, the ongoing task was a decision task involving Arabic number processing. Participants had to decide whether two numbers were presented in the same or in different colour(s). Instructions on the pre-instructed stimulus emphasized that when the two numbers were of the same parity (i.e., even or odd), they had to use inverse pliers with a large or small object. For the ongoing and tool-use tasks, small and large Arabic numbers were used. Clearly, during this event-based task, we hypothesized a slower tool-use initiation to grasp a small object after the processing of large numbers and no interaction between numbers and tool actions towards a large object.

This last expectation can be considered as a control condition because other studies did not find such interaction between small Arabic numbers and goal-based action toward large object (Badets & Pesenti, 2010, 2011). In this perspective, Badets and Pesenti (2010; Experiment 3) revealed that the observation of a finger closing action postponed the processing of large Arabic numbers but no such interference was detected for finger opening action and the processing of small or large Arabic numbers. For the authors, such partial effect (i.e., an interaction between the processing of large Arabic numbers and closing action) could come from the circumstance that picking up an object usually involves closing action between the index and the thumb finger in humans, and not an opening action. Such a closing movement is very usual in daily life and should engage a person in a deeper movement simulation that, in turn, affords more opportunity to process semantics of large numbers.

Method

Participants

For the present study, we estimated the sample size with the G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007). We used the repeated-measures analysis of variance design from the data obtained in Osiurak and Badets (2014; Cohen's d = 1.28, correlations among repeated measures = 0.5). Statistical significance was set at $p < .05$ and the power at 0.90. The results indicated that 20 participants would be enough to provide an estimated power of 0.92. Consequently, 24 students from the university of Bordeaux volunteered to participate in the study (*mean age*: 22 years; *SD* = 1 year; 19 right-handed as assessed by the Edinburgh test; 14 females). None of them had prior experience with or knowledge of the task or the experimental procedure. Each participant was requested to read and sign an informed consent form about the general procedure in experimental psychology. This study was performed in accordance with the ethical principles specified in the 1964 Helsinki Declaration.

Apparatus

Participants were seated on a chair with the head aligned approximately 80 cm from a personal computer with a 17.3-inch screen. The computer was connected to two key-response devices (a response keyboard and a response box from Chronos) associated with the E-prime program (Schneider et al. 2002), which was used to run the experiment and store raw data for subsequent offline analysis. Participants positioned their middle and index finger of the left hand on the "c" and "v" key of the keyboard, respectively. The right hand positioned the handle tool on the middle-key of the response box in a push position. The keyboard and the response box are not represented in the Fig. 1A. From a neutral position (the tool was not closed or opened), the inverse pliers were used to execute closing and opening actions with a trident object (see Fig. 1A).

The event-based task and specific instructions

The event-based task consisted of an ongoing colour discrimination task with the left hand on the keyboard and a tool-use task with the right hand on the response box (Bisiacchi et al., 2009). Specifically, participants were required to manage an ongoing task with the left hand, and in some trials, a pre-instructed stimulus invited them to use the inverse pliers with a trident-object in using the right hand. For these specific trials, participants did not perform the ongoing task but switched to the tool-use task.

Before the ongoing colour discrimination task, the instructions emphasized that participants would have to manage a task with Arabic numbers from 1 to 9. Specifically, the task requested discriminating the colour of two presented Arabic numbers by pressing a corresponding key (the “c” and “v” key on an AZERTY keyboard positioned to the left side of the participant). An asterisk was presented for 1000 ms before the appearance of the first Arabic number (see Fig. 1B). Then, the first Arabic number was presented on the upper side of the screen for 500 ms, and the second Arabic number was presented on the lower side of the screen until the manual response. If the two numbers were identical in colour, participants were required to press the “c” key. For dissimilar colours, the required response was the “v” key pressing (the response keys were counterbalanced for similar and dissimilar colours). For this task, the dependent variable called response latency represented the time between the presentation of the second number and the key press. After the manual response, participants pressed the space key to perform the next trial. Because we specifically expected an effect between number processing and the tool-use task, the instructions of this ongoing task emphasized simply the accuracy.

When the two Arabic numbers were identical in parity, participants were required to switch on the tool-use task (Fig. 1A). In this case, participants removed the handle of the tool from the pressed key of the response box in order to grasp the trident object. For this task, the dependent variable called response latency represented the time between the presentation of the second number and the lifting of the handle of the tool. After grasping the trident with the tool, participants replaced the handle of the tool on the corresponding key of the response box (in a push position). The dependent variable called movement time represented the time between the lifting of the handle of the tool and the final push position. Note that during the whole tool-use task, the word “action” was presented on the centre of the screen (see Fig. 1C).

For the next trial, an asterisk was presented for 1000 ms before the appearance of the first Arabic number. For this task of interest, the instructions emphasized the speed and accuracy.

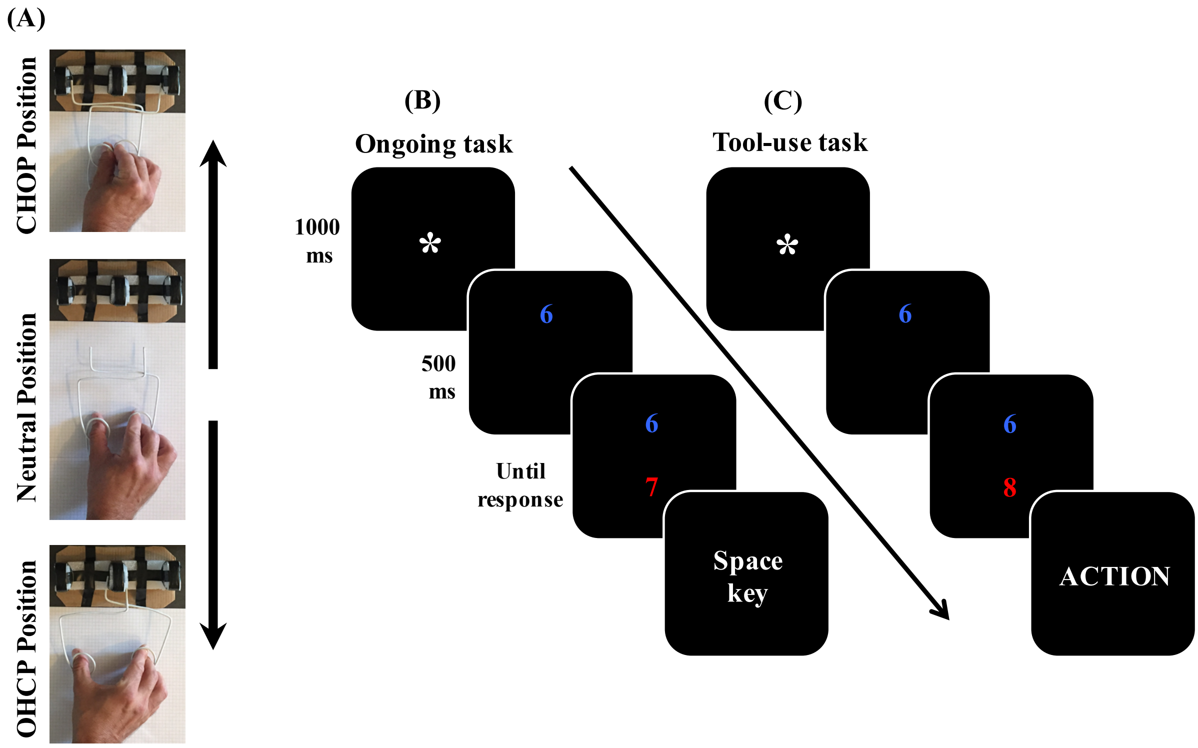

Figure 1: Experimental set-up. (A) represents the two different tool actions required after the processing of the same number parity during the tool-use task (i.e., CHOP for closing-hand/opening-pliers; and OHCP for opening-hand/closing-pliers). (B) and (C) represent temporal events for the ongoing and tool-use trials, respectively. Note that the example for the ongoing task required the participant to give a negative response (or pressing the “v” key) because the two colours are different. The example of the tool-use task requires participants to use the tool because the two numbers present the same parity (here, even numbers).

Stimuli

For the ongoing colour discrimination task, the parity of the two numbers was always different. However, the magnitudes of the two numbers were always small or large (i.e., small magnitude: from 1 to 4; large magnitude: from 6 to 9). The number 5 was never presented. For strength magnitude information, the second number presented was always smaller for small magnitudes ("3" for the first number and "2" for the second number) and larger for large magnitudes ("6" for the first number and "9" for the second number). The Arabic numbers were coloured in red, blue, or green and could be presented at the bottom or the top of the screen. The positions on the screen and the colours were counterbalanced across trials. Half of the trials required the response "c" (144 trials for same colour between the two Arabic numbers), and the other half required the response "v" (144 trials for different colours between the two Arabic numbers).

For the tool-use task, the two Arabic numbers were always identical in terms of parity in order to trigger the to-be-enacted action. Twenty-four trials presented the same colours between the two Arabic numbers, and for the remaining 24 trials, different coloured Arabic numbers were presented. The magnitudes/positions on the screen and colours were counterbalanced across trials.

Procedure

The whole experiment comprised five blocks (one training block and four experimental blocks). The first block constituted the training block and was composed of 8 and 2 trials for the ongoing manual task and the tool-use task, respectively. The second and third experimental blocks required using the tool with action that represented an opening hand to close the pliers towards the trident object (OHCP for opening-hand/closing-pliers). For the fourth and fifth experimental blocks, required action that represented a closing hand to open the pliers towards the trident object (CHOP for closing-hand/opening-pliers). Only one single action (OHCP or CHOP) was performed per block of trials because only one single prospective stimulus was used (e.g., the parity between two numbers). Both actions for the different blocks were counterbalanced across participants. One hundred sixty-eight trials presented in a random order composed one experimental block (144 trials for the ongoing task and 24 trials for the tool-use task).

Results

For the ongoing task, unreliable responses due to action errors were not included in the analysis (5%). For example, these errors represented (1) the pressing key "c" when the key "v" was required or (2) the enactment of the tool toward the trident object. Response latencies below or above two standard deviations from the mean were removed from the analysis (22%). Note that instructions emphasized the accuracy, explaining why we reported 22% of outliers for response latencies (not a priority for participants) in this task, and only 5% of errors (the priority).

For the tool-use task, no action error was detected. Response latencies below or above two standard deviations from the mean were removed from the analysis (7.81%). Finally, movement times of the tool-use task below or above two standard deviations from the mean were also removed from the analysis (5.51%).

Response latency for the tool-use task

To best capture the influence of number magnitude on the tool-use task, we performed an analysis of variance (ANOVA) on the response latency with action (OHCP *vs.* CHOP) and magnitude (small *vs.* large Arabic numbers) as within-subject factors (called the 2x2 ANOVA for subsequent analyses). Post hoc comparisons were computed with Duncan's technique. The analysis revealed a main effect of magnitude, $F(1, 23) = 5.71$; $p < .02$; $\eta^2 = .19$; no main effect of action, $F(1, 23) = 2.41$; $p = .13$ and more importantly for our hypothesis, a significant interaction between these two factors, $F(1, 23) = 6.14$; $p < .02$; $\eta^2 = .21$. For this interaction, post hoc comparisons revealed that the response latency was slower for the OHCP action after the processing of large numbers in contrast with all other three situations (OHCP-small numbers / CHOP-small and -large numbers). Fig. 2 presents the mean response latencies as a function of action tool and number magnitude.

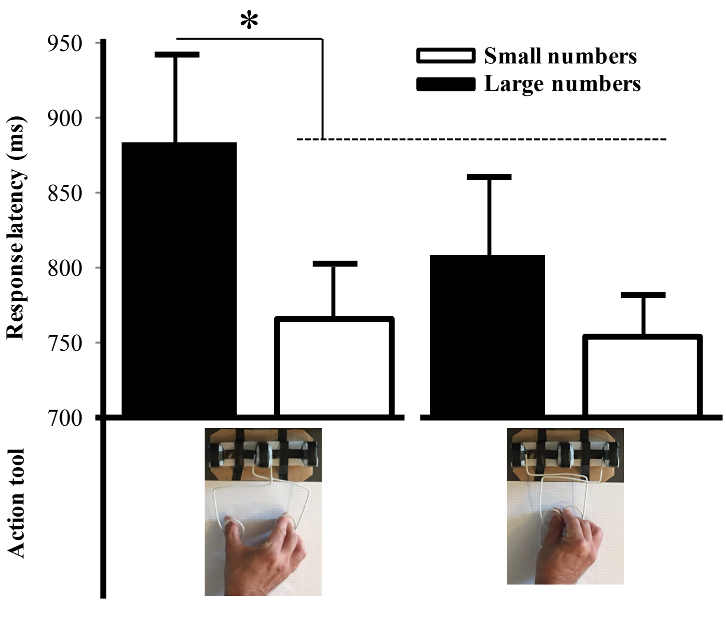

Fig. 2. Mean response latencies as a function of action tool and number magnitude.

Non-switch error for the tool-use task

Non-switch error represented trials occurred when participants forgot to use pliers and responded to the ongoing manual task (16% of trials). The 2x2 ANOVA revealed no significant effects for the main factors of action or magnitude or their interaction (F<1; $F(1, 23) = 2.04$; $p = .17$; and F<1, respectively).

Movement time for the tool-use task

The 2x2 ANOVA revealed only a main effect of action, $F(1, 23) = 7.42$; $p < .01$; $\eta^2 = .24$. Participants were faster to use pliers with large objects (CHOP; 1689 ± 405 ms) than with small objects (OHCP; 1906 ± 569 ms). This effect reveals that the movement time increases as a function of task difficulty. Indeed, it is easier to reach and grasp a large target than a small one (Fitts, 1954). The main effect magnitude and the interaction between the two factors were not significant (F<1).

Response latency for the ongoing colour discrimination task

To assess the influence of the to-be-enacted action in the ongoing colour discrimination task, we conducted a 2x2 ANOVA. This analysis revealed only a main effect of magnitude, $F(1, 23) = 23.7$; $p < .001$; $\eta^2 = .50$. Participants were faster to respond to small numbers than to large numbers (814 ± 186 ms; 854 ± 201 ms, respectively). This effect is known as the "problem-size effect", and it suggested that participants processed the small versus large magnitudes of numbers despite the colour discrimination task. Finally, the main effect action and the interaction between the two factors were not significant (F<1).

Discussion

The main goal of this study was to assess the potential link between tool use and semantic processing during a prospective memory task. The results confirmed our predictions. In the tool-use task (and not during the ongoing task), latencies for the tool action to grasp the small object were slower after the processing of large numbers stimuli, and no effect was detected between small numbers stimuli and tool actions for the large object. This effect seems robust because it perfectly replicates the semantic effect on tool use obtained by Badets et al. 2017 (for a similar effect between hand action and number processing, see Badets & Pesenti, 2010; 2011). Our findings also suggest that this effect is relatively robust given that it can be obtained in several paradigms with different levels of difficulty. For instance, Badets et al. (2017) reported it in a paradigm involving a continuous tool-number trial by trial processing. By contrast, in the present study, we reported this effect in a paradigm in which participants had to keep in mind the tool-use action for prospective enactments, which occurred only for some trials. As a consequence, the present task was also more difficult, leading to reaction times around 800 ms (only 400 ms in Badets et al.'s study) and a high number of outliers (about 8% of the data).

The ideomotor mechanism appears to be particularly suited to interpret this effect in the context of tool use (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Janczyk, Pfister, & Kunde, 2012; Koch, Keller, & Prinz, 2004; Pfister, 2019). According to this theory, perception and action share common representations. As claimed by Fagioli, Hommel, and Schubotz (2007), "it is plausible to assume that to-be-perceived events ('perceptions') and to-be-generated events ('actions') are coded and stored together in a common representational domain" (Prinz, 1990, 1997) (p. 28). Osiurak and Badets (2016, 2017) developed an ideomotor approach to tool use based on converging evidence from neuropsychology and experimental psychology. This approach suggests that, in the context of tool use, events may be coded in terms of mechanical actions rather than motor actions. In other words, when people use tools, there might be a priority of tool-action effects toward the object to-be grasped over hand-action effects toward the tool. In this context, the inverse-pliers paradigm is appropriate to demonstrate this hypothesis, given that the action performed by the hand goes in the opposite direction to that performed by the pliers (an opening action of the hand leads to a closing action of the pliers, and a closing action of the hand leads to an opening action of the pliers). The prediction from the ideomotor approach to tool use is straightforward: people should expect the action performed by the pliers and not by the hand.

Based on the interpretation given above about the inverse-pliers paradigm, it can be predicted that the initiation of the pliers' action should be facilitated *or* inhibited by any stimulus sharing a common effect with the effect produced by the pliers. In the case of number processing, the presentation of numbers stimuli with small magnitudes should facilitate the initiation of a closing action with the pliers and that of numbers with large magnitudes stimuli the initiation of an opening action. As discussed, this prediction was partly confirmed by Badets et al. (2017) in that a significant effect was only observed for numbers with large magnitudes stimuli. Nevertheless, and importantly, we replicated this effect here, confirming that tool use and semantic processing might interact together, with the magnitude of the action performed with tools interacting with the magnitude of semantic information (e.g., number stimuli). In broad terms, our findings, taken together with previous findings supporting an ideomotor account for semantic processing (Badets, Koch & Toussaint, 2003; Badets, Philipp, & Koch, 2016; Badets & Osiurak, 2017; Földes, Philipp, Badets, & Koch, 2017), demonstrate that ideomotor theory can spread its influence to other functions beyond motor control in linking tool use and semantic processing. In addition, the tool-semantic account is not inconsistent with the idea that hand actions could have also been the basis of semantics for human communication (Badets & Pesenti, 2010; Corballis, 2018; Rizzolatti &

Arbib, 1998). However, it suggests that in the context of tool use, semantics are based on the actions performed by the tool more than those performed by the hand.

The inverse-pliers paradigm can also be useful to explore the link between tool use and prospective memory task. In this case, the key prediction is that the dimension of the pre-instructed stimulus that shares a common code with the action of the tool should facilitate the initiation of the tool action (the event-based task). However, this dimension should not interact with the ongoing colour discrimination task. The originality of the present study is nevertheless to extend it to the domain of semantic processing because the dimension shared between the pre-instructed stimulus and the action of the pliers was not "analogical" (a closing or opening action) but abstract (the large or small magnitude provided by the symbols). More specifically, concerning the present experiment, during the ongoing colour discrimination task, a main recognition process (a) was in charge of the colour discrimination, and for the to-be-enacted action (the tool action), several sub-processes were concerned: (b) recognition of the pre-instructed stimulus (the number parity), (c) retrieval of the tool action, and (d) coordination of the intended action with the ongoing task (see Marsh et al. 2002; Badets et al. 2012 for these sub-processes). During the recognition process (a), the magnitude effect from the Arabic numbers is implicitly present despite the explicit colour judgement. In the same vein, during the recognition process (b), the magnitude effect from the Arabic numbers is implicitly present despite the explicit parity judgement. However, during the retrieval process (c), the initiation of the tool action is affected because the mechanical action of the pliers and the processing of the prospective stimulus are coded in a common magnitude format (Fagioli et al. 2007). If the action is relevant enough in terms of an experience like grasping a small object with inverse pliers, then its initiation is slowed if the processing of the prospective stimulus is a large number.

To conclude, our results are consistent with many empirical findings indicating that when an action is relevant toward an object to be grasped (i.e., a small object), the processing of an Arabic number can influence such goal-directed behaviours (Badets & Pesenti, 2010; 2011; Badets et al. 2017). Here, we found this effect during a task that involved the capacity to imagine the tool action in a far future. Consequently, we can argue that when people travel in mind toward the future, a cognitive representation based on semantic dimension and shared with tool use is largely activated. Accordingly, it can be hypothesized that tool use, semantic processing and the capacity to imagine the future have probably evolved in a mutual way during hominid evolution (Badets & Osiurak, 2017; Larsson, 2015; Suddendorf & Corballis, 2007). The consequence of this speculative hypothesis on brain evolution is that it could be possible today to detect some behavioural markers that can support this link. Our results afford the first piece of evidence for this story, but certainly require more scientific effort to support it through future research.

Compliance with Ethical Standards:
Authors declare that they have no conflict of interest.
All procedures performed in this study were in accordance with the ethical standards of the institutional and national research committee, and with the 1964 Helsinki declaration. Finally, informed consent was obtained from all individual participants included in the study.

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