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1 **GRIP SELECTION WITHOUT TOOL KNOWLEDGE: END-STATE**

2 **COMFORT EFFECT IN FAMILIAR AND NOVEL TOOL USE**

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## **ABSTRACT**

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A well-known phenomenon for the study of movement planning is the end-state comfort (ESC) effect: When they reach and grasp tools, individuals tend to adopt uncomfortable initial hand postures if that allows a subsequent comfortable final posture. In the context of tool use, this effect is modulated by tool orientation, task goal, and cooperation. However, the cognitive bases of the ESC effect remain unclear. The goal of this study was to determine the contribution of semantic tool knowledge and technical reasoning to movement planning, by testing whether the ESC effect typically observed with familiar tools would also be observed with novel tools. Twenty-six participants were asked to reach and grasp familiar and novel tools under varying conditions (i.e., tool's handle downward vs. upward; tool transport vs. use; solo vs. cooperation). In our findings, the effects of tool orientation, task goal and cooperation were replicated with novel tools. It follows that semantic tool knowledge is not critical for the ESC effect to occur. In fact, we found an "habitual" effect: Participant adopted uncomfortable grips with familiar tools even when it was not necessary (i.e., to transport them), probably because of the interference of habitual movement programming with actual movement programming. A cognitive view of movement planning is proposed, according to which goal comprehension (1) may rely on semantic tool knowledge, technical reasoning, and/or social skills, (2) defines end-state configuration, which in turn (3) calibrates beginning-state comfort and hence the occurrence of the ESC effect.

43      **KEYWORDS**

44      **Keywords:** *End-state comfort; Joint action; Motor planning; Movement planning; Tool use;*

45      *Semantic memory; Technical reasoning*

## 46 **1. INTRODUCTION**

47 Humans and animals perform thousands of goal-directed actions each day. These actions  
48 range from simple motor acts (e.g., grasping a coffee cup) to complex tool use actions and  
49 problem solving tasks (e.g., cooking, handiwork). They may also be very familiar (e.g., using  
50 a pen to write) or novel (e.g., using a pen as a blowpipe), and be performed alone or together  
51 with peers (e.g., imagine a surgeon and their assistant). Despite the virtually infinite number of  
52 possible task goals and motor activation patterns at a given moment, healthy individuals gener-  
53 ally demonstrate accurate movements (Wolpert & Ghahramani, 2000). This raises a critical  
54 issue in the field of motor cognition, namely, how higher-order cognitive processes may con-  
55 tribute to movement planning to allow efficient and straightforward reach-to-grasp movements  
56 (e.g., Cisek, 2007; Cisek & Kalaska, 2010; Rosenbaum et al., 2012). Movement planning de-  
57 pends on biomechanical constraints (e.g., possible or impossible joint angles, muscle synergies,  
58 movement speed and precision) and contextual cues, like tool orientation in the reaching space  
59 (Rosenbaum et al., 2012; Rosenbaum & Jorgensen, 1992), task goal (i.e., tool transport versus  
60 tool use; Grafton & de C. Hamilton, 2007; Osiurak et al., 2008; Randerath, 2011; Randerath et  
61 al., 2009), and cooperation (e.g., Gonzalez, 2011). However, reaching and grasping studies fo-  
62 cusing on tool use have investigated these parameters only in the context of familiar tool use,  
63 which prevents drawing firm conclusions regarding the contribution of semantic tool  
64 knowledge to movement planning. While neuropsychological, tool use studies have put more  
65 and more focus on the human ability to use novel tools (Baumard et al., 2016; Goldenberg &  
66 Hagmann, 1998; Hartmann et al., 2005; Hodges, 2000; Jarry et al., 2013), little is known as to  
67 how tool novelty impacts reaching and grasping movements. The aim of this study was to fill  
68 this gap by [testing how using either familiar or novel tools may impact grasp selection \(i.e., the](#)  
69 [presence/absence of the end-state comfort effect, see below\).](#)

70 *1.1. THE END-STATE COMFORT EFFECT*

71 Movement planning can be studied through the end-state comfort (ESC) effect. Rosen-  
72 baum and colleagues (1992, 2012) have demonstrated that when participants are asked to grasp  
73 an object using pronation/supination movements, they tend to avoid extreme joint angles, prob-  
74 ably because those are costly for the motor system (see also Modersitzki & Studenka, 2020).  
75 Authors report that individuals tend to adopt uncomfortable initial hand postures (e.g., grasping  
76 the handle of a coffee cup with a supination movement, the thumb at 6 o'clock), if that allows  
77 a subsequent comfortable final posture (e.g., dropping the cup with the thumb at 12 o'clock;  
78 Rosenbaum et al., 1990). This finding has been largely replicated with slightly different para-  
79 digms (Cohen & Rosenbaum, 2004; Rosenbaum et al., 1996; Short & Cauraugh, 1999; Weigelt  
80 et al., 2006), suggesting that the selection of initial posture during reach-to-grasp movements  
81 relies on a cost-benefit analysis that takes into account biomechanical constraints as well as  
82 spatial and temporal parameters of the forthcoming action.

83 In the ESC effect paradigm, the initial grip depends on three parameters of interest for the  
84 present study: Tool orientation, task goal, and cooperation. Task goal is critical for the ESC  
85 effect to occur. Indeed, dissociations have been documented between tool transport (i.e., a clas-  
86 sical pick-and-place task in which participants are asked to move a tool from one location to  
87 another), and tool use (i.e., demonstrating the conventional use of the tool): Individuals demon-  
88 strate uncomfortable initial postures more often in the use condition than in the transport con-  
89 dition when the handle of the tool is oriented upward, which corresponds to the classical ESC  
90 effect (Osiurak et al., 2008; Randerath et al., 2009). In other words, the intention of the actor  
91 (i.e., task goal) is used by internal models to constrain initial grip selection. Furthermore, tool  
92 orientation and task goal interact. When the handle of the tool is oriented away from a partici-  
93 pant, she/he has to adopt an uncomfortable initial grip to make the subsequent tool use action  
94 more comfortable, however, this effect vanishes when the tool has to be merely transported or

95 when the handle of the tool is oriented toward the participant (e.g., Randerath et al., 2009). So,  
96 when individuals are asked to grasp and use tools, presenting tools with the handle oriented  
97 upward or away from the participant increases the number of initial, uncomfortable grips. Fi-  
98 nally, a growing body of literature has suggested that social interaction modulates movement  
99 planning. Cooperation paradigms have been found to modulate the ESC effect (Dignath & Eder,  
100 2013; Herbort et al., 2012). In a cooperative context, individuals maximize the confederates'  
101 biomechanical comfort by passing them the tools in a manner that minimizes subsequent tool  
102 manipulation (see “joint ESC effect”; Dötsch & Schubö, 2015; Gonzalez, 2011; Hommel &  
103 Colzato, 2009; Meyer et al., 2013; Ray & Welsh, 2011). These studies have demonstrated that  
104 individuals can integrate the goal of others in cost-benefit computations underlying movement  
105 planning.

## 106 *1.2. FAMILIAR VERSUS NOVEL TOOL USE*

107 The use of familiar tools in activities of daily living relies on semantic tool knowledge,  
108 the role of which is to inform individuals on the canonical function of tools (e.g., knowing that  
109 the function of a blender is to mix food; Roy & Square, 1985; Stamenova et al., 2012). Neuro-  
110 psychological studies have indeed shown that patients with severe semantic loss demonstrate  
111 abnormal use of familiar tools (Baumard et al., 2016; Bozeat et al., 2002; Hodges, 2000; Hodges  
112 et al., 1999).

113 However, a considerable body of neuropsychological evidence has demonstrated that se-  
114 mantic tool knowledge is neither necessary nor sufficient to use tools. For instance, patients  
115 who demonstrate impairments in the use of familiar tools may also have difficulties in novel  
116 tool use tasks (Baumard et al., 2014; Goldenberg & Hagmann, 1998; Jarry et al., 2013). In the  
117 latter, patients are generally asked to use novel tools (i.e., tools for which participants do not  
118 have previous knowledge of a canonical function) to solve a mechanical puzzle (e.g., extracting  
119 a target from a transparent box, or selecting a tool to lift a cylinder; (Baumard et al., 2016;

120 Bozeat et al., 2002; Buchmann & Randerath, 2017; Goldenberg & Hagmann, 1998; Hodges,  
121 2000; Jarry et al., 2013; Ochipa et al., 1992). Patients with severe semantic loss may demon-  
122 strate normal novel tool use skills in these tests. This led to the conclusion that familiar tool use  
123 depends not only on semantic tool knowledge, but also on the ability to infer the function of  
124 tools and objects based on their mechanical properties and complementarity (e.g., understand-  
125 ing that a wooden stick is heavy and dense enough to write in the sand, but not to break a rock).  
126 This ability has been referred to as causal reasoning (Vaesen, 2012), structural inference (Gold-  
127 enberg & Hagmann, 1998), or technical reasoning skills (Osiurak, 2014; Osiurak et al., 2010,  
128 2011). For the sake of clarity, in the rest of the paper we shall refer only to the concept of  
129 “technical reasoning”.

130       Semantic tool knowledge and technical reasoning depend critically on the temporal and  
131 left parietal lobes, respectively (Buxbaum, 2017; Goldenberg & Spatt, 2009; Lesourd et al.,  
132 2021; Reynaud et al., 2016). They can be viewed as two complementary mechanisms underly-  
133 ing task goal comprehension during the completion of tool use tasks. Semantic tool knowledge  
134 has been proposed to underlie movement planning (Cisek, 2007; Cisek & Kalaska, 2010). As a  
135 matter of fact, the ESC effect has been consistently demonstrated with familiar tools. Never-  
136 theless, there has been contradictory evidence as to the role of semantic tool knowledge in the  
137 occurrence of the ESC effect. Creem and Proffitt (2001) have found that a semantic interference  
138 task, but not a visual-spatial task, interfered with the ESC effect, suggesting that movement  
139 planning relies partly on semantic memory. The ESC effect has however been demonstrated  
140 with unfamiliar devices (e.g., transporting or rotating a dowel; Rosenbaum et al., 1992). Re-  
141 cently, Benson and colleagues (2018) observed the same ESC effect with a dowel and with a  
142 familiar tool. In fact, there has not been direct evidence that the ESC effect depends on semantic  
143 tool knowledge because there has not been direct comparison of this effect with familiar and

144 novel tool use tasks. As a result, the potential contribution of technical reasoning to movement  
145 planning remains an open issue.

### 146 *1.3. RATIONALE OF THE PRESENT EXPERIMENT*

147 The ESC effect has been demonstrated with handling objects that are not obviously tools  
148 (e.g., bars, dials), meaning that semantic knowledge is not necessary for the ESC effect to occur.  
149 When it comes to tools, however, some cognitive mechanisms may contribute to the ESC effect,  
150 as the presentation of tools may activate semantic tool knowledge, and their use may call for  
151 technical reasoning. While effects of tool orientation, task goal, and cooperation have been  
152 demonstrated with familiar tools, it is not known whether these effects are dependent or inde-  
153 pendent of semantic tool knowledge. The contribution of technical reasoning to movement  
154 planning is also an open issue. The goal of this study was therefore to determine the contribution  
155 of semantic tool knowledge and technical reasoning to what may be called the “tool-related  
156 ESC effect”, by testing whether the ESC effect typically observed with familiar tools would  
157 also be observed with novel tools. If the ESC effect depends on semantic tool knowledge, then  
158 it should be observed with familiar tools, but not with novel tools. On the contrary, documenting  
159 the ESC effect with novel tools would suggest that technical reasoning contributes to movement  
160 planning.

161 Three main effects were expected. First, when asked to use the tools, participants were  
162 expected to select more uncomfortable initial grips when tools were presented with the handle  
163 pointing upward, than when they were presented with the handle pointing downward. Second,  
164 a task effect was expected, i.e., more uncomfortable initial grips in a use condition than in a  
165 transport condition. Third, an effect of cooperation (i.e., joint ESC effect) would be demon-  
166 strated by a reversal of the classical ESC effect during joint action, i.e., more uncomfortable  
167 initial grips in a USE condition when the handle of the tool is oriented downward, and less

168 when the handle is oriented upward – because this maximizes the peer’s biomechanical com-  
169 fort.

## 170 **2. MATERIALS AND METHODS**

### 171 *2.1. PARTICIPANTS*

172 Thirty right handed participants, naïve to the objective of the experiment, volunteered to  
173 participate in the study (examples of comparable sample sizes can be found in Logan &  
174 Fischman, 2015; Löhr-Limpens et al., 2022; Modersitzki & Studenka, 2020; Scharoun et al.,  
175 2018). Participants were recruited among students or their relatives. They were not rewarded  
176 for their participation. They had normal or corrected-to-normal visual acuity. Handedness was  
177 self-reported by the participants. Three participants were excluded because the selection  
178 interview revealed they had history of neurological disease (e.g., multiple sclerosis, traumatic  
179 brain injury), and the data of one participant were lost because of video recording failure. The  
180 final sample was composed of 26 participants [20 females,  $M = 28.8$  ( $SD = 11.5$ ) years old,  $M$   
181  $= 13.6$  ( $SD = 1.9$ ) years of education). All participants gave informed written consent.

### 182 *2.2. APPARATUS AND MATERIAL*

183 Participants were presented with 8 familiar tools (i.e., nutcracker, bottle-opener, stapler,  
184 knife, hammer, wrench, screwdriver, vegetable peeler) and 8 corresponding, familiar objects  
185 (i.e., nut, bottle, two sheets of paper, a carrot, a nail partially driven into a wooden board, a nut  
186 partially screwed onto an axis, a screw partially driven into a woodenboard, and a potato). The  
187 tools and objects were very common and it was assumed that all participants already knew their  
188 names and functions. The tools were presented one at a time on a wooden, vertical panel (75  
189 cm high) positioned 30 cm away from the participant, on her/his right side (Figure 1).  
190 Participants reached and grasped the tools with their right hand.

191 Participants were also presented with 6 novel tools composed of a handle (i.e., a section  
192 of a wooden broom handle) and two “active” parts (one at each end of the handle; see Figure  
193 1). There were fewer novel than familiar tools due to the cost and complexity of designing new  
194 tools and problems. With these novel tools, participants were asked to solve original mechanical  
195 problems inspired by the ones already described in the apraxia literature (Baumard et al., 2016;  
196 Goldenberg & Hagmann, 1998; Jarry et al., 2013; Ochipa et al., 1992). One tool-problem pair  
197 served as an example item to ensure comprehension of task goal. Participants were instructed  
198 to use the novel tool to remove a ball from its base (Example problem, problem 1), to rotate a  
199 cylinder (problem 2), or to extract a cube, cylinder, or ball out of the box (problems 3, 4, 5,  
200 respectively; see Figure 1). The examiner explicitly stated the goal of the task to make this test  
201 comparable to familiar tool use (e.g., “extract the bead out of the box”). Only one of the two  
202 active parts of the novel tools allowed to solve each problem, so that participants had to infer  
203 which part of the tool was relevant for the task. Indeed, novel tools with only one active part  
204 would have been very similar to familiar tools and could have elicited specific grasps just  
205 because most tools with a handle and one active part are generally grasped in the same way  
206 (e.g., a hammer and a knife are grasped with the thumb pointing toward the active part). So,  
207 this design ensured that movement planning would be based on the analysis of tool-problem  
208 complementarity (i.e., technical reasoning).

### 209 2.3. *DESIGN AND PROCEDURE*

210 There were two main conditions: “Familiar tools”, and “Novel tools”. Each of these  
211 conditions was subdivided into three factors: “Tool orientation” (i.e., handle pointing either  
212 upward or downward), and “Task” (i.e., Transporting the tool from one location to another vs.  
213 Using the tool with the corresponding object), and “Interaction” (i.e., performing the action solo  
214 vs. together with the examiner) conditions. The conditions formed a 13 Tool (8 familiar, 5  
215 novel) × 2 Orientation (upward, downward) × 2 Task (transport, use) × 2 Interaction (solo,

216 coop) × 2 Trials (i.e., each condition was repeated twice in a row) design. As regards to tool  
217 orientation, the tools were presented on the vertical panel with the handle pointing upward in  
218 half of the items, and downward in the other half. The examiner then instructed the participants  
219 to either transport them to drop it on a target zone (i.e., a green sheet of paper of 210 x 297 mm  
220 or 8.3 x 11.7 inches; Transport-Solo conditions), use them with a target object/problem (Use-  
221 Solo conditions), or give them to her so that she could put them on the target zone (Transport-  
222 Coop condition) or use them with the object or problem “as quickly and efficiently as possible”  
223 (Use-Coop condition; see Gonzalez, 2011 for similar instructions). In the coop conditions, the  
224 examiner sat in front of the participant with the target on her right side (i.e., either a sheet of  
225 paper for the transport condition, or the familiar object or problem for the use condition), and  
226 participants gave her the tools for her to perform the action. The same design was applied for  
227 both familiar and novel tools, with one exception: There was no “Transport-Coop” condition  
228 with novel tools because there was no prediction relating to this condition.

229 As a result, the sequence of conditions was as follows: Familiar tool transport (solo),  
230 Novel tool transport (solo), Familiar tool use (solo), Novel tool use (solo), Familiar tool use  
231 (coop), Novel tool use (coop). Familiar tools were presented before novel tools to ensure that  
232 participants would understand the basics of the task before continuing with more complex  
233 problem-solving tasks. Transport conditions were presented before use conditions to avoid  
234 proactive interference: [Since tool use is known to yield more uncomfortable initial grips than](#)  
235 [tool transport, testing “use” before “transport” might have resulted in an unexpectedly high](#)  
236 [number of uncomfortable initial postures in the “transport” condition \(because participants](#)  
237 [might have kept using the same planning strategy as in the “use” condition\).](#) The order of  
238 conditions was fixed, given the high number of conditions. Within each condition, the tools  
239 were presented four times in a blocked fashion based on tool orientation. As a result, there were  
240 32 items in the familiar tools conditions (i.e., 8 familiar tools x 2 orientations x 2 trials) divided

241 into four blocks (Block 1, handle oriented downward; Block 2, handle oriented upward; Block  
242 3 and 4 were repetitions of blocks 1 and 2). Likewise, the novel tools were presented with the  
243 useless active part (i.e., the part of the tool that was not relevant to solve the problem) oriented  
244 either downward or upward and there were 20 items in the novel tools conditions (i.e., 5 novel  
245 tools  $\times$  2 orientations  $\times$  2 trials). Within each block, the tools were presented in a pseudorandom  
246 sequence.

#### 247 2.4. DATA ANALYSIS

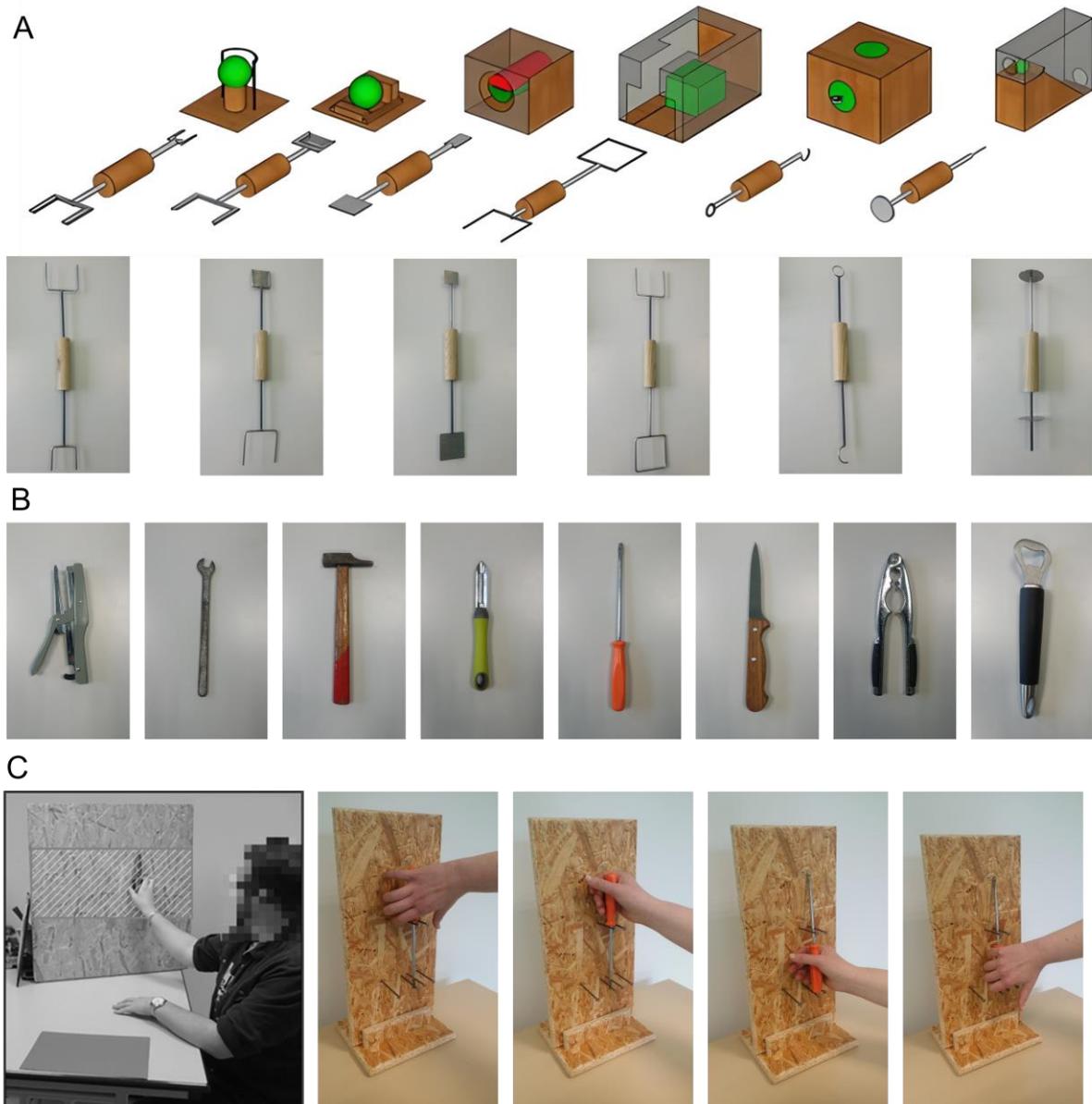
248 Initial grips were later coded based on the video recordings. Grips were judged  
249 “uncomfortable” when the participant grasped the tool with the thumb pointing at 6 o’clock.  
250 They were considered “comfortable” in the absence of supination movement, when the thumb  
251 pointed at 12 o’clock (Figure 1). The final score was the number of uncomfortable initial grips  
252 for each condition, converted into percentage to allow comparison between conditions. Four  
253 naïve judges as well as the examiner coded 52 trials from three video sequences of 8 to 12  
254 minutes, corresponding to three randomly selected conditions: Novel tool transport (Solo),  
255 Familiar tool use (Solo), and Familiar tool use (Coop). The four naïve judges agreed with the  
256 examiner on 92% of trials, and 3 judges (the majority) agreed with the examiner on the  
257 remaining 8% trials – there were no 50/50 situations. The percentage of agreement (i.e., the  
258 number of judgeX/judgeY agreements, out of the total number of judge/judge comparisons)  
259 was 99.2%. The judges did not meet to discuss imperfect agreement. The average examiner-  
260 judge correlation value was high (Spearman rank order correlations,  $r = 0.94$ , all  $ps < .01$ ).

#### 261 2.5. STATISTICAL ANALYSIS

262 Non-parametric statistical analyses were preferred based on the sample size and because  
263 the data were not normally distributed (Shapiro tests). [Interaction effects were tested with](#)  
264 [Aligned Ranks Transformation ANOVA](#). Wilcoxon tests were used for between-task  
265 comparisons. Effect size was calculated with Cliff’s delta. P values were adjusted with Holm’s

266 correction to control for the risk of type I error due to multiple comparisons. A “tendency toward  
267 significance” was accepted if p-value was no longer significant after applying the correction.

268



269 **Figure 1. Materials and setup.** Upper panel (A): Novel tools and problems used in the experiment. The first tool-  
270 problem pair to the left is an example item, which goal was to lift the ball. In experimental problems, the goal was  
271 to lift the ball (problem 1), to turn the cylinder (problem 2), to pull the green target (problems 3, 4), and to push  
272 the green ball (problem 5). Only one end of each novel tool was useful to solve the problem. Middle panel (B):  
273 Familiar tools used in the experiment (stapler, wrench, hammer, vegetable peeler, screwdriver, knife, nutcracker,  
274 bottle-opener). Lower panel (C): Tools were displayed on a vertical panel, within the hatched area. Examples of  
275 comfortable (i.e., thumb at 12 o'clock) and uncomfortable grips (i.e., thumb at 6 o'clock), and tool orientation  
276 (handle downward, handle upward).  
277

### 278 3. RESULTS

279        *3.1. EFFECT OF TOOL ORIENTATION*

280        The effect of tool orientation (i.e., handle oriented either downward or upward) in the  
281 USE condition reflects the influence of biomechanical constraints on grip selection, in that in-  
282 dividuals prefer to grasp tools with an uncomfortable initial grip to ensure a comfortable hand  
283 posture during tool use. There was a main effect of tool orientation in the USE condition with  
284 both familiar and novel tools (Figure 2). Block-by-block analysis of novel tool use (Figure 3)  
285 confirmed significant differences between block 1 and block 2 ( $W = 22.5, p < .001, \Delta = -0.73,$   
286 large), between block 2 and block 3 ( $W = 296.5, p = .002, \Delta = 0.61,$  large), and between block  
287 3 and block 4 ( $W = 34.5, p = .001, \Delta = -0.69,$  large).

288        *3.2. EFFECT OF TASK GOAL*

289        The effect of task goal reflects how the end goal of the action (i.e., tool use vs. transport)  
290 constrains the motor system. The descriptive data are displayed in Figure 2. We conducted an  
291 Aligned Ranks Transformation ANOVA with factors “Task goal” (transport, use) and “Tool  
292 familiarity” (familiar, novel), while fixing other factors (handle upward, solo condition). It re-  
293 turned a main effect of task goal ( $F(1) = 22.1, p < .001$ ), but no main effect of tool familiarity  
294 ( $F(1) = 2.6, p = .10$ ) and no interaction effect ( $F(1) = 3.1, p = .08$ ). When the handle was oriented  
295 upward, there was a main effect of task with familiar tools ( $W = 14.0, p < .001, \Delta = -0.39,$   
296 medium) as well as with novel tools ( $W = 38.0, p = .002, \Delta = -0.53,$  large). We conducted the  
297 same ANOVA with the other tool orientation (handle downward). It returned a main effect of  
298 task goal ( $F(1) = 4.5, p = .035$ ), a main effect of tool familiarity ( $F(1) = 5.9, p = .016$ ), but no  
299 interaction effect ( $F(1) = 2.6, p = .11$ ). When the handle was oriented downward, there was a  
300 main effect of task with familiar tools ( $W = 158.0, p = .001, \Delta = 0.39,$  medium) but not with  
301 novel tools ( $W = 150.0, p = .09, \Delta = 0.09,$  negligible). To sum up, participants adopted uncom-  
302 fortable initial postures more frequently when they were instructed to use the tools, than when

303 they were instructed to transport them. This effect was significant mainly when the handle of  
304 the tool was oriented upward.

305 These findings were confirmed by the block-by-block analysis (Figure 3), as the effect of  
306 tool orientation was significant for tool use (see statistics in section 3.1), but not for tool  
307 transport. The effect of task goal was consistent across different familiar and novel tools (Sup-  
308 plementary Table 3). The ESC effect (i.e., more initial uncomfortable postures in the USE than  
309 in the TRANSPORT condition when the handle is oriented upward) was relatively consistent  
310 across participants, whether with familiar or novel tools (Supplementary Figure 1). A minority  
311 of participants (2 or 3) showed a pattern of performance almost orthogonal to the one of the  
312 group, perhaps due to individual strategies or biomechanical specificities.

### 313 3.3. *EFFECT OF COOPERATION*

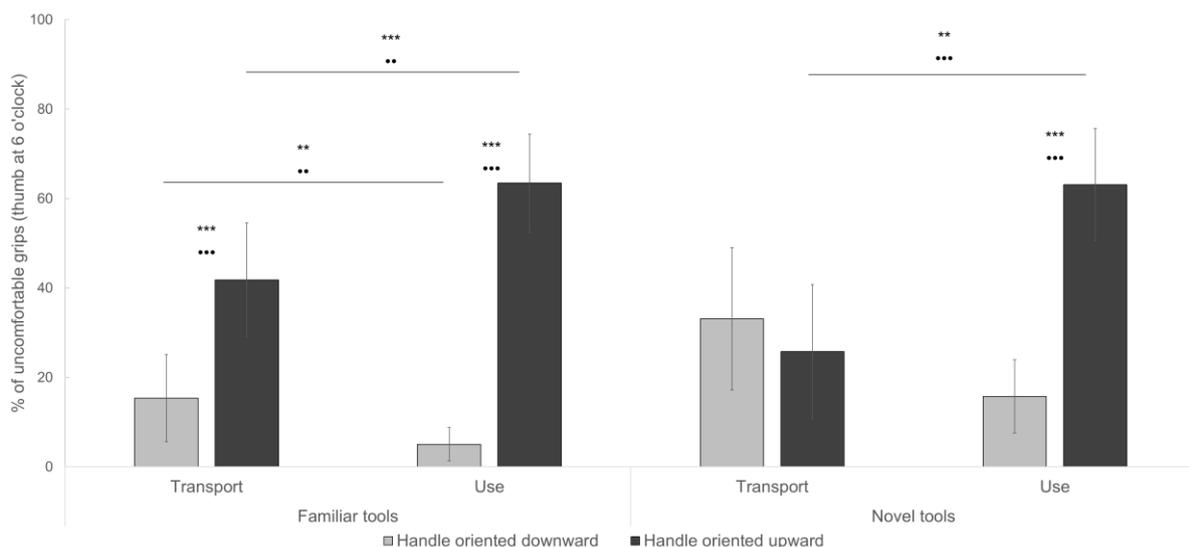
314 The effect of cooperation on grip selection can be demonstrated by a reversal of the ESC  
315 effect in the cooperation condition, compared to the solo condition. Namely, participants tend  
316 to grasp familiar tools upside down to pass them in a manner that allows confederates to have  
317 beginning state comfort, specifically when using (but not transporting) tools. The results con-  
318 firmed this prediction with both familiar and novel tools (Figure 4). In the familiar tool use  
319 condition, there was a significant Solo/Coop action difference for both tool orientations (handle  
320 downward:  $W = 0.0$ ,  $p < .001$ ,  $\Delta = -0.69$ , large; handle upward:  $W = 329.0$ ,  $p < .001$ ,  $\Delta = 0.71$ ,  
321 large). The same was found regarding novel tool use (handle downward:  $W = 56.0$ ,  $p = .088$ ,  
322 tendency,  $\Delta = -0.30$ , small; handle upward:  $W = 273.0$ ,  $p = .001$ ,  $\Delta = 0.71$ , large). So, cooper-  
323 ation induced a shift in grip selection with both familiar and novel tools.

### 324 3.4. *FAMILIAR VERSUS NOVEL TOOLS*

325 All of the participants completed the novel problems perfectly. [In addition with the results](#)  
326 [of the ANOVA \(see section 3.2\)](#), we studied the effect of tool familiarity by comparing the  
327 same conditions with familiar and novel tools. In the solo condition first, there was an effect of

328 familiarity on movement planning in the tool transport condition, when the handle was oriented  
 329 upward ( $W = 225.0, p = .007, \Delta = 0.52$ , large), but not when the handle was oriented downward.  
 330 In other words, participants demonstrated initial uncomfortable postures with familiar tools  
 331 even when it did not serve any functional purpose (Figure 2). There was also an effect of famil-  
 332 iarity in the tool use condition, when the handle was oriented upward ( $W = 25.0, p = .004$ ), with  
 333 low effect size ( $\Delta = -0.32$ , small), but not when the handle was oriented downward. Finally, in  
 334 the coop condition (Figure 4), there was an effect of tool familiarity for both orientations (both  
 335  $ps < .05$ ), although with small to medium effect sizes.

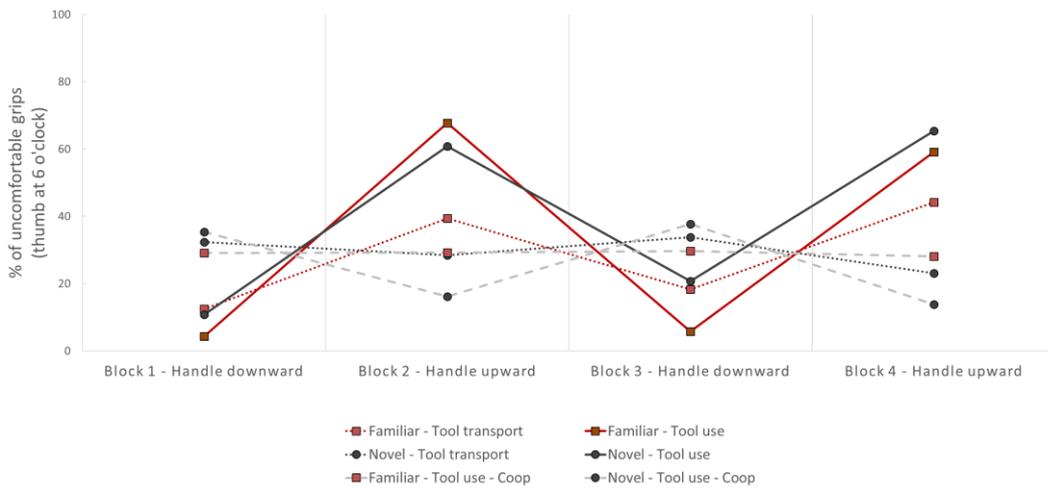
336 Since tool orientation was fixed within each block, the useful end of the novel tools al-  
 337 ways pointed in the same direction (upward, downward) within a given block. If participants  
 338 noticed it, they could use the same strategy across trials (e.g., if the useful end of the tool was  
 339 oriented downward in trial 1, then some participants could expect the same orientation in trials  
 340 2-5 of the same block). If this is correct, then participants should improve across trials within a  
 341 given block. So, we compared the mean number of uncomfortable initial grips on trials 1-2 and  
 342 trials 4-5 of the same block, for each of the 4 blocks in the novel tool use condition. The mean  
 343 difference was -1 uncomfortable initial grips (sd 2.7 uncomfortable initial grips), suggesting  
 344 there was only a limited learning effect (see Supplementary Tables 1 and 2).



345

346 **Figure 2. Effects of tool orientation and task goal on grip selection (solo conditions only).** Bars indicate mean  
 347 values, vertical lines indicate 95% confidence intervals. Between-task differences were significant with \*\*  $p < .01$ ,  
 348 \*\*\*  $p < .001$ . Effect size was •• medium to ••• large.

349



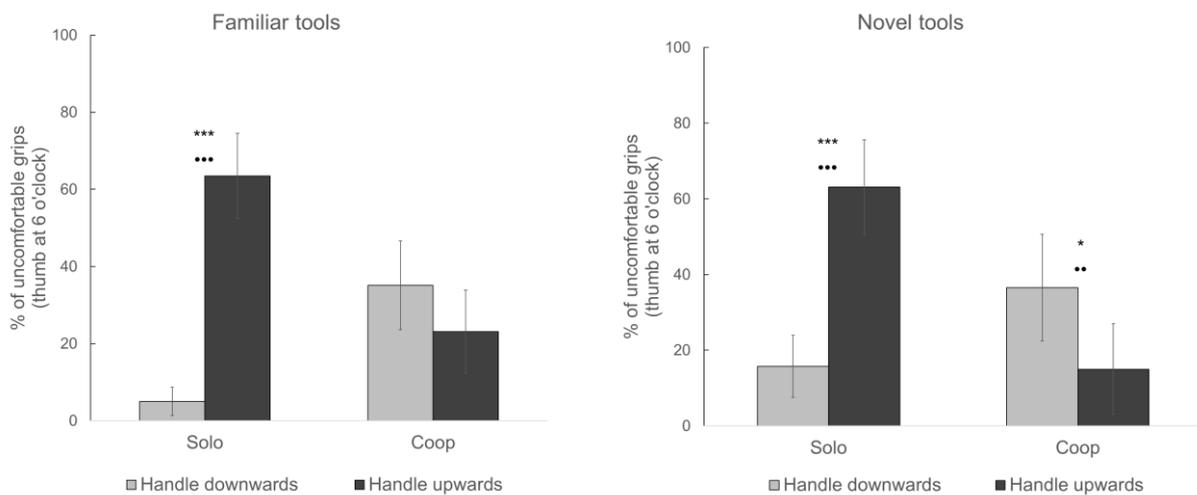
350

351 **Figure 3. Block-by-block analysis of tool orientation and task effects (Solo conditions only).** Values  
 352 correspond to mean values. Statistics can be found in the text.

353

354

355



356

357 **Figure 4. Effect of cooperation on the ESC effect (tool use only).** Bars indicate mean values, vertical lines  
358 indicate 95% confidence intervals. Solo/Coop statistical comparisons are given in the text.

## 359 **4. DISCUSSION**

360 The goal of this study was to test whether classical ESC effects typically observed with  
361 familiar tools, would be observed in the context of novel tool use, in order to test the  
362 contribution of semantic tool knowledge and technical reasoning to movement planning. The  
363 rationale was that, if semantic tool knowledge plays a critical role in planning, then ESC effects  
364 should vanish with novel tools. Conversely, the observation of ESC effects with novel tools  
365 would demonstrate a potential role of technical reasoning in motor preparation. Our findings  
366 supported the second hypothesis in that similar effects were found in both familiar and novel  
367 tool use. It follows that tool familiarity, and hence semantic tool knowledge, is not critical for  
368 the ESC effect to occur. Importantly, the novel tools were two-ended and only one of the two  
369 active parts was useful to solve the problems, so that participants had to analyze which end of  
370 the tool was useful for the subsequent use action. Grip selection, therefore, had to be based on  
371 the analysis of tool/object complementarity, presumably thanks to technical reasoning. In the  
372 following sections we discuss how semantic tool knowledge, technical reasoning, but also  
373 social skills, may contribute to movement planning.

### 374 *4.1. THE RELATIVE CONTRIBUTION OF SEMANTIC TOOL KNOWLEDGE AND* 375 *TECHNICAL REASONING TO MOVEMENT PLANNING*

376 Considering the very similar results with familiar and novel tools, semantic tool  
377 knowledge did not seem to provide a clear-cut processing advantage. Actually, participants  
378 demonstrated an “habitual” pattern with familiar tools, namely, they adopted uncomfortable  
379 grips even when it was not necessary (i.e., in the Transport condition). This pattern has already  
380 been documented and proposed to reflect the influence of semantics on grip selection (Creem

381 & Proffitt, 2001; Randerath et al., 2009). It may also reflect the interference of habitual grasping  
382 strategies consisting of grasping tools the way they are usually grasped, with efficient, planned  
383 grasping strategies (Herbort & Butz, 2011; Jovanovic et al., 2022). It may also be interpreted  
384 as an effect of functional fixedness (Adamson, 1952; Duncker, 1945), i.e., the detrimental effect  
385 of prior learning, including tool knowledge, in novel settings (Munoz-Rubke et al., 2018). In  
386 the present study, participants probably adopted uncomfortable initial grips when transporting  
387 tools because the latter automatically elicited functional grips, namely, grips that are consistent  
388 with the canonical function of the tool (Buxbaum & Kalénine, 2010). Considering that the effect  
389 of habits was observed with familiar but not novel tools, semantic tool knowledge **probably**  
390 **biases grip selection when reaching and grasping familiar tools. However, adopting initial**  
391 **uncomfortable postures is not necessary to transport tools, because the end posture is not critical**  
392 **for task fulfillment (e.g., one may grasp a hammer upside down to transport it). In other words,**  
393 **semantic tool knowledge seems to constrain the motor system even when it does not serve any**  
394 **functional purpose.**

395         This is not to say that technical reasoning is the only cognitive mechanism that underlies  
396 grip selection. The ESC effect has actually been observed in bar transport or rotation paradigms  
397 that probably put little load on technical reasoning, and call for more straightforward predictions  
398 about the future state of the world (i.e., the final position of a dowel, rather than a specific tool-  
399 object interaction; Rosenbaum et al., 1992). It has also been documented in non-human primates  
400 (Chapman et al., 2010), while tool use skills call for different mental processes in humans and  
401 in animals (Vaesen, 2012). It means that the ability to use tools is not critical for the ESC effect.  
402 A critical issue to solve is, therefore, to understand how the ESC effect may occur in the context  
403 of novel tool use.

#### 404         4.2. *A COGNITIVE VIEW OF MOVEMENT PLANNING*

405           What is critical for the ESC effect to occur is the ability to predict the end of the  
406 movement; and in the context of user-tool interactions, what is critical to predict the end of the  
407 movement is the ability to predict the final action of the tool with the object. For example, if  
408 one wants to reach and grasp a knife to cut a piece of bread in a comfortable way, she/he has to  
409 imagine the forthcoming position of the knife on the bread (Osiurak & Badets, 2017). This has  
410 been demonstrated by task effects (Randerath et al., 2009) and replicated in the present study  
411 with novel tools (i.e., tool transport vs use). The idea that hand postures depend on the  
412 comprehension of tool-object interactions is also at the core of the “categorical apprehension  
413 hypothesis” (Goldenberg, 2009). According to this view, the parietal lobe codes a mechanical  
414 chain that configures both hand-tool and tool-object interactions simultaneously. In another  
415 account of action selection, Cisek (2007; Cisek & Kalaska, 2010) has proposed that the saliency  
416 of stimuli depends on the intention and needs of the actor, and that affordance selection relies  
417 not only on cost/benefit analysis, but also on any variable allowing to make the right choice.  
418 This includes both information about object identity associated with temporal lobe activity, and  
419 emotion and motivation associated with orbitofrontal activity. This view is not that different  
420 from Liepmann’s view on apraxia (Goldenberg, 2003), a neuropsychological impairment of  
421 action, for whom the formulation of movement emerged from the whole cerebral cortex and  
422 not only from primary motor areas. In line with these approaches, it is proposed that movement  
423 planning may be grounded on any mental process, provided that the latter allows individuals to  
424 anticipate the result of their user-tool and tool-object interactions in a near future. In this regard,  
425 semantic tool knowledge and, based on our findings, technical reasoning, may fulfil this role in  
426 humans (Figure 5).

427           Another key finding of the present work is the effect of cooperation in tool use situations,  
428 not only with familiar but also with novel tools. Although previous works have focused on how  
429 individuals handed the tool to peers (e.g., Gonzalez, 2011; Ray & Welsh, 2011), we focused on

430 initial grip selection because our goal was to find out how cooperation would modulate inverse  
431 internal models. We found a relative reversal of performance pattern between the Solo and  
432 Cooperation action conditions, meaning that individuals tended to sacrifice their own  
433 biomechanical comfort to maximize the one of the examiner. A critical issue is therefore to  
434 determine what cognitive processes allowed this adaptation of the internal models underlying  
435 the ESC effect, considering that semantic tool knowledge and technical reasoning cannot  
436 explain this phenomenon. Previous research has suggested that the future actions of others are  
437 implemented within internal predictive models (i.e., participants anticipate the confederate's  
438 intended tool-related actions; Gonzalez, 2011). It means, logically, that individuals need to be  
439 able to understand the tool-related actions of others. This may rely on the same cognitive  
440 mechanisms as those needed for individual performance, namely, technical reasoning and  
441 semantic tool knowledge (for a similar view, see Osiurak & Reynaud, 2020).

442         Another hypothesis would rather put the emphasis on the role of social skills. Previous  
443 research has put forward the role of the social meaning that objects carry with them (Schmidt,  
444 2007), but also the role of personality traits (Dötsch et al., 2021; see also Scharoun et al., 2018  
445 on the effect of gender). Similarly, infant studies have suggested that internal models may  
446 depend on both a “teleological stance” (i.e., the ability to make predictions on the physical  
447 world) and a “mentalist” stance (i.e., the ability to formulate hypotheses regarding the beliefs,  
448 desires, and intentions of peers; Gergely & Csibra, 2003). In this view, the joint ESC effect  
449 observed in the cooperation condition may depend not only on task goal comprehension, but  
450 also on mentalization to infer the expectations of others. Pending future studies to disentangle  
451 the relative contributions of both dimensions to the ESC effect, we make the assumption that  
452 goal comprehension (1) may rely on semantic tool knowledge, technical reasoning, and/or  
453 social skills, (2) defines end-state configuration, which in turn (3) calibrates beginning-state  
454 comfort and hence the occurrence of the ESC effect (Figure 5; see also Logan & Fischman,

455 2015, on the role of working memory). It should be noted that the model applies to the ESC  
456 effect in tool use situations specifically, and not to the ESC effect in general – as the latter has  
457 been described in humans and animals with bar rotation and bar transport tasks which involve  
458 only minimal cognitive processes. It is assumed that in the case of tool use situations, the system  
459 has to simulate the forthcoming tool-object interaction (e.g., the action of the hammer on the  
460 nail) to determine the action of the hand on the tool (i.e., the end and initial grasp; but see also  
461 Herbort et al., 2019, on the role of motor/mental simulation).

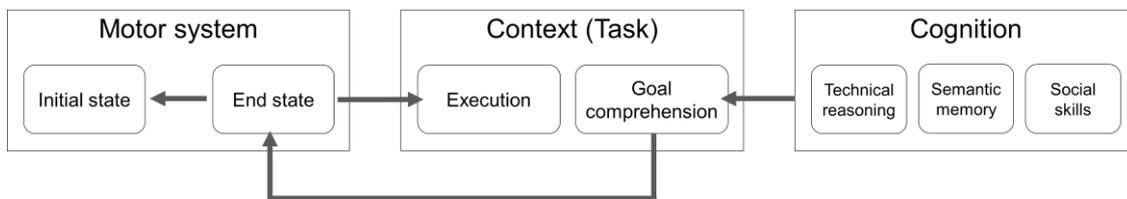
#### 462 4.3. *LIMITATIONS OF THE STUDY*

463 Since familiar tools were presented before novel ones, we cannot rule out an interference  
464 effect resulting in more frequent ESC effect than if the novel conditions had been presented in  
465 isolation. One may indeed assume that participants showed habitual movement planning in the  
466 novel tool use condition. It is, however, quite unlikely because if participants had adopted a  
467 “repetition” strategy, then they should have shown perseverative movements. Since the  
468 Transport condition preceded the Use condition, and the Self condition preceded the Joint action  
469 condition, we should have found similar results in the Transport and Use conditions on the one  
470 hand, and in the Self and Joint action conditions; yet we did observe different patterns. Between-  
471 block differences also rule out this hypothesis. If participants had merely repeated previous  
472 movements (e.g., thumb at 12 o’clock when the handle points downward, therefore thumb at  
473 12 o’clock when the handle points upward in the next block), then we should not have observed  
474 tool orientation effects. Taken together, these findings suggest that the ESC effects we observed  
475 were due to adaptive action selection, rather than to stereotypical movement repetition.

476 In addition, future works may better control for sex ratio (20/26 females in the present  
477 study); control for handedness with objective measures; test the effect of personal familiarity  
478 and prior experience with tools, rather than the effect of general, semantic tool knowledge;  
479 compare tool transport and tool use in cooperation paradigms; use a random design rather than

480 a block design to control for proactive interference effects and prevent participants from using  
481 grip selection strategies; and analyze the dynamics of initial-to-final configurations with  
482 kinematic analysis of pronation-supination movements as well as time measures. Also, the  
483 typical ESC effect is known to be a very fast motor response that does not rely on leisurely  
484 planning (Rosenbaum et al., 1992), yet we used complex tool use and problem-solving tasks, a  
485 modification of the classical paradigm that is probably not without consequences on motor  
486 programming and movement parameters.

487



488

489 **Figure 5. Indirect effect of cognition on the end-state comfort effect.** Cognitive processes help individuals  
490 comprehend the goal and means of their forthcoming actions, which is a prerequisite for anticipating the end state  
491 of the motor system during tool-related actions, and hence, the initial state of the movement.

492

## 493 **5. CONCLUSION**

494 The goal of this study was to test how semantic tool knowledge and technical reasoning  
495 contribute to the ESC effect. We replicated the ESC effect with familiar as well as with novel  
496 tools. Classical effects of task goal and cooperation were documented with novel tools for the  
497 first time. This suggests that semantic tool knowledge is neither necessary nor sufficient for the  
498 ESC effect to occur, as already suggested by studies using bar transport and bar rotation para-  
499 digms. That said, we documented a “habitual effect”, namely, participants adopted unnecessary,  
500 uncomfortable initial grips to transport familiar tools. This effect demonstrates that semantic  
501 tool knowledge does have an influence on grip selection and hence contributes to constrain the

502 motor system. As a result, a cognitive model of the ESC effect in the context of tool use is  
503 proposed, according to which cognitive dimensions, including semantic tool knowledge, tech-  
504 nical reasoning, but also social skills, contribute to determining task goal, which in turn strains  
505 the motor system and determines grip selection.

506

507

## **CONFLICT OF INTEREST STATEMENT**

508

The authors declare no conflict of interest.

509

510 **DATA AVAILABILITY STATEMENT**

511 The datasets generated during and/or analysed during the current study are available from  
512 the corresponding author on reasonable request.

513

514

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519

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