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Hazardous tools: the emergence of technical reasoning in human tool use

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Abstract

Humans are unique in the way they understand the causal relationships between the use of tools and achieving a goal. The idea at the core of the present research is that tool use can be considered as an instance of problem-solving situations supported by technical reasoning. In an eye-tracking study, we investigated the fixation patterns of participants ($N = 32$) looking at 3D images of thematically-consistent (e.g., nail – steel hammer) and thematically-inconsistent (e.g., scarf – steel hammer) object-tool pairs that could be either “hazardous” (accidentally electrified) or not. Results showed that under thematically-consistent conditions, participants focused on the tool’s manipulation area (e.g., the handle of a steel hammer). However, when electrified tools were present or when the visual scene was not action-prompting, regardless of the presence of electricity, the tools’ functional/identity areas (e.g., the head of a steel hammer) were fixated longer than the tools’ manipulation areas. These results support the reasoning-based approach and document, for the first time, the crucial role of mechanical/semantic knowledge in tool visual exploration.

Keywords

Human Tool Use; Technical Reasoning; Mechanical Knowledge, Action Reappraisal; Technition

1. Introduction

Tool use, alongside language and bipedal locomotion, is a characterising ability of human beings. While non-human primates can manipulate tools (e.g., Baber, 2003), the main differences between human and non-human tool use can be traced in the evolutionary discontinuities related to hand-eye coordination, social learning and intelligence, teaching, language, function representation, executive functioning and, most importantly, causal reasoning (Vaesen, 2012). Indeed, humans appear to be unique in the way they understand the causal relationships between the use of tools and achieving a goal (Povinelli et al., 2000). Such a noticeable differentiation becomes particularly apparent if one considers how individuals spontaneously and frequently use tools to solve everyday-life problems, in common (e.g., pounding a nail by using a hammer) and uncommon (e.g., screwing a screw by using a knife) ways, according to their goals (e.g., hang a picture on the wall) and intentions (e.g., furnish the living room). In a way, tool use can be easily considered as an instance of problem-solving situations sustained by technical reasoning (Osiurak & Badets, 2016; see also: Beck, Apperly, Chappell, Guthrie, & Cutting, 2011).

When considering such a kind of reasoning-centred abilities, the emphasis on motor aspects given by “manipulation-based” theories of human tool use seems quite peculiar (e.g., Thill, Caligiore, Borghi, Ziemke & Baldassarre, 2013). By echoing the embodied-cognition account (Barsalou, 2008), the manipulation-knowledge hypothesis put in the foreground the role of the sensorimotor knowledge in tool use: Humans manipulate tools and, consequently, they store information regarding how to manipulate them. The corollary idea is that, when we perceive a tool, we automatically activate motor simulations of actions that are associated with the tool. In this way, the notion of “affordance” (Gibson, 1977) has become highly (ab)used in the field of tool use, on the presumptive basis that the ecological approach is limpidly embodied (i.e., perception for action). Notwithstanding, it should be noted how, for Gibson (1977) himself, an affordance is not a form of sensorimotor knowledge. Instead, it is an *opportunity for action* that an animal *could* perceive (Gibson, 1977). Thus, although stressing the role of the object-provided motor affordances can be an effective way to understand the prehensile mechanisms and the associative-learning skills implicated in how chimpanzees use objects (Orban & Caruana; 2014), the manipulation-based approach might not be as much adequate to fully understand the “cognitive magnitude” associated with human tool use. Hence, despite its undoubted success, the manipulation-based hypothesis was challenged by recent evidence that highlighted the crucial role of technical reasoning in human tool use (e.g., Osiurak & Badets, 2016; see also: Goldenberg, 2013).

In the reasoning-based perspective, humans are not seen as *manipulators*. Instead, they are considered as *problem solvers* who can transform their physical environment

according to their goals (Osiurak, Lesourd, Navarro & Reynaud, 2020). Tool use is thereby incorporated in a wider cognitive framework that emphasises reasoning on the basis of the so-called mechanical knowledge, i.e., a non-declarative form of knowledge associated with tools and objects that contains abstract information about mechanical actions. Thus, when we see a screwdriver on the table, we do not automatically activate manipulation knowledge to use it. Rather, based on the physical problem we intend to solve, we use mechanical knowledge to reason about how to use the screwdriver with an appropriate object (e.g., screw). Hence, it is thereby expected a kind of mechanical-to-motor “cascade” mechanism through which an agent, in a recursive way, first generates the mechanical actions to be executed, then places constraints on the motor actions that should be selected by the motor-control system in order to actualise the action. This mechanism is substantiated by the multiplicity of neurocognitive systems involved in tool use (e.g., Reynaud, Lesourd, Navarro & Osiurak, 2016; Orban & Caruana, 2014). In particular, mechanical knowledge (i.e., the ventro-dorsal system) seems to be a kind of bridge system between the semantic system associated with tools’ identity and functions (i.e., the ventral system) and the motor-control system (i.e., the dorso-dorsal system; Osiurak, Rossetti & Badets, 2017).

The effects of the interaction between the aforementioned neurocognitive systems on tool visual exploration have been recently explored by Federico and Brandimonte (2020). By comparing an implicit motoric task with an explicit recognition task, in two eye-tracking experiments the authors investigated how the visuoperceptual context and the goal of the task influenced the visual-attentional processing of tools that were part of object-tool pairs. The first key result was that, within the first 500ms of visual exploration, participants focused on the tools’ functional areas in any experimental condition. In contrast, when participants looked at the scene in a natural way and a longer time window of analysis was considered (1000ms), the fixation pattern focused on the tool’s manipulation area (e.g., the handle of a screwdriver) under thematically-consistent conditions (e.g., screw-screwdriver) and on the tool’s functional area (e.g., the head of a screwdriver) under thematically-inconsistent conditions (e.g., nut-screwdriver). Crucially, looking at the tools to recognise them, generated longer fixations on the tools’ functional areas, irrespective of thematic consistency. Thus, when the visuoperceptual context prompts high action readiness, the easiest resolution of the cascade mechanism is reflected in a visual-attentional pattern that emphasises the tool’s manipulative part to actualise the action. Conversely, when the visual scene is not prompting action readiness or when there is an explicit non-motoric goal, individuals do not proceed toward motor processing. These results were interpreted by the authors as indicating a mechanism of “action reappraisal”, that is, a reasoning-based multidimensional cognitive process through which people can flexibly use multiple sources of information to exploit the environment in terms of action.

In the present study, we moved a step further and devised a task that enables technical reasoning only if it is based on the understanding of classical Physics principles. To date, electrical conductivity is a measure of the ability of a substance to conduct an electric current. Metals are capable of conducting electricity so that no one would touch a metal tool if it were electrified. Hence, a steel hammer seen next to a nail, with both objects placed on a steel tray, would be seen less graspable if a stripped electrical cable was plugged in the power line and its stripped part was accidentally in contact with the tray. In such a situation, an agent should prevent herself from using the electrified tool as an effect of an inferential process. Consequently, we should expect a fixation pattern that, despite the higher action readiness prompted by the thematic consistency of the visual scene (Federico & Brandimonte, 2019), does not favour the tool's manipulation area.

To test the above hypothesis, in the present study, we analysed by eye-tracking the fixation patterns of participants looking at 3D colour images reproducing thematically-consistent (e.g., nail – steel hammer) and thematically-inconsistent (e.g., scarf – steel hammer) object-tool pairs that could be electrified or not (Figure 1). We hypothesised that, as an effect of technical reasoning, tools that were part of thematically consistent and electrified object-tool pairs should be looked at their manipulative area less than their correspondent non-electrified pairs. Conversely, electricity should not produce any effect under thematically-inconsistent conditions, given the lower action readiness produced by the visual scene. Hence, in these control conditions, we expected a pattern that did not favour the tool's manipulative part, regardless of the presence of electricity.

2. Methods

2.1. Participants

Thirty-two right-handed participants (22 females; mean age = 25.69 years, S.D. = 4.19) engaged in the experiment. All had a normal vision and no history of psychiatric/neurological disorders. Written informed consent was obtained from all participants involved in the experiment. The sample size was calculated on the basis of similar studies (Federico & Brandimonte, 2019, 2020) and by performing a power analysis (Faul, Erdfelder, Lang & Buchner, 2007) to detect a small effect size ($\eta_p^2 = .10$) within a repeated-measures ANOVA, with a power of .95 and an alpha level of .05.

2.2. Materials

We used twenty 3D computer-graphics generated colour images as stimuli for the experiment. Stimuli were divided into four different groups. The first two groups of images (Figure 1A and Figure 1B) represented object-tool pairs that were thematically consistent (a

tool made of steel on the right – e.g., steel whip – and an object on the left, e.g., a bowl). The objects were placed on a steel tray that was located on a table in close proximity to the observer, within the participant's peri-personal space. For each group, there were the following five object-tool pairs: nail – steel hammer, bowl – steel whip, bottle – steel bottle opener, salami – steel knife, coffee cup – steel teaspoon. The first group of stimuli (Figure 1A) presented a stripped power cord that was plugged in the power line on the wall, with the stripped part of the cable accidentally in contact with the steel tray, while the second group (Figure 1B) showed the same stripped power cord unplugged from the power line. The third and fourth group of stimuli (Figure 1C and Figure 1D) depicted pairs of thematically-inconsistent objects (a tool made of steel on the right – e.g., a steel teaspoon – and an object on the left, e.g., a cap). The pairs appeared arranged on a steel tray that was placed on a table, within the peri-personal space of participants. Both groups comprised five object-tool pairs: scarf – steel hammer, women shoe – steel whip, alarm clock – steel bottle opener, nut – steel knife, cap – steel teaspoon. Once again, the third (Figure 1C) and fourth (Figure 1D) group of stimuli showed one of two scenarios with either plugged or unplugged power cords. In all experimental conditions, the object-tool pairs appeared placed directly on the steel tray located on the table. The mean perceived centre-to-centre distance between the tool and the object was about 25cm, with an angle of approximately 180deg (taking the horizontal line of the table as a reference). Some examples of the stimuli used in the experiment are shown in Figure 1.

Figure 1 about here

2.3. Procedure

The experiment was performed in the Laboratory of Experimental Psychology of the Suor Orsola Benincasa University of Naples (Italy). All procedures were in accordance with the ethical standards of the 1964 Helsinki Declaration. The Ethics Committee of the Suor Orsola Benincasa University approved the study. Before starting with the experiment, written informed consent was obtained from each participant. Then, participants were asked to self-report the absence of any psychiatric/neurological diseases, their adequate visual acuity and their right-handedness. The participants were seated on a chair, with a headrest used to limit their head movements to permit an accurate eye-tracking data recording. Participants were positioned at a distance of 54cm from a 23-inches monitor. They were then asked to keep their hand motionless on the desk. The right hand was resting on the right side of the monitor, hence being peripherally visible. Then, the experimental instructions were provided. Participants completed an eye-tracking software calibration procedure. Subsequently, participants were asked to "observe what appeared on the screen in the most natural way as

possible" and the experiment initiated. For each experimental condition, five images were administered. Thus, being the design a within-participants design, twenty images were randomly presented to each participant, in accordance with the experimental visual flow (Figure 2). A fixation point (i.e., a white cross positioned in the centre of a black screen) appeared for 500ms before each stimulus. Then, the stimulus was shown for 5000ms. To permit retina relaxation, a black screen appeared for 4000ms after each stimulus. Each stimulus presentation lasted 9.5 seconds (500ms + 5000ms + 4000ms) whereas the overall stimuli presentation lasted 190 seconds (9500ms x 20 stimuli). Then, participants were asked to perform a reachability task using the same stimuli as those used during the experiment. Participants were asked to indicate if both the objects of the pairs were graspable with their right hand. All participants reported that they were reachable. Most importantly, in the thematically-consistent condition, tools were reported as potentially usable on the objects (e.g., the steel knife was considered effectively usable on the salami) only when the tools were considered not electrified by the presence of the plugged-in stripped power cord placed in contact with the steel tray, whereas, in the thematically-inconsistent condition, tools and objects were considered not properly usable with each other (e.g., the steel hammer was not considered usable on the scarf), regardless of the presence of electricity. For each participant, the experiment lasted about 20 minutes. All participants were debriefed about the aims of the research. None of the participants was excluded from the sample.

Figure 2 about here

2.4. *Apparatus*

The eye-tracking data were collected through a Full-HD Webcam (Logitech HD Pro C920, with a sampling rate of 60Hz). RealEye.io platform (RealEye sp. z o. o.) was used to manage the experiment and to acquire gaze-behaviour data. The eye-tracking technologies at the core of the platform we used are based on WebGazer (Papoutsaki et al., 2016). A 23-inches monitor was used to show the stimuli at a resolution of 1920*1080px. The experimental software and scripts were executed on an Apple Mac Mini (2018) running macOS Catalina (version 10.15).

2.5. *Eye-tracking data*

We analysed the participants' visual-attentional patterns by considering the mean fixation time (milliseconds) on different Areas of Interest (AOIs) of the tools. In particular, we defined two different AOIs (Figure 3): the manipulation part of the tool (i.e., the middle-bottom area where to put the hand in order to use the tool) and the functional part of the tool (i.e., middle-

top area through which it is possible to understand the identity/function of the tool). The AOs considered in the study are shown in Figure 3. To overcome the technical limitations of the eye-tracking technology used here (Papoutsaki et al., 2016), we increased the perimeter of the AOs by 64 pixels in all directions. The mean fixation time to the AOs was averaged for each condition. Eye-tracking data related to the first 250ms of each stimulus were excluded to reduce the error produced by the initial fixation point in participants' visual-exploration patterns. For each stimulus, we considered only the first 2000ms of visual-exploration data. Such a time-window of analysis was chosen to decrease data dispersal effects due to participants' visual-scene exploration. Preliminary qualitative indications of differences in participants' visual-attentional patterns may be appreciated by looking at the fixation heatmaps (Figure 4).

Figure 3 and Figure 4 about here

2.6. Data analyses

We analysed how participants looked at the tools as the visuoperceptual context changed by performing a 2 x 2 x 2 repeated-measure ANOVA with *AOIs* (functional vs. manipulative part of the tool), *Thematic Consistency* (thematically-consistent vs. thematically-inconsistent object-tool pairs), and *Electricity* (electrified vs. non-electrified tools) as 2-level factors on tools' fixation time (milliseconds). An alpha level of .05 was used for all the analyses. For multiple comparisons, we used the Tukey HSD test. We used the open-source software "R" and the graphical user interface "Jamovi" (both for Apple macOS operating system) to perform all the statistical analyses.

3. Results

Eye-tracking data related to the temporal allocation of visual-spatial attention (i.e., mean fixation time) to the tools' function and manipulation AOs are synthesised in Table 1.

Table 1 about here

A repeated-measure analysis of variance revealed a main effect of *AOIs* on tools' mean fixation time, $F(1, 31) = 128,34$, $p < .001$, $\eta_p^2 = .81$. This main effect was due to a longer fixation duration for the tool's functional area ($M = 361\text{ms}$, $SD = 187$) than the tool's manipulation area ($M = 144\text{ms}$, $SD = 158$). A main effect of *Electricity* was also found, $F(1, 31) = 4,15$, $p = .05$, $\eta_p^2 = .12$. This main effect was due to a longer fixation duration for Non-Electrified tools ($M = 264\text{ms}$, $SD = 187$) than Electrified tools ($M = 241\text{ms}$, $SD = 217$). Three statistically significant interactions were found: (1) *AOIs* * *Electricity*, $F(1, 31) = 39,61$, $p <$

.001, $\eta_p^2 = .56$; (2) *AOLs * Thematic Consistency*, $F(1, 31) = 68,65$, $p < .001$, $\eta_p^2 = .69$; (3) *AOLs * Electricity * Thematic Consistency*, $F(1, 31) = 35.14$, $p < .001$, $\eta_p^2 = 0.53$. We restricted the description of results to the three-way interaction “*AOLs * Thematic Consistency * Electricity*” in order to simplify the pattern of results. Hence, post-hoc pairwise comparisons revealed that, for the thematically-consistent object-tool pairs, the tool’s manipulation area was fixated longer than the tool’s functional area in the Non-Electrified condition ($p < .05$), whereas, in the Electrified condition, the visuo-attentional pattern was reversed, with tools fixated longer in their functional area ($p < .001$). In addition, the manipulation area of tools that were part of thematically-consistent object-tool pairs obtained longer fixation time in the Non-Electrified condition as compared to the remaining conditions (all with $p < .001$). Conversely, the tool’s functional area was fixated longer than the manipulation area in the thematically-inconsistent conditions, regardless of the presence of electricity (all with $p < .001$). Finally, tools of thematically-consistent pairs were fixated longer in their functional area in Electrified condition ($p < .001$). The three-way interaction effect reported here is shown in Figure 5. No main effect of *Thematic Consistency* was found.

Figure 5 about here

4. Discussion

In the present study, we investigated the impact of inferential technical reasoning on the tool’s visual-attentional patterns of participants engaged in a free-to-look-at task in which stimuli composed by 3D images of thematically-consistent (nail – steel hammer) and thematically-inconsistent (scarf – steel hammer) object-tool pairs were randomly administered. These pairs could appear as electrified or not by means of a stripped power cord that could be plugged in or unplugged from the electrical line. In all experimental conditions, the stripped part of the cable was placed accidentally in contact with a steel tray upon which the objects were located (Figure 1).

Results showed that under the thematically-consistent, non-electrified condition, the mechanical knowledge issue (How to use the tool with the object?) was presumably easily solved so that the mechanical-to-motor cascade mechanism could proceed fast (Federico & Brandimonte; 2019). This was reflected in a fixation pattern (Figure 4 and Figure 5) that focused on the manipulative part of the tool, in order to actualise the action (i.e., using the tool with the object). However, such a visual-attentional pattern is far from suggesting an automatic motor engagement. In fact, as soon as the same consistent pairs appeared electrified, the manipulation-centred pattern disappeared and was replaced by an opposite pattern in which the tools’ functional areas were fixated longer than the tools’ manipulation areas. Therefore, it appears that reasoning about the electricity circumstance inhibited

participants from proceeding toward the motor processing of the visual scene. In other words, the mechanical-to-motor cascade mechanism was not finalised as participants lingered in technical reasoning. Interestingly, the same fixation pattern was obtained – regardless of the presence of electricity – when the visual scene was not action-prompting “by default”. Namely, in the control condition with thematically-inconsistent pairs, participants explored the visual scene in a reasoning-based way, with motor processing and electricity being no longer relevant. Finally, tools were fixated longer under non-electrified than electrified conditions, as evidenced by the main effect of electricity.

The involvement of reasoning processes in tool visual exploration makes the present results very difficult to interpret within a manipulation-centred framework (e.g., Buxbaum 2001; Buxbaum & Kalénine 2010; Thill et al., 2013). Participants appeared to be able to implicitly distinguish the “opportunities for action” (Gibson, 1977) prompted by the visual scene on the basis of an inferential process (i.e., understanding the hazardousness elicited by the visual scene) supported by technical reasoning, which, in turn, was made possible through the knowledge of a principle of Physics (i.e., electrical conductivity). These results may help understand how a reasoning-based agent can use tools by processing and integrating multiple types of information through distinct neurocognitive systems. Such an integrated perspective has been recently proposed by Federico & Brandimonte (2020) by introducing the concept of “action reappraisal” as a way to conceptualise human tool use as the product of dynamic interactions between semantic knowledge, mechanical knowledge, and the motor-control system. It is worth to emphasise how the action-reappraisal perspective might find an echo in the recent neuroscientific debate about the identification of cortical convergence areas that combine different kinds of knowledge in order to construct generalisable object and action representations (e.g., Lambon Ralph, Jefferies, Patterson & Rogers, 2017; Chen, Garcea, Jacobs & Mahon, 2018; De Bellis et al. 2018; Wurm & Caramazza 2019; see also: Rogers & McClelland, 2004; Bar et al. 2006).

The flexible interactions between neurocognitive systems we outlined here are well testified by the wide and composite interplay of frontoparietal and occipitotemporal brain networks involved in human tool use (e.g., Reynaud et al., 2016, 2019; Orban & Caruana, 2014). In particular, mechanical knowledge appears to be stored within the cytoarchitectonic “PF” area (Caspers et al., 2006, 2008) of the supramarginal gyrus (SMG), in the left inferior parietal cortex. Such a neurocognitive system seems to act as a bridge between the tools’ function knowledge (i.e., semantic knowledge associated with tools’ identity and functions; Garcea & Mahon, 2012) and the motor-control system (Osiurak et al., 2017). These latter two systems have specific neural correlates. Indeed, the function knowledge produces sparse activations in the left temporal cortex, in the lateral occipital complex and in the left posterior middle temporal gyrus (Reynaud et al., 2016; see also: Boronat et al., 2005;

Canessa et al., 2007; Goldenberg; 2013; Orban & Caruana, 2014; Roux-Sibilon, Kalénine, Pichat & Peyrin; 2018). The bilateral superior parietal cortex and the intraparietal sulcus (the anterior dorsal IPS and the putative human anterior intraparietal sulcus area) appear to be the neural substrates associated with the motor-control system (Reynaud et al., 2016; see also: Chao & Martin; 2000; Johnson-Frey; 2004; Goldenberg & Spatt; 2009). Most importantly, the left anterior portion of the SMG, extending to the cytoarchitectonic “PFT” area of the SMG appears to be an area that integrates information between mechanical knowledge and the motor-control system (Reynaud et al., 2016; Caspers et al., 2006, 2008). Thus, when an agent reasons on the feasibility of an action, an initial activation of the cytoarchitectonic PF area may reflect the degree of technical-reasoning involvement in visual scene analysis. Then, it is conceivable that when the agent decides to actualise the action, as in the case of a non-electrified nail-steel hammer pair, we should expect the activation of the motor-control system (i.e., superior parietal areas such as the IPS) while looking at the handle of the tool. Conversely, lower or no activation of the same parietal areas should be expected when an agent does not decide to use a tool (i.e., when the agent does not look at the tool's manipulation area), as in the case of electrified tools or thematically-inconsistent pairs. Currently, the present findings do not speak directly to the issue of the neural correlates of the effects reported here. Therefore, future fMRI studies should specifically test the cascade-mechanism hypothesis.

To sum up, our results clearly support a reasoning-based approach to tool use by highlighting, for the first time, the role of technical reasoning in tool visual exploration. As we discussed before, an important limitation of the mainstream embodied approach is that it might induce us to under-intellectualise the cognitive bases of human tool use, thereby leading us to pay attention mainly to the manipulative component (Osiurak et al., 2020). This limitation is not specific to the cognitive science literature and can also be found in other domains such as in archaeology or anthropology (for discussion, see Osiurak & Reynaud, 2019). In contrast, it has been repeatedly shown that people may focus on the goal component of the action more than on its manipulative component (e.g., Massen & Prinz, 2007; Osiurak & Badets, 2014). This pattern has also been found in observational studies in which participants looked at a model using a tool (e.g., Decroix & Kalénine, 2018, 2019; Naish, Reader, Houston-Price, Bremner, & Holmes, 2013; Nicholson, Roser, & Bach, 2017; van Elk, van Schie, & Bekkering, 2008). Interestingly, the goal component explored in those different studies generally refers to the mechanical action involving the functional part of the tool and its associated object. Nevertheless, the results are frequently interpreted within the embodied-cognition framework, perhaps because of the absence of an alternative comprehensive framework. In this context, the technical-reasoning framework, as well as relevant associated concepts as the action reappraisal idea (Federico & Brandimonte, 2019,

2020), might be useful to generate alternative predictions, which can be tested against those of the embodied cognition account, as in the present study. Hopefully, this line of research might help open new avenues toward a better understanding of the neurocognitive bases of human tool use (i.e., “technition”; Osiurak et al., 2020).

5. Conclusion

Tool use is a fundamental characteristic of human beings. Current theories of human tool use can be divided into two contrasting approaches: mainstream “manipulation-based” theories which, by echoing the embodied-cognition account, consider tool use as deriving from past sensorimotor experiences, and “reasoning-based” theories, which explain tool use as an instance of problem-solving situations based on technical reasoning. Our study provides answers related to the crucial role of a non-declarative form of knowledge that contains abstract information about mechanical actions attainable by tools and objects (i.e., mechanical knowledge) in the elaboration of the causal relationship between tools and goal achievement. In particular, by analysing the visual-attentional patterns associated with object-tool pairs, we found that participants focused on the tool’s manipulation area under thematically-consistent conditions. Crucially, when tools appeared electrified or when the visuo-perceptual context was not action-prompting (i.e., thematically-inconsistent conditions), the tools’ functional areas were fixated longer than the tools’ manipulation areas, regardless of the presence of electricity. The results presented here challenge the embodied cognition view and suggest that a reasoning-based approach may lead to a better understanding of the mechanisms at the roots of human tool use.

Declarations

Funding:

No funding was received.

Conflict of Interest:

The authors declare that they have no conflict of interest.

Ethics approval:

This study was performed in line with the principles of the Declaration of Helsinki.
The Ethics Committee of the Suor Orsola Benincasa University approved the study.

Consent to participate:

Informed consent was obtained from all individual participants included in the study.

Consent for publication:

Not applicable.

Data availability:

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Code availability:

Software code and scripts are available on reasonable request to the corresponding author.

Authors' contributions:

G. Federico and M. A. Brandimonte conceived and designed the study and the experiment. G. Federico developed the experimental software, conducted the experiment, analysed the data, prepared the figures, and wrote the paper. M. A. Brandimonte and F. Osiurak revised the manuscript and provided critical comments and theoretical contribution. All authors approved the final version of the manuscript for submission.

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		Areas of Interest (Mean Fixation Time - mean and SD)	
		<i>Manipulation AOI</i>	<i>Functional AOI</i>
Thematically-consistent object-tool pairs	<i>Electrified</i>	86ms (89)	389ms (221)
	<i>Not electrified</i>	320ms (186)	214ms (115)
Thematically-inconsistent object-tool pairs	<i>Electrified</i>	85ms (100)	403ms (165)
	<i>Not electrified</i>	85ms (88)	437ms (149)

Table 1: Tool's Manipulation and Functional AOIs: Mean Fixation Time

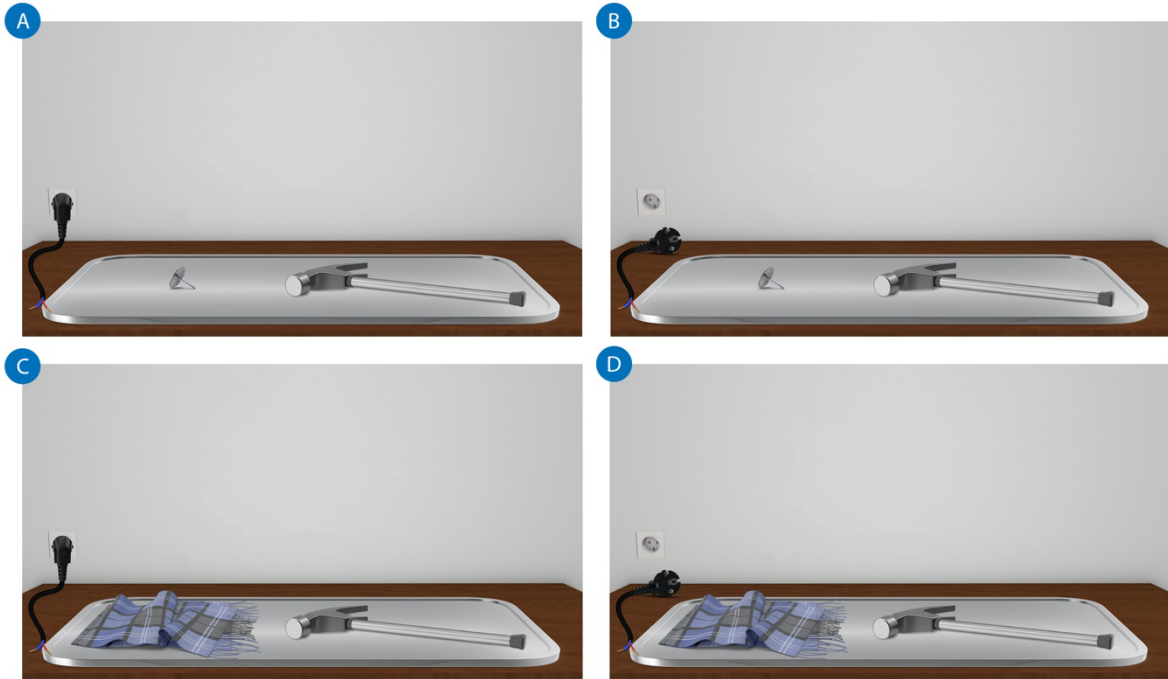


Figure 1: Example of stimuli used in the experiment

- (A) Electrified, thematically-consistent, object-tool pair (nail – steel hammer).
- (B) Non-electrified, thematically-consistent, object-tool pair (nail – steel hammer).
- (C) Electrified, thematically-inconsistent, object-tool pair (scarf – steel hammer).
- (D) Non-electrified, thematically-inconsistent, object-tool pair (scarf – steel hammer).



Figure 2: Experimental flow

A fixation point appeared for 500ms before each trial, then an object-tool pair appeared for 5000ms. Such a pair could be electrified or not, thematically consistent or not. Every pair was followed by a black screen that appeared for 4000ms to permit retina relaxation.

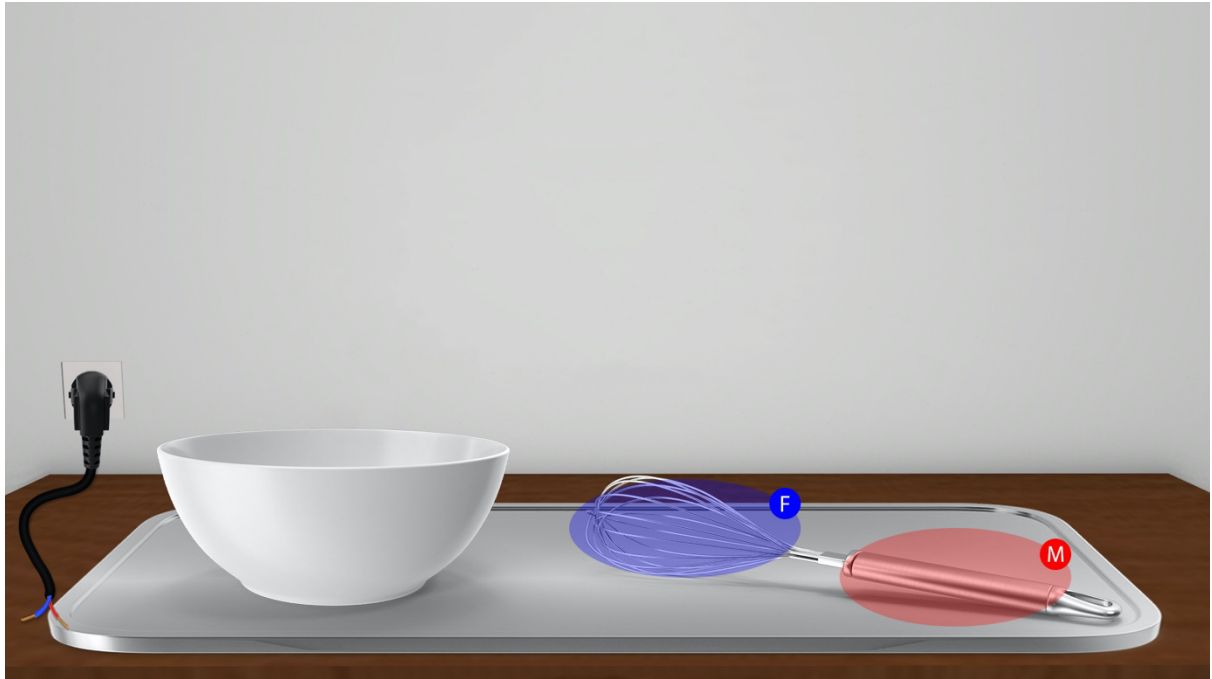


Figure 3: Areas of Interest analysed in the experiment

The AOIs analysed in the experiment were the functional area (highlighted in blue, labelled as “F”) and the manipulation area (highlighted in red, labelled as “M”) of the tool.

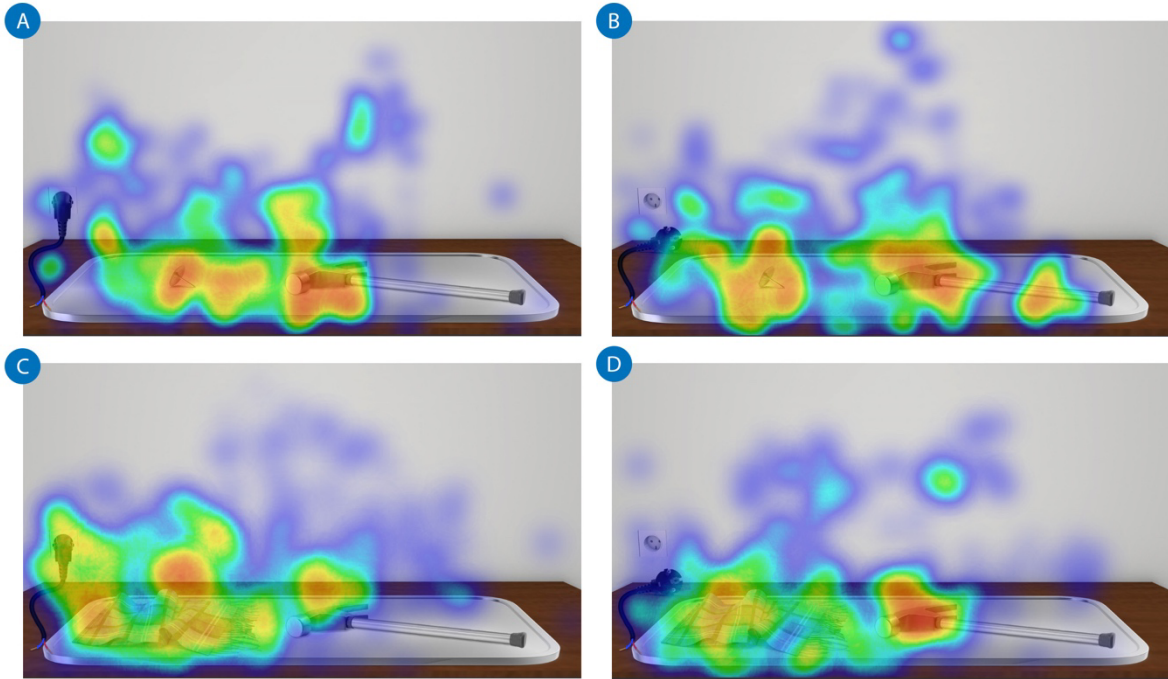


Figure 4: Visual-scene exploration heatmaps

Examples of heatmaps associated with the way participants explored the visual scene.

(A) A heatmap of an electrified, thematically-consistent, object-tool pair (nail – steel hammer).

(B) A heatmap of a non-electrified, thematically-consistent, object-tool pair (nail – steel hammer).

(C) A heatmap of an electrified, thematically-inconsistent, object-tool pair (scarf – steel hammer).

(D) A heatmap of a non-electrified, thematically-inconsistent, object-tool pair (scarf – steel hammer).

The time window of the eye-tracking analysis for (A), (B), (C), (D) was 2000ms.

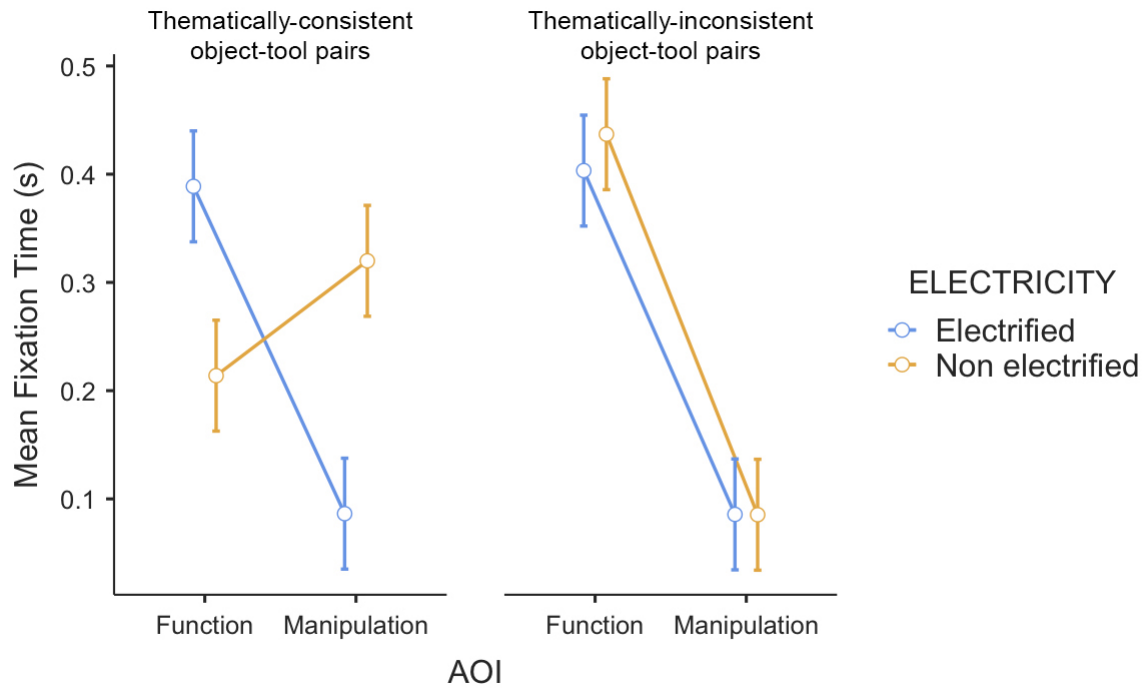


Figure 5: Visual exploration of the tools

Three-way interaction between AOIs, Thematic Consistency and Electricity. When object-tool pairs were thematically consistent, but not electrified, the tool's manipulation area was fixated longer than the tool's functional area. Crucially, when objects were electrified, an inverse visual-attentional pattern was registered, with the tool's functional area fixated longer than the tool's manipulation area. Analogously, fixation of the functional area was longer when object-tool pairs were thematically inconsistent, irrespective of the presence of electricity. Vertical bars denote .95 confidence intervals.