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Tool use in left brain-damaged patients: Difficulties in reasoning but not in
estimating the physical properties of objects

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Abstract

Objective: The purpose of this study was to deepen our understanding of the cognitive bases of human tool use based on the technical reasoning hypothesis (i.e., the reasoning-based approach). This approach assumes that tool use is supported by the ability to reason about physical object properties (e.g., length, weight, strength, etc.) in order to perform mechanical actions (e.g., lever). In this framework, an important issue is to understand whether left brain-damaged (LBD) with tool-use deficits are still able to estimate the physical object properties useful to use tools.

Method: Eleven LBD patients and 12 control participants performed three original experimental tasks: “Use-Length” (visual evaluation of the length of sticks to bring down a target), “Visual-Length” (to compare visually objects of different lengths) and “Addition-Length” (to compare visually added lengths). Participants were also tested on conventional tasks: Familiar Tool Use and Mechanical Problem Solving (novel tools).

Results: LBD patients had more difficulties on both conventional tasks as compared to controls. No significant difference was observed for the three experimental tasks.

Conclusions: These results extend the reasoning-based approach stressing that it might be not the representation of length that is impaired in LBD patients but rather the ability to generate mechanical actions based on physical object properties.

Keywords: Tool Use; Technical Reasoning; Left Brain Damage; Physical Object Properties; Mechanical Knowledge.

Public Significance Statements:

Tool-use deficits can decrease the autonomy of patients and their quality of life. For example, if patients show difficulties in determining the sharpness of knife, they may endanger themselves. This study provides insights into the understanding of the cognitive origins of tool-use deficits.

1. Introduction

Tool use is a defining feature of human species. Humans are capable of transforming objects in the environment and building new objects from raw materials. These features are universal, common to all cultures and pass on to future generations (Johnson-Frey, 2004; Osiurak et al., 2016). Therefore, one fundamental question is to understand the cognitive bases of human tool use. The neuropsychological studies of patients are appropriate to answer this question, particularly through observation of left brain-damaged (LBD) patients with tool-use deficits. Two main approaches have been formulated to account for these deficits.

The first one, namely the manipulation-based approach, assumes that two types of knowledge support tool use: sensorimotor knowledge about tool manipulation (i.e., manipulation knowledge) and semantic knowledge about familiar tools (i.e., function knowledge) (Buxbaum, 2001). First, manipulation knowledge acts as gestural memories (Liepmann, 1908) containing the main features of the gesture associated with the manipulation of a tool (Borghi, 2004; Borghi & Riggio, 2009; Buxbaum & Kalénine, 2010; Buxbaum & Saffran, 1998; Buxbaum & Saffran, 2002; Heilman, Rothi, & Valenstein, 1982; Rothi, Ochipa, & Heilman, 1991; Thill, Caligiore, Borghi, Ziemke, & Baldassarre, 2013; van Elk, van Schie, & Bekkering, 2014). This knowledge encodes egocentric relationships (i.e., tool-user relationships) and is supposed to be stored within the left inferior parietal lobe (Buxbaum, 2001; Liepmann 1905; Rothi et al., 1991, 1908). Second, function knowledge contains long-term information about the usual use of familiar tools: their functions (e.g., a knife is used for cutting) and their context (e.g., knives are stored in the kitchen). This knowledge encodes allocentric relationships (i.e., tool-object relationships) and is supposed to be stored within the left temporal cortex (Buxbaum, 2001). The manipulation-based approach assumes that this two types of knowledge support tool use independently, suggesting that manipulation knowledge can be compensated by function knowledge, and

vice-versa) Buxbaum, 2001; Buxbaum & Saffran, 2002; Buxbaum, Schwartz, & Carew, 1997). This is in line with the multiple-routes-for-action developed by Humphreys (2001).

However, several studies have questioned the manipulation-based approach. The role of function knowledge in tool use poses a problem. Indeed, different studies have shown that patients with temporal lobe lesions were able to succeed both usual and unusual tool use tasks whereas their function knowledge was impaired (Osiurak et al., 2008; Sirigu, Duhamel, & Poncet, 1991). According to the manipulation-based approach, an isolated deficit does not produce a tool use deficit. Consequently, impaired function knowledge could be compensated by intact manipulation knowledge (i.e., the multiple-routes-for-action). This seems delicate at a theoretical level because manipulation knowledge encodes egocentric (i.e., tool-user) but not allocentric (i.e., tool-object) relationships. Said differently, in this framework, it remains to be explained how manipulation knowledge could help these patients to determine the relationships between tools and objects (e.g., screwdriver with a screw; i.e., tool-object relationships). Moreover, manipulation knowledge is supposed to be associated with the conventional use of familiar tools based on our experience with these tools. Therefore, it does not explain the unusual use of familiar tools or how we use novel tools in order to solve mechanical problems (Goldenberg & Hagmann, 1998; Goldenberg & Spatt, 2009; Hartmann, Goldenberg, Daumüller, & Hermsdörfer, 2005; Jarry et al., 2013; Osiurak, Jarry, & Le Gall, 2011). Novel tool use and unusual use need to understand the mechanical relationships between the tools and the objects (i.e., tool-object, allocentric relationships; Goldenberg & Hagmann, 1998; Goldenberg & Spatt, 2009; Hartmann et al., 2005; Jarry et al., 2013; Osiurak et al., 2011).

Based on these limitations, a second approach has been recently proposed, namely, the reasoning-based approach (i.e., the technical reasoning hypothesis). This approach assumes that people reason about the physical properties of objects (e.g., length, weight, strength) to

solve everyday life problems (Osiurak, 2014a; Osiurak & Badets, 2016; Osiurak et al., 2009; Osiurak, Jarry, & Le Gall, 2010; Osiurak, Jarry, Lesourd, Baumard, & Le Gall, 2013; Reynaud, Lesourd, Navarro, & Osiurak, 2016; see also Goldenberg & Hagmann, 1998; Goldenberg & Spatt, 2009). In this framework, it is no longer a matter of manipulation knowledge, but of mechanical knowledge, “which corresponds to knowledge about physical principles” (Osiurak & Badets, 2016¹). This knowledge encodes allocentric relationships (i.e., tool-object), it is non-declarative and it views as abstract: there is no overlapping between the physical reality and the technical reality (e.g., the lead of a pencil is friable when applied to paper sheet but not to leather) (Osiurak & Badets, 2016; Osiurak et al., 2010). It has been suggested that all the situations involving tool use (familiar or novel) require mechanical knowledge, regardless of context. Support for this approach comes from evidence indicating a strong link in LBD patients between real tool use and mechanical problem solving² (Goldenberg & Hagmann, 1998; Goldenberg & Spatt, 2009; Hartmann et al., 2005; Jarry et al., 2013, 2015; Osiurak et al., 2009, 2013; for reviews see Goldenberg, 2013; Osiurak, 2014a). Furthermore, neuropsychological and neuroimaging studies have shown that mechanical knowledge could be supported by the left inferior parietal lobe and particularly the cytoarchitectonic area PF (i.e., Parietal area *F*; Caspers et al., 2006) within the left supramarginal gyrus (Fridman et al., 2006; Goldenberg & Hagmann, 1998; Goldenberg &

¹ Recent theoretical models have however assumed that both manipulation knowledge and mechanical knowledge could coexist (Buxbaum, 2017; Canzano et al., 2016; Caruana & Cuccio, in press).

² Given that solving mechanical problems requires the use of novel tools, one may consider that this kind of task involves primarily executive functions. Nevertheless, Goldenberg and Spatt (2009) demonstrated that only patients with parietal lobe lesions had a deficit on real tool use and mechanical problem solving tasks (see also Goldenberg & Hagmann, 1998; Goldenberg, Hartmann-Schmid, Surer, Daumüller, & Hermsdörfer, 2007; Reynaud et al., 2016). In addition, performance on a task as the Tower of London task should correlate with that of mechanical problem solving tasks. Several studies have not shown such correlations (Jarry et al., 2013; Osiurak et al., 2013) and it has also been observed that patients with a dysexecutive syndrome do not fail mechanical problem solving (Goldenberg et al., 2007) In total, executive functions are not critical to the ability to use novel tools to solve mechanical problems. Besides, other functions are involved in some forms of apraxia as spatial and body representations or monitoring systems. We will not develop them because we focused on apraxia of tool use (but, for a review, see Canzano et al., 2016).

Spatt, 2009; Orban and Caruana, 2014; Peeters et al., 2009; Peeters, Rizzolatti, & Orban, 2013; Vingerhoets, Vandekerckhove, Honoré, Vandemaele, & Achten, 2011; see also Reynaud et al., 2016). Concerning function knowledge, the reasoning-based approach posits that this serves to organize the search in memory in order to find tools and objects more easily (e.g., when tools and objects are not present together in the workspace). This knowledge is not necessary or sufficient for supporting tool use and no compensation is possible between mechanical knowledge and function knowledge.

In sum up, the reasoning-based approach could be an appropriate framework for the study of the cognitive bases of human tool use. However, an unresolved issue concerns the nature of the cognitive mechanisms involved. More particularly, two alternative hypotheses can be provided. The first one is that patients with tool use disorders are no longer able to use mechanical knowledge so that they become unable to determine which is the correct mechanical action to be performed. However, patients might still be able to estimate the physical properties of tools and objects. For example, if they are presented with a piece of bread and three tools (including a knife) they could fail to extract the abstract principle of cutting (i.e., mechanical knowledge) even if they could determine which one of the three tools is long enough to perform the tool-use action correctly (Hypothesis A: deficit of reasoning only). The second hypothesis is that those patients are unable to estimate the physical object properties in the tools and objects proposed. The corollary is that they could no longer reason about these physical object properties (Hypothesis B: deficit of both estimation and reasoning). In order to test these both hypothesis, we chose to focus on the representation of length because this physical property is central in many tool use situations. For example, the use of many tools is based on the principle of lever, which assumes that the more the rotation point of the tool (e.g., a hammer) is far from the point of percussion, the more the hammer's impact strength is amplified (Osiurak, 2014b). In other cases, it is useful to select tools that

are long enough in order to reach an object (e.g., to retrieve an object under furniture). Note also that LBD patients who fail to solve mechanical problems can sometimes select too short sticks to reach the target (Osiurak et al., 2013). This might suggest agnosic deficits; however, these patients recognized tools and objects and they could identify them, thereby excluding aperceptive agnosia. Although this observation does not allow us to decide between Hypotheses A and B, it demonstrates that length can be an interesting physical property to determine whether the deficit concerns estimation and/or reasoning skills. The originality of this study was the design of an experimental task in order to evaluate the representation of the length. There were three conditions. The Use-Length condition (visual evaluation of the length of sticks to bring down a target) allowed us to evaluate the representation of the length in tool-use situation. The Visual-Length (to compare visually objects of different lengths) and Addition-Length conditions (to compare visually added lengths) served as control tasks.

In sum, the aim of this study was to deepen the understanding of tool use disorders in LBD patients, based on the reasoning-based approach. Specifically, we wanted to examine if the capacity to estimate physical object properties was impaired in these patients.

2. Method

2.1. Participants

Eleven LBD patients and 12 healthy controls participated in the study. Patients were tested at the Henry Gabrielle Hospital (Hospices Civils de Lyon, Saint Genis Laval). All patients were hospitalized for a unilateral cerebral vascular accident or a brain tumor surgery. Most of them returned home and all were chronic patients. During this study, the language capacities have been tested by a speech therapist. Four LBD patients had production difficulties and three patients suffered from expressive aphasia, none suffered from receptive

aphasia. However, the instructions were adapted in order to be understood by all patients with the minimum of verbal instructions (Jarry et al., 2013). Patients were included only if they succeeded the visual gnosis evaluation (Table 1). One LBD patient suffered from hemianopia and none suffered from hemineglect. The cognitive efficiency of control participants was assessed with the Mini Mental State Examination ($M = 29.5$, $SD = 1.15$; Kalafat, Hugonot-Diener, & Poitrenaud, 2003).

< INSERT TABLE 1 ABOUT HERE >

All participants were right-handed. LBD patients used their left hand in order to avoid effects of motor or sensory impairment. In control group, half used the right hand and the other half the left hand (this research was part of a larger study including right brain-damaged patients but it has been shown that the used hand had no impact on the performance; Osiurak et al., 2009). No participant had a previous history of neurological or psychiatric diseases. All participants gave their informed consent and the study was conducted in accordance with the Declaration of Helsinki. Demographic and clinical data are displayed in Table 1. There were no significant differences between the two groups with respect to age, gender, and education level.

2.2. Material and procedure

Participants were video-recorded to facilitate the scoring of the tasks.

2.2.1. Conventional tasks

2.2.1.1. Familiar Tool Use task in Choice and No-Choice conditions

This task consisted on ten familiar tools (screwdriver, match, light bulb, scissors,

bread-knife, bottle-opener, hammer, pitcher, electrical plug, saw) and the corresponding objects usually used with tools (screw, candle, socket, sheet of paper, piece of bread, bottle with cap, nail, glass, electrical plug, piece of wood) (figure 1) (Jarry et al., 2013). All tools were adapted to enable a one-handed performance. The examiner presented the objects one at a time between the participants and the “horizontal tool panel”. In first, they performed the Choice condition where in all tools were presented together on the “horizontal tool panel”. They had to select the tool corresponding to the object and to execute the conventional use of the tool on the object (e.g., when presenting with a piece of bread, participants had to choose the knife, then they had to cut the piece of bread with the knife). In the No-Choice condition, only the tool associated with the object was presented in the panel and participants had to actually perform the mechanical action intended between the tool and the object. Testing was preceded by two practice items (key/padlock and cork-screw/bottle of wine) where in the participants were helped to select the tool and to execute the correct action if they failed. Each condition was rated on a 3-point scale per item (i.e., 10 items in total, corresponding to 10 tool-object pairs). Three points were given if they selected the tool corresponding to the object and if the expected action was carried out in 20 seconds, 2 points between 21 and 40 seconds and 1 point between 41 and 60 seconds. No point was given if the typically use was not demonstrated at all in 60 seconds (maximum = 30 points per condition; the raw score was subsequently transformed into percentages).

< INSERT FIGURE 1 ABOUT HERE >

2.2.1.2. Mechanical Problem-Solving task in Choice and No-Choice conditions

This task was designed by Jarry et al., (2013) and is based on two principles: it needs to execute a sequence of several actions to solve the problem and trial-and-error strategies do not allow succeeding the test. The aim of this task is to extract a target outside from a box

(figure 2). Three transparent boxes were presented one after the other. For the box A, the participants had to retrieve the target (a square piece of wood with ring) by creating a hook with a folding wire. For the box B, they had to introduce an adapted stick in the “chimney” to push the target (a wooden cube) and bring the cube out from the box. For the box C, they had to tip the mobile compartment inside the box with a rigid stick in order to roll the target (a wooden ball). Then, the participants had to extract the ball from the box. For each box, they were invited to observe each side thereof. Then the position of the target was clearly showed to them. A similar target was shown to the participants to be sure they identified the target. The task was adapted to enable one-handed performance. There were two conditions. In the Choice condition, the 16 sticks were presented simultaneously on the table from the side of the used hand. All the sticks had different physical properties: half of the sticks were made in metal and half of wood; half had a right angle and half do not; half were cylindrical and half “parallelepipedic”; half were thick and half thin; half were long and half short; and half was rigid and half flexible (Jarry et al., 2013). The participants had to choose the stick(s) that would enable to extract the target. In No-Choice condition, only the most appropriate stick was presented. In both conditions, participants had to extract the target out from the box with selected stick(s) (i.e., Choice condition) or with the appropriate stick (i.e., No-Choice condition). The boxes were still presented in the same order: box A then box B and finally box C. Each condition was rated on a 5-point scale per item (i.e., 3 items in total, corresponding to 3 boxes). Five points were given if the target was extracted in 60 seconds, 4 points between 61 and 120 seconds and 3 points between 121 and 180 seconds. Two points were given if participants did move the target and one point if they touched it. If none of these criteria were respected, no points were given (maximum = 15 points per condition; the raw score was subsequently transformed into percentages).

< INSERT FIGURE 2 ABOUT HERE >

2.2.2. *Experimental task*

2.2.2.1. *Use-Length condition*

This condition was composed of 9 target-sticks (i.e., 9 items) (figure 3). Their length varied between 16.8 cm and 23.2 cm (0.8-cm increment). These 9 items were randomly presented twelve times each (i.e., 108 trials in total). A box was presented in front of the participants at a distance of about 60 cm. A cube was positioned inside the box to 20 cm from the edge (figure 3). A target-stick was presented between the participants and the box. They had to indicate whether the stick could push off the cube by inserting the stick into the hole on the right side of the box. For aphasic LBD patients, color cardboards allowed to respond: a green cardboard for the answer “yes, the stick can push off the cube” and a red cardboard for the answer “no, the stick cannot push off the cube”. Psychometric curves were computed by using R version 3.2.2 (R Foundation for Statistical Computing). They represented the evolution of response for each group (LBD, control) and for each item. This curves allowed us to extract two indicators. The first, the Point of subjective equality (Pse), corresponded at the time of the participants changed their responses (short stick then long stick). Normally, the change of response had to occur in item 5 because this item was exactly between the length of the short stick and that of the long stick. The second, the Slope corresponded at the participants’ accuracy. The higher the slope the more participants encountered difficulties to make accurate responses. These data were then fitted locally using the `modelfree` package (Zychaluk & Foster, 2009; see also Rey, Vallet, Riou, Lesourd, & Versace, 2015). Pse and Slope were estimated from the fitted values.

2.2.2.2. *Visual-Length condition*

This condition was composed of the same 9 target-sticks as those used in the Use-Length condition. These 9 items were also randomly presented twelve times each (i.e., 108 trials in total). The item was presented in front of the participants at a distance of about 60 cm. Two sticks were also always presented on each side of them (figure 3). For half of the participants, the short stick (12-cm long) was displayed on the right and the long stick (28-cm long) on the left and vice versa for the other half. The participants had to indicate whether the length of the item was closer to that of the short stick or to that of the long stick. As in the Use-Length condition, two indicators were computed based on participants' psychometric curves, the Pse and the Slope.

2.2.2.3. Addition-Length condition

This condition was composed of the same 9 target-sticks as those used in both previous conditions. These 9 items were randomly presented twelve times each (i.e., 108 trials in total). On each side of participants, two sticks were arranged one above the other (figure 3). For half of participants, the short sticks (4-cm and 8-cm long) were displayed on the left and the long sticks (9-cm and 19-cm long) on the right and vice versa for the other half. The item was presented at a distance of about 60 cm from them. The instruction was to decide whether the length of the target stick was closer to that of the addition of the two shorter sticks or to that of the addition of the two longer sticks. Such as in the both previous conditions, the Pse and the Slopes were taken into account based on participants' psychometric curves.

< INSERT FIGURE 3 ABOUT HERE >

2.3. Statistics

Because of unequal group sizes and unequal variances we preferred non-parametric tests. For conventional tasks, between-group comparisons were carried out with Mann-Whitney tests.

3. Results

3.1. Conventional tasks

Figure 4 displays the results of the conventional tasks for LBD patients and for the control group. LBD patients scored significantly lower than controls on Familiar Tool Use (Choice condition, $U = 11.5$, $z = 3.35$, $p = .0003$; No-Choice condition, $U = 32$, $z = 2.09$, $p = .04$) and on Mechanical Problem-Solving in Choice condition ($U = 18.5$, $z = 2.92$, $p = .003$).

< INSERT FIGURE 4 ABOUT HERE >

3.2. Experimental tasks

Mann-Whitney tests with the between-subject factor group (LBD, Control) were run for each condition separately and for the following measures: the Pse and the Slopes.

In the Use-length condition, we did not observe significant differences between groups for the Pse measure (Control, $M = 5.89$, $SE = 2.15$; LBD, $M = 5.70$, $SE = 1.25$; $U = 55$; $z = 0.68$; $p = 0.50$) and for the Slopes measure (Control, $M = -0.43$, $SE = 0.22$; LBD, $M = -1.10$, $SE = 2.26$; $U = 60$; $z = 0.37$; $p = 0.71$). As can be seen in figure 5, we observed that the two groups tended to overestimate the length of item 4. They tended to underestimate the length

of items 6 to 8. On the whole, LBD patients responded more accurately than the control group.

There was not significant difference between groups for the Pse measure in the Visual-Length condition (Control, $M = 4.83$, $SE = 1.85$; LBD, $M = 4.23$, $SE = 1.78$; $U = 59$; $z = 0.43$, $p = 0.67$). However, we found a significant difference for the Slopes measure (Control, $M = -0.41$, $SE = 0.12$; LBD, $M = -0.33$, $SE = 0.14$; $U = 33$; $z = -2.03$; $p = 0.04$). As shown in figure 5, we noticed that the both groups tended to overestimate the length of item 2, item 3 and item 4. They tended to underestimate the length of items 6 and 7. Generally, the both groups had the same degree of accuracy.

In the Addition-Length condition, there was not significant difference between groups for the Pse measure (Control, $M = 4.85$, $SE = 1.61$; LBD, $M = 5.79$, $SE = 0.67$; $U = 30$; $z = -1.01$; $p = 0.31$) and for the Slopes measure (Control, $M = -1.14$, $SE = 2.75$; LBD, $M = -1.80$, $SE = 3.48$; $U = 34$; $z = 0.68$; $p = 0.50$). As shown in figure 5, the control group tended to overestimate the items 2 to 4. The LBD patients tended to overestimate the item 5. The both groups tended to underestimate the item 6. Generally, LBD patients responded more accurately than control group until the item 4.

< INSERT FIGURE 5 ABOUT HERE >

4. Discussion:

It has long been established that some LBD patients may suffer from tool use difficulties. Through the study of these patients, it is possible to better understand the cognitive bases of human tool use. Several hypotheses have been proposed in order to explain human tool use (i.e., manipulation-based approach) but this study aimed to deepen the

reasoning-based approach. Specifically, the question is to determine whether LBD patients were able to estimate the physical object properties. The participants were tested on conventional (Familiar Tool Use and Mechanical Problem Solving tasks) and experimental (Use-Length, Visual-Length and Addition-Length conditions) tasks. In this framework, we became interested in the estimation of the length in order to examine whether LBD patients with tool use deficits had difficulties to estimate the length of tools in tool-use (Use-Length) or non-tool-use situations (Visual-Length, Addition-Length). We developed two hypotheses: LBD patients with tool use deficits have preserved capacity of estimation of the length but altered mechanical knowledge (Hypothesis A: deficit of reasoning only) or they could no longer reason about length (Hypothesis B: deficit of both estimation and reasoning).

To sum up, our results showed that LBD patients performed worse than the control group on conventional tasks: Familiar Tool Use in both conditions and Mechanical Problem Solving in Choice condition. In other words, LBD patients had difficulty to choose and to use tools in Familiar Tool Use task but they had no difficulty in using the appropriate tool in Mechanical Problem Solving task. In this study, it seems like patients' disorder on tool use resulted mainly from the inability to select appropriate tools. Moreover, these results showed that the patients are no longer able to determine which is the correct mechanical action to be performed because they failed in both conditions in Familiar Tool Use task. Their mechanical knowledge seemed altered. Nevertheless, no significant difference was observed between both groups for the three experimental tasks evaluating the estimation of the length except for the Slope indicator in Visual-Length condition. Therefore, we can deduce that patients had not difficulties in estimating the length of objects and tools. In sum, the Hypothesis A appears validated.

In view of these results, we propose that the main difficulty for LBD patients with tool use disorders may consist in producing themselves the tool-use solution. For example, as

shown in figure 5, we observed that control group was better than LBD patients in the Visual-Length and Addition-Length conditions (where the participants estimated 3 lengths in the same time) whereas they were better in the Use-Length condition than control group (where they estimated one length). In this condition, the participants had no choice as if the solution of the problem was given to them. In another study, Osiurak et al. (2013) showed that LBD patients used more irrelevant sticks (too short, too long, too flexible, too rigid or too fragile) than the control group in the Choice condition of the Mechanical Problem Solving task, (for results in Alzheimer's Disease, see: Lesourd et al., 2015). This seems paradoxical from the results in this study. Perhaps, it is not a problem in estimating the length but rather for forming a more abstract representation of the problem to be solved (Osiurak & Badets, 2016). Their main difficulty would be to know which mechanical action to perform, namely, which strategy to adopt when the situation involves tool use. Indeed, Osiurak et al. (2013) noted that LBD patients spent an important time to handle irrelevant sticks, to box manipulation or no manipulation, compared to control group in Mechanical Problem Solving task in Choice condition. The authors concluded that LBD patients were perplexed by tool use situations showing an inability to reason technically (as the best control participants) and to use a trial-and-error strategy (as the worst control participants). This suggests difficulties about the implementation of strategies. The patients could be unable to generate the mechanical actions in order to achieve the goal.

In conclusion, this leads us to suggest that the ability to correctly estimate physical object properties would be necessary but not sufficient for technical reasoning and as result to use objects and tools appropriately. Said differently, tool use and estimation of physical objects properties might be two independent capacities processed by different networks. In this respect, the ability to use tools has been associated with activity of the left inferior parietal lobe, whereas estimation of physical properties might involve bilateral parietal lobes.

This would explain the LBD patients' success in length estimation tasks: Intact right hemisphere might be recruited to compensate for damage to the left inferior parietal lobe. Moreover, according to Walsh (2003; Buetti & Walsh, 2009), there would be a generalized magnitude system for estimating numerical quantities, time, space and other magnitudes (i.e., ATOM, A Theory Of Magnitude), located in bilateral parietal lobes. Therefore, the ability to estimate physical object properties might be part of this generalized magnitude system.

For future research, an open issue will be to test other properties (strength, flexibility, etc.) in order to know whether the estimation of physical object properties other than visual-based ones is preserved in LBD patients with tool use disorders. Moreover, the representation of the length is essentially based on visual information while the representation of the weight, for instance, is based on multisensory information (e.g., tactile and visual). It would be interesting to consider other physical properties combining several sensorial capacities as far as the left inferior parietal lobe that underlies tool use is also a multisensory association region. Another interesting future research will be to know whether it is possible to bring closer the tool use and the numerical cognition. Indeed, the reasoning-based approach suggests that tool use would need calculation capacities in order to estimate the physical object properties in the environment (e.g., Is this tool long enough order to make a lever?) and also in order to add or subtract this properties (e.g., Does the addition of these tools allows to reach the appropriate length in order to make a lever?). Furthermore, several links can be made between tool use and numerical cognition. First, at the cognitive level, we make the connection between the ability to estimate physical object properties (e.g. to estimate quantities of weight or solidity of hammer) and the ability to estimate numerosities (e.g. to estimate which set contains the most points). These both abilities require a common process of magnitude estimation. Second, at the cerebral level, tool use and numerical cognition have been located in the inferior parietal lobe (Dehaene, Dehaene-Lambertz, & Cohen, 1998;

Fridman et al., 2006; Goldenberg & Hagmann, 1998; Goldenberg & Spatt, 2009; Lyons, Ansari, & Beilock, 2015; Nieder & Miller, 2004; Orban & Caruana, 2014; Piazza, Pinel, Le Bihan, & Dehaene, 2007; Peeters et al., 2009; Peeters, Rizzolatti, & Orban, 2013; Reynaud et al., 2016; Vingerhoets, Vandekerckhove, Honoré, Vandemaele, & Achten, 2011). According to Walsh (2003; Buetti & Walsh, 2009), there would be a generalized magnitude system in the parietal lobe (i.e., ATOM: A Theory Of Magnitude). To date, no study has verified this hypothesis.

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Tool use in left brain-damaged patients

Table 1. Demographic and clinical data

	LBD (<i>n</i> = 11)	Control (<i>n</i> = 12)	LBD vs Control
Gender (<i>n</i>): W/M	5/6	8/4	ns
Age (years)	54.6 (13.20)	55.1 (13.81)	ns
Education (years)	12.4 (3.32)	14.3 (3.55)	ns
Handedness: right/left	11/0	12/0	
Type of lesions:			
ischemic stroke/hemorrhagic stroke/tumor	7/2/2	-	
Years since lesions	2.2 (1.56)	-	-
Hemiparesis (<i>n</i>): present/absent	3/8	-	
Hemiplegia (<i>n</i>): present; absent	2/9	-	
Hemianopia (<i>n</i>): present; absent	1/10	-	
Hemineglect (<i>n</i>): present; absent	0/11	-	
Visual gnosis evaluation* ^β			
Similar Figures	9.33 (1.32)	-	-
Overlapping Figures	35.22 (0.83)	-	-
Functional Associations	9.88 (0.33)	-	-
Categorical Associations	9.77 (0.44)	-	-
Line bisection test (percentage of deviation)	-0.93 (2.75)		-
Ota test			
Number of missed stimuli (max. 60)	0.50 (0.53)		-
Number of open circles surrounded (max. 20)	0.1 (0.32)		-
Stars Test (Halligan)			
Number of left missed stimuli (max. 27)	0.1 (0.32)		-
Number of right missed stimuli (max. 27)	0.2 (0.42)		-
Semantic knowledge	58 (2.28)	59 (0.29)	ns
Functional Associations	19.5 (0.93)	20 (0)	ns
Categorical Associations	18.7 (1.56)	20 (0)	ns
Contextual Associations	19.5 (0.82)	19.5 (1.08)	ns

Between-group comparisons were performed with χ^2 analysis for "Gender" and Kruskal-Wallis ANOVAs and Mann-Whitney tests for the other variables.

n, number of participants; ns, non significant ($p < .05$); s, significant ($*p < .05$).

Values in brackets are standard deviation.

* Protocole Montréal-Toulouse d'Évaluation des Gnosies Visuelles (P.E.G.V.). In the Similar Figures subtest, the participants had to choose the picture similar to the target item. In the Overlapping Figures subtest, the participants had to choose the three pictures that compose the target item (this item was presented as in the Poppelreuter test). In the Functional Associations subtest, the participants had to choose the object functionally associated with the target item (screwdriver with screw). In the Categorical Associations subtest, the participants had to choose the object belonging to the same semantic category as the target (piano with violin).

^β Pathological scores on the Protocole Montréal-Toulouse d'Évaluation des Gnosies Visuelles (P.E.G.V.). Similar Figures subtest: score of less than 8; Overlapping Figures subtest: score of less than 30; Functional Associations: score of less than 9; Categorical Associations: score of less than 9.

Tool use in left brain-damaged patients



Figure 1: Familiar Tool Use task. The left picture represents the “horizontal tool panel” in the Choice condition. The four right pictures show 4 examples of tools with their corresponded object, in Choice and No-Choice conditions (Jarry et al., 2013).

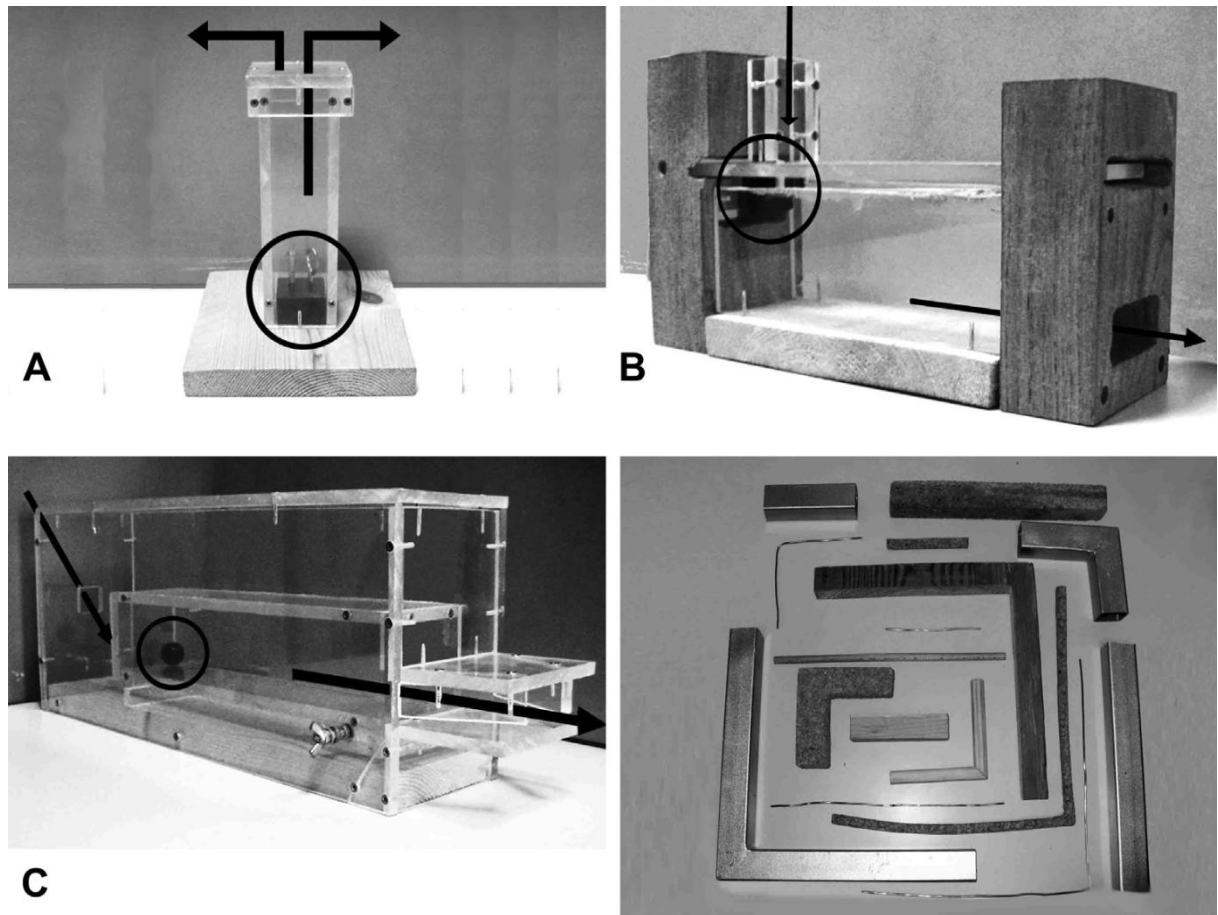


Figure 2: Mechanical Problem-Solving task. The bottom right picture displays the 16 sticks used in Choice condition. The three other pictures show the 3 boxes (A, B and C) used in both conditions. Black circles indicate the wooden targets. Black arrows indicate the entrances of the boxes (Jarry et al., 2013).

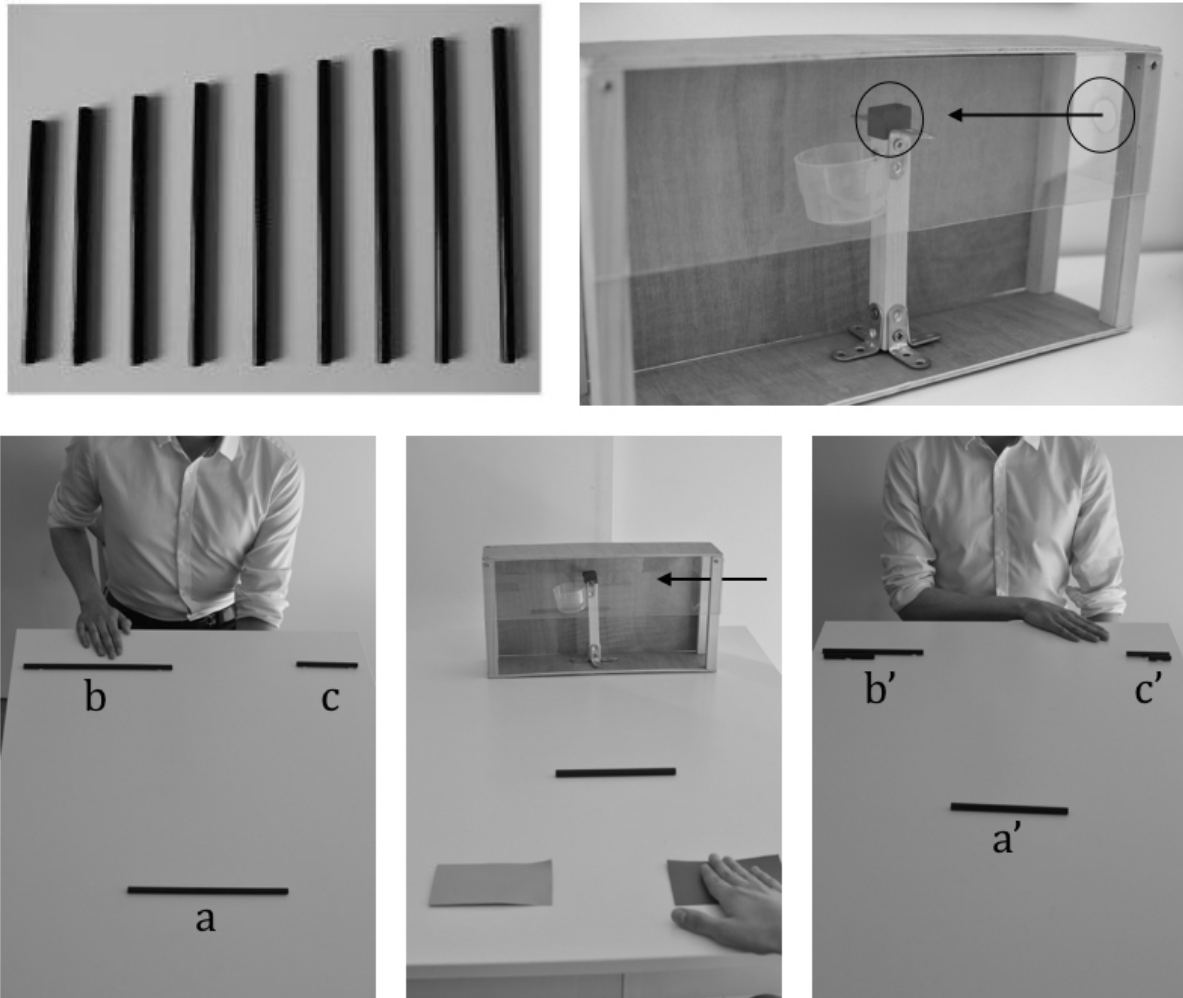


Figure 3: Experimental tasks. The top left picture displays 9 target-sticks (items) in ascending order. The bottom left picture shows the Visual-Length condition. In this condition the participant compared the item (a) with the long stick (b) and the short stick (c). The second picture at the bottom represents the Use-Length condition, the black arrow indicates the hole of the box. The top right picture shows the cube and the hole into which the stick had to be inserted to push off the cube. The bottom right picture displays the Addition-Length condition. The participant compared the item (a') with the two long sticks (b') and the two short sticks (c') which were disposed one above the other.

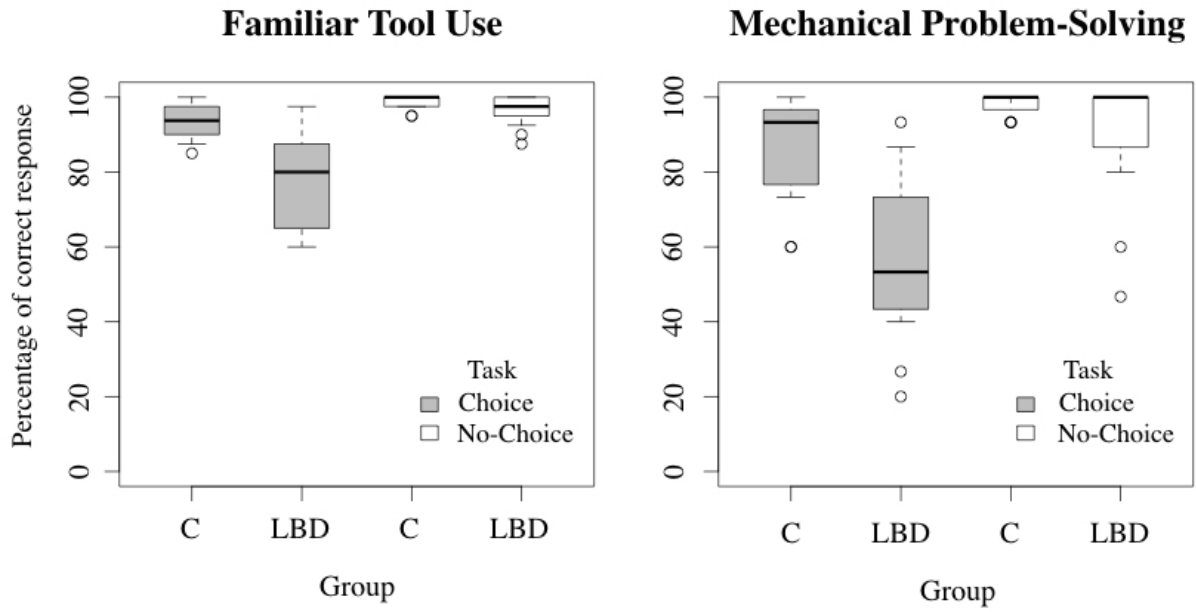


Figure 4: Percentage of correct response for conventional tasks. The boxplots represent median value for each group, interquartile range, minimum and maximum. Participants whose performance was lower or upper of the edge of the box at 0.5, they were classified as outliers (circles in the figure). The left figure shows Familiar Tool Use task and the right figure displays Mechanical Problem-Solving task, for both groups (LBD patients and control groups).

Tool use in left brain-damaged patients

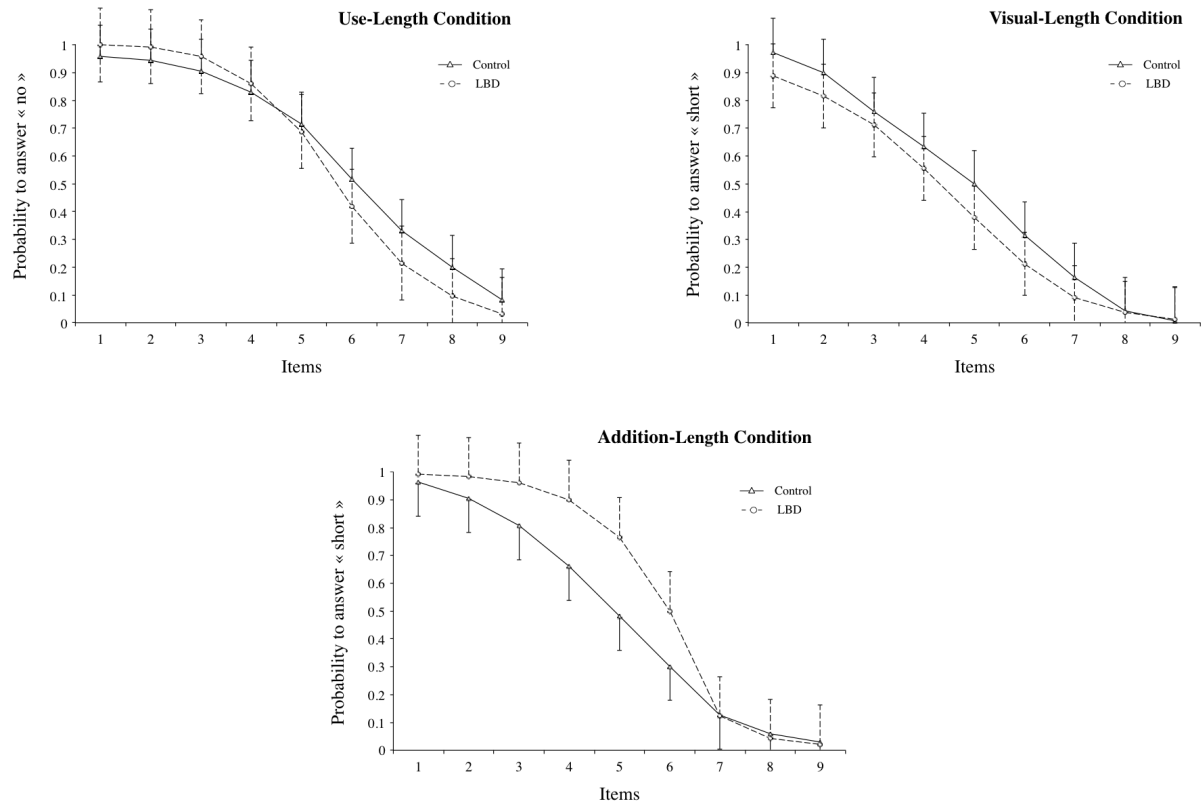


Figure 5: Experimental tasks. Curves represent the probability to answer “short” for Visual-Length and Addition-Length conditions and the probability to answer “yes” for Use-Length condition, with standard error of mean for each group.