Acta Psychologica 190 (2018) 11–26

Contents lists available at ScienceDirect

Acta Psychologica

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

Functional fixedness in tool use: Learning modality, limitations and individual differences

Felipe Munoz-Rubke[a,b,c,*], Devon Olson[c,d], Russell Will[c,d], Karin H. James[b,c,d]

[a] Instituto de Psicología, Universidad Austral de Chile, Puerto Montt, Chile
[b] Cognitive Science Program, Indiana University, Bloomington, IN, USA
[c] Program in Neuroscience, Indiana University, Bloomington, IN, USA
[d] Department of Psychological and Brain Sciences, Indiana University, Bloomington, IN, USA

ARTICLE INFO

Keywords:
Tool use
Functional fixedness
Mechanical problem solving
Training
Active learning

ABSTRACT

Functional fixedness is a cognitive bias that describes how previous knowledge of a tool's function can negatively impact the use of this tool in novel contexts. As such, functional fixedness disturbs the use of tools during mechanical problem solving. Little is known about whether this bias emerges from different experiences with tools, whether it occurs regardless of problem difficulty, or whether there are protective factors against it. To resolve the first issue, we created five experimental groups: Reading (R), Video (V), Manual (M), No Functional Fixedness (NFF), and No Training (NT). The R group learned to use tools by reading a description of their use, the V group by watching an instructional video, and the M group through direct instruction and active manipulation of the tools. To resolve the remaining two issues, we created mechanical puzzles of distinct difficulty and used tests of intuitive physics, fine motor skills, and creativity.

Results showed that misleading functional knowledge is at the core of functional fixedness, and that this bias generates cognitive impasses in simple puzzles, but it does not play a role in higher difficulty problems. Additionally, intuitive physics and motor skills were protective factors against its emergence, but creativity did not influence it. Although functional fixedness leads to inaccurate problem solving, our results suggest that its effects are more limited than previously assumed.

1. Introduction

Humans use tools to solve problems and by doing so modify other objects, beings, and/or themselves (Baber, 2003). This behavior is the result of three interrelated components: functional, mechanical, and manipulation knowledge (Frey, 2007; Goldenberg, 2013).

Functional knowledge refers to information about how certain tools are associated with contexts, purposes, and other objects (Buxbaum, Veramontil, & Schwartz, 2000; Canessa et al., 2008; Goldenberg, 2013; Osiurak & Badets, 2016). For example, hammers are stored in tool boxes, are used for delivering blows to objects, and are usually associated with nails. Functional knowledge represents 'tool-centered' information because it focuses on the interaction between tools and objects to which they are related (Osiurak & Badets, 2016).

Human tool use is also influenced by the physical structure and composition of tools. **Mechanical knowledge** refers to our understanding of the physical principles that determine the interactions between tools and other objects (Battaglia, Hamrick, & Tenenbaum, 2013; Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Fischer, Mikhael, Tenenbaum, & Kanwisher, 2016; Goldenberg & Hagmann, 1998; Hegarty, 2004; Jarry et al., 2013; McCloskey, Washburn, & Felch, 1983; Osiurak et al., 2009; Zago & Lacquaniti, 2005). As such, it reflects an intuitive grasp of physics that, according to recent research, could operate as an 'intuitive physics engine' in the brain (Battaglia et al., 2013; Fischer et al., 2016). Mechanical information allows humans to understand that tools can be used in numerous contexts and serve multiple purposes. For instance, hammers can be used as weapons in threatening situations or as paperweights when it is windy. Mechanical knowledge also represents 'tool-centered' information (Osiurak & Badets, 2016).

Manipulation knowledge refers to information about how tools must be physically grasped and acted upon to achieve specific goals. It is based on sensorimotor experience acquired both during the passive observation of others and during active manual engagement with tools (Boronat et al., 2005; Buxbaum, 2014; Buxbaum et al., 2000; Buxbaum & Saffran, 2002; Canessa et al., 2008; Sirigu, Duhamel, & Poncet, 1991). This procedural information allows individuals to correctly grasp and manipulate tools for the goals they have been primarily designed to achieve (van Elk, van Schie, & Bekkering, 2014). Different from

* Corresponding author at: Los Pinos s/n Balneario Pelluco, Puerto Montt, Chile.
E-mail address: felipe.munoz@uach.cl (F. Munoz-Rubke).

https://doi.org/10.1016/j.actpsy.2018.06.006
Received 21 March 2018; Received in revised form 8 June 2018; Accepted 19 June 2018
Available online 06 July 2018

functional and mechanical knowledge, manipulation knowledge highlights the direct interaction between user and tool and, therefore, corresponds to 'hand-centered' information (Osiurak & Badets, 2016).

While the optimal use of known tools is based on these three interrelated components (German, Truxaw, & Defeyter, 2008), attempts to use unknown tools or objects without a clear and unique function is mostly based on mechanical knowledge alone (Osiurak, 2014; Osiurak et al., 2008; Sirigu et al., 1991). To exemplify this, let us suppose that we are presented with implements owned by an expert watchmaker. If we were told the main functions of these tools and were then asked to actively use them, we would probably skillfully manipulate only some of them; as we would not have enough sensorimotor information to appropriately grasp and handle them for their intended purposes. If, in contrast, we were to manipulate these tools and were then asked to identify their culturally assigned functions, we would probably only correctly guess a few of them. Our ability to correctly ascertain some of the functions would be supported by our mechanical knowledge. This example highlights that to optimally use tools it is important that we know their primary functions, that we recognize they have appropriate physical properties to achieve these purposes, and that we know how to adequately manipulate them.

However, depending on the context, functional knowledge can either promote or obstruct problem solving. While it can promote problem solving when tools are used in familiar situations, it can obstruct problem solving when dealing with novel settings. The cognitive bias operating in this latter context has been called functional fixedness.

1.1. Functional fixedness

Functional fixedness illustrates how our functional knowledge, based on prior learning, can be detrimental in novel settings. It does this by interfering with the mechanical knowledge we commonly use to identify alternative functions for tools.

Functional fixedness interferes with innovative problem solving (Carr, Kendal, & Flynn, 2016; Chrysikou, Motyka, Nigro, Yang, & Thompson-Schill, 2016; Duncker, 1945; Maier, 1931; McCaffrey, 2012, 2016; Reed, 2016) and increases through development, with older children performing worse than younger children in susceptible situations (Defeyter & German, 2003; German & Defeyter, 2000). Further, this bias seems to be a widespread phenomenon, as adolescents from technologically sparse cultures with access to fewer tools are also vulnerable to it (German & Barrett, 2005).

Functional fixedness occurs because our first strategy when facing novel problems is to rely on our functional knowledge. When this initial attempt does not lead to satisfactory solutions, as with functional fixedness, we enter a state of cognitive impasse characterized by the subjective feeling of not knowing how to proceed (Knoblich, Ohlsson, Haider, & Rhenius, 1999; Ohlsson, 1984a, 1984b). Some researchers have emphasized that to overcome this state we need to adjust our incomplete or incorrect initial representation of the problem (Knoblich et al., 1999; Öllinger, Jones, & Knoblich, 2014; Patrick & Ahmed, 2014), while others have recommended that we need to focus on unnoticed or obscure features present in the initial settings (McCaffrey, 2012, 2016).

Functional fixedness does not explain how cognitive impasses are solved, but it does explain why they arise (Knoblich et al., 1999). Given that the current project focuses on functional fixedness, we are more concerned about the processes leading to the occurrence of cognitive impasses than on the psychological processes that occur after their manifestation or eventually lead to their resolution.

The current study was concerned by five issues related to the occurrence of functional fixedness during the resolution of novel mechanical problems. Concretely, we studied the influence that distinct ways of learning to use tools had on the generation of functional fixedness (**learning modality**); whether functional fixedness has a role in the generation of cognitive impasses regardless of mechanical problem difficulty (**difficulty of problem**); whether the effect of functional fixedness in the generation of cognitive impasses remained following initial failures to solve problems (**limits**); whether emphasizing tool function during testing was a requisite for evoking functional fixedness (**context**); and whether individual differences in intuitive physics knowledge, fine motor skills, and creativity affected the way functional fixedness interfered with mechanical problem solving (**individual differences**).

Learning modality (**A**): The first issue addressed was whether functional fixedness occurs regardless of how we learn to use tools. To investigate this, we divided our participants into five training groups: Reading (R), Video (V), and Manual (M), No Functional Fixedness (NFF), and No Training (NT). The first three groups experienced functional fixedness because the functional knowledge they received during an initial training phase was useless when it came to solve a set of novel mechanical problems. Participants in the R group read a description on how to use tools. Due to this, they only received functional information. Participants in the V condition watched an instructional video that provided a similar description on how to use the tools, but also showed how the tools could be physically manipulated for their primary purpose. Due to this, participants in the V condition received both functional knowledge and passive manipulation knowledge. Participants in the M condition were orally provided with the same functional information than those in the R and V groups. However, M participants also actively used the tools for their intended purpose. Therefore, participants in the M condition received both functional knowledge and active manipulation knowledge. Participants in the NFF and NT conditions did not experience functional fixedness.

We selected these conditions for three reasons. First, we were interested in studying the potential role that manipulation knowledge could have in the elicitation of functional fixedness. Although, by definition, functional fixedness represents the negative interference of functional knowledge on mechanical knowledge when facing novel tasks, it is unknown whether manipulation knowledge plays a secondary role in the generation or modulation of this cognitive bias.

Second, we were interested in contrasting the effects of passive (V) and active (M) interactions with tools because previous studies have suggested that different ways of object engagement can have distinct behavioral and neural consequences (Butler & James, 2013; Harman, Humphrey, & Goodale, 1999; James & Bose, 2011).

Third, we selected these conditions because they represent how people learn to use tools in everyday life. For instance, people learn to use tools by reading an instruction manual (R group), by watching instructional videos in YouTube (V group), or by direct instruction (M group).

Difficulty of problem (**B**): Although previous research has suggested that functional fixedness plays an important role in the origination of cognitive impasses (German & Defeyter, 2000; Knoblich et al., 1999), it is unknown whether this cognitive bias is always relevant for their occurrence. To address this, we studied the interaction between functional fixedness and mechanical problem difficulty to discover whether functional fixedness is pervasive across problem difficulty (MacGregor & Cunningham, 2008; MacGregor, Ormerod, & Chronicle, 2001).

Limits (**C**): We then focused on whether functional fixedness is affected by the experience of failing to solve a mechanical problem. That is, if a participant fails to solve a problem due to functional fixedness, and then is given another chance, would they still be susceptible to functional fixedness? To address this, we gave our participants two attempts to solve each mechanical problem and studied their performance during these secondary attempts.

Context (**D**): During testing, most previous experimental work has

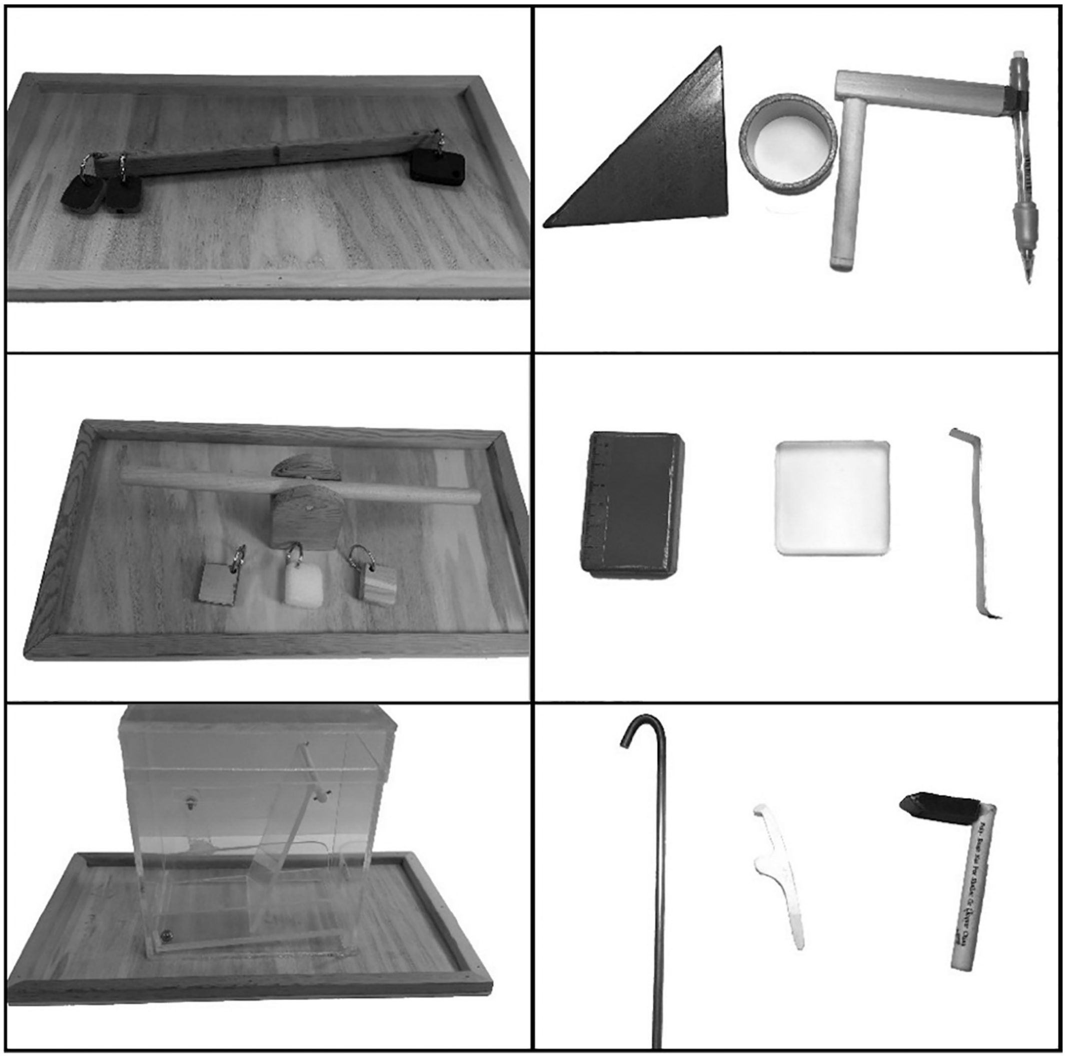

Fig. 1. Three of the puzzles (left column) used in the present experiment, as well as their respective tools (right column). From the top down, the first row shows the "Scale Balance" puzzle, the second row shows the "Scale Prop" puzzle, and the third row shows the "Box Flap" puzzle.

highlighted the functional information that leads to functional fixedness by presenting the tools next to the objects to which they are usually associated (e.g. presenting a spoon within a bowl), (Defeyter & German, 2003; German & Defeyter, 2000; German et al., 2008; for an exception see Maier, 1931). Due to this, we do not know whether actively stressing misleading information during problem solving is a requisite for functional fixedness to occur. The limitation of the approach taken by other studies is that previously acquired functional knowledge is not always emphasized in natural settings.

Individual Differences (E): To our knowledge, previous work has not tested whether differences in intuitive physics knowledge (intuitive comprehension of the physical principles governing the interactions among objects), fine motor skills (coordination of movements that require integration of hand movements and vision), or creativity (capability of generating original ideas; related to divergent thinking) influence or modulate the generation of this cognitive bias. However, there are reasons to believe that individual differences could affect how much functional fixedness affects each person. For instance, a better understanding of how things work, a type of knowledge that has been posited as a core domain of human cognition (Baron-Cohen, Wheelwright, Spong, Scahill, & Lawson, 2001; Hespos & vanMarle, 2012; Sperber, Premack, & Premack, 2002), may help individuals select an appropriate solution and disregard biases created by functional fixedness. Additionally, individuals with better motor skills may be able to extract relevant information from tools that may help them identify alternative functions (Wiesen, Watkins, & Needham, 2016). Also, it is possible for more creative individuals to be better at finding alternative functions because they tend to access remote associations and avoid high-frequency responses (Gupta, Jang, Mednick, & Huber, 2012). Although previous research favors the idea that the type of divergent thinking showed by creative individuals boosts problem solving (DeYoung, Flanders, & Peterson, 2008), a recent study suggests that the association between divergent thinking and innovative problem solving may not always be present (Beck, Williams, Cutting, Apperly, & Chappell, 2016), at least among children.

The present project addressed these five issues to better understand the effects of functional fixedness on tool use during novel mechanical problem solving. To do this: (A) we separated participants into five groups, three of whom were to experience functional fixedness by learning about how to use tools in different ways; (B) we created six different mechanical puzzles with the expectation that we would be able to study the interaction between functional fixedness and puzzle difficulty; (C) we provided participants with two attempts to solve each mechanical puzzle to test the limits of functional fixedness; (D) we did not emphasize tool function during puzzle solving presentation; (E) and we used standardized tests to measure intuitive physics knowledge, fine motor skills, and creativity.

2. Materials & methods

2.1. Participants

A hundred and fifty-three native English speakers (mean age = 19.36, age range = 18–23; 94 females; 19 left handed) took part in the experiment. They were randomly assigned to one of 5 conditions: reading (R) (n = 31); Video (V) (n = 30); or Manual (M) (n = 30); No Functional Fixedness (NFF) (n = 32); No Training (NT) (n = 30).

All participants were undergraduate students at Indiana University Bloomington and received course credit as compensation for their participation. Participants had normal or corrected to normal vision and reported no history of neurological disorders. Informed consent was obtained from each participant before the experiment, in accordance with the IUB Institutional Review Board approved protocol.

2.2. Materials

2.2.1. Puzzles and tools

We created six 3D puzzles to test mechanical problem solving: *Scale Balance*, *Scale Prop*, *Box Flap*, *Marble Push*, *PVC Pipe*, *Weight Wheel* (see Fig. 1). Puzzles were named for ease of identification, but these names were not divulged to participants. Each puzzle was made of wood, metal, and/or plastic and it was individually positioned on top of a wooden tray with dimensions 45 cm × 25 cm × 1.5 cm. All puzzles were generally manipulated with both hands (see Appendix A for a description of the 3D puzzles).

Each puzzle was associated with 3 'options' or tools (see Fig. 2). Participants had to use one of these tools to solve each 3D puzzle, following instructions described in the Experimental Procedures. The tools were constructed out of wood, metal, and/or plastic and their sizes ranged from 4 cm to 25 cm along their largest axis (see Appendix B for descriptions of the 18 tools).

2.2.2. Standardized tests

We evaluated relevant pre-existing skills. We were particularly interested in estimating the effects of intuitive physics knowledge, fine-motor skills, and creativity on 3D mechanical problem solving.

We used a Folk Physics Test to measure intuitive physics knowledge (Baron-Cohen et al., 2001). This test comprised 20 multiple choice questions and it evaluated the understanding of causal relationships regarding physical mechanics. This understanding comes from everyday experiences of these physical principles, rather than from education received in classrooms (Kaiser, Proffitt, & McCloskey, 1985; McCloskey, 1983). Participants had 10 min to complete the Folk Physics Test. Performance was evaluated by calculating the proportion of correct answers.

We used the Lafayette Grooved Pegboard Test (© Lafayette Instrument Company) to measure fine-motor skills (Bryden & Roy, 2005; Yancosek & Howell, 2009). Participants were asked to place and then remove 25 pegs into holes on the pegboard, one at a time. Participants repeated this procedure three times. Their forward and backward times for each trial were added together. Subsequently, forward and backward times were averaged to create a final single score for each participant.

We used the Alternative Uses Test to measure creativity (Gilhooly, Fioratou, Anthony, & Wynn, 2007; Guilford, Christensen, Merrifield, & Wilson, 1978). This procedure has been used in previous studies for this purpose (Colzato, Ozturk, & Hommel, 2012; Sellaro, Hommel, de Kwaadsteniet, van de Groep, & Colzato, 2014). Participants were asked to write down alternative uses for six different objects: shoe, brick, newspaper, pen, towel, and bottle. Answers were valid if the alternative functions did not correspond to the standard function of the object. Participants had 1 min to write down as many answers as they could for each object. From their answers, we calculated 4 different scores following the instructions provided by Colzato et al. (2012). The fluency score corresponded to the total number of responses. One point was provided for each answer. The originality score was based on the frequency of each answer. Responses given by only 5% of participants received 1 point while responses provided by only 1% of them received 2 points. The flexibility score was based on the number of categories used and the elaboration score reflected how much detail was given in each answer. For instance, saying "a doorstop" counted as 0, whereas "a doorstop to prevent a door slamming shut in a strong wind" counted as 2. One point was given for introducing door slamming and another for providing further detail about the wind. The final score for each participant was calculated by adding all 4 scores together.

2.3. Experimental procedures

2.3.1. General procedure

Each session started with participants taking the Folk Physics Test followed by the Pegboard Test. This took approximately 15 min in total. We then randomly assigned participants into one of the experimental groups. The assigned group defined the instruction that a participant received. This learning phase lasted for approximately 20 min. Following this, all participants took a 4 Alternative Forced Choice (4AFC) test for 3–5 min to ensure that they had learned to use the tools. This test was followed by the mechanical puzzles testing session, which was then followed by the administration of the Alternative Uses Test (see Fig. 3).

2.3.2. Learning conditions

Reading (*R*): Participants were briefly told how to use a tool and then asked to read a document describing how the tool was used. This document also contained a colored picture of the tool (like paper instructions). Note that the set of instructions pertaining to how to use the tools, were kept constant for the R, V, and M groups.

Video (*V*): Participants watched a video where they were briefly told how to use a tool and then observed how an experimenter used the tool (similar to a YouTube video). Actions executed by the experimenter in the video where the same as those instructed in the M condition.

Manual (*M*): Participants were briefly told how to use tools and then asked to actively use them for such purpose.

No Functional Fixedness (*NFF*): Participants received information that would help them solve the mechanical puzzles. For instance, if the target tool was a hammer that had to be used as a weight, these participants were taught to use a hammer as a weight. This group was not susceptible to functional fixedness.

No Training (*NT*): This group was used as a control because they were not exposed to the novel tools prior to solving the target puzzles.

Differences among learning groups can be clarified by way of an example. To solve the Scale Prop puzzle (see Appendix A), participants had to make use of the tool we called Field Scale (see Appendix B). We did not tell participants in the NFF group that the Field Scale was used to determine the length of objects in centimeters, as we did for participants in the R, V, and M conditions. Instead, we told them that the tool was used to prop up objects in tilted positions (the correct use in this case). Participants in the R condition were told that this tool was used to measure the length of objects and then read a document about this. Participants in the V condition watched a video where an experimenter first told them that this tool was used to measure the length of objects and then proceeded to measure some objects himself; participants in the M condition were told that this tool was used to measure the length of objects and were then provided with the same objects used

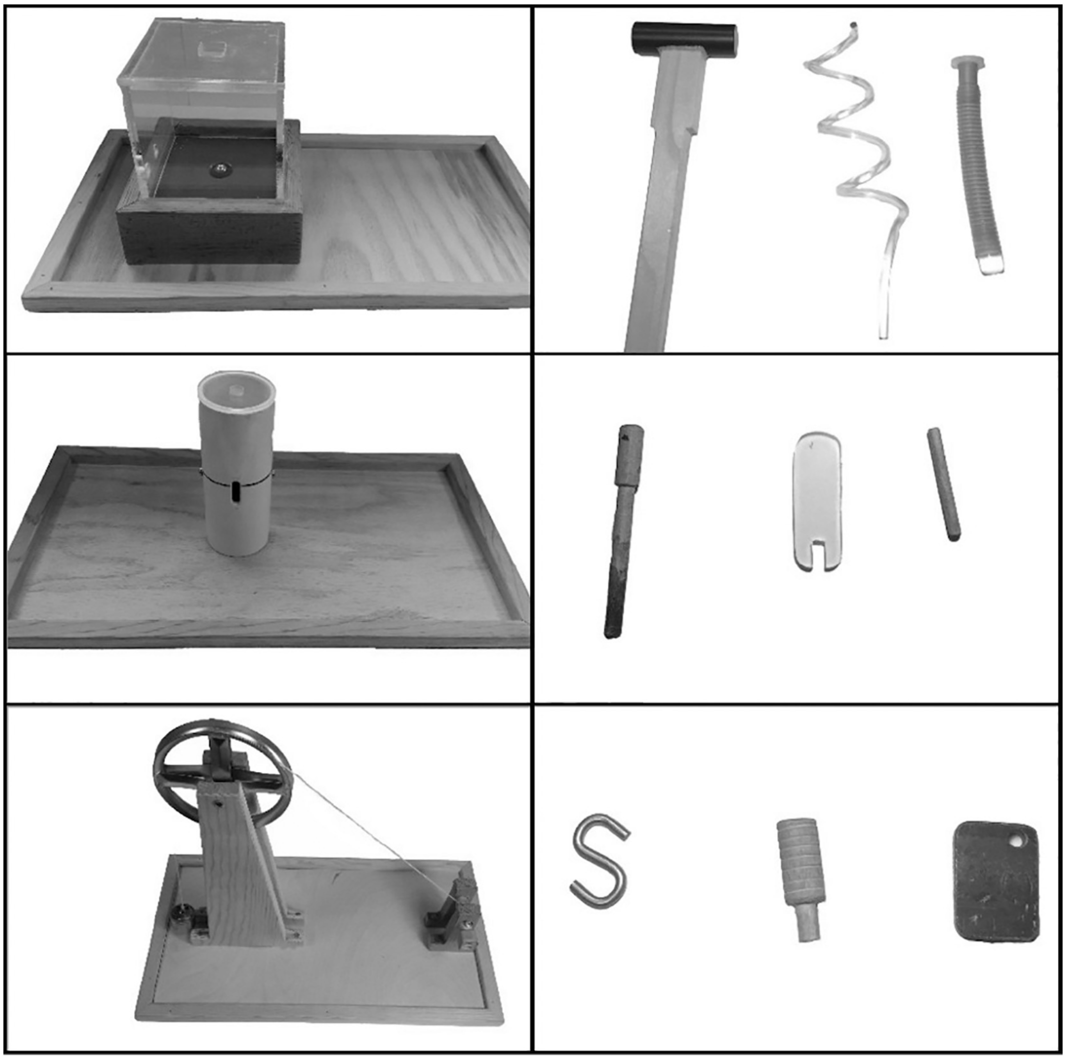

Fig. 2. The remaining three puzzles (left column) used in the present experiment, as well as their respective tools (right column). From the top down, the first row shows the "Marble Push" puzzle, the second row shows the "PVC Pipe" puzzle, and the third row shows the "Weight Wheel" puzzle.

in the V condition to be measured.

2.3.3. Forced-choice test phase

Following training, participants in the NFF, R, V and M groups completed va 4AFC test. The test contained tool pictures and four alternatives describing potential functions. The test was used to verify that participants had successfully learned the correct functions during training. We required them to achieve a 90% of correct answers to advance to the next stage. Up to this point, participants were neither aware of the existence of the mechanical puzzles nor that they would be required to employ the tools any further.

2.3.4. Mechanical problem solving phase

After the 4AFC test, participants were instructed to solve mechanical puzzles with the same tools they previously learned to use. They had a maximum of 2 attempts to solve each puzzle, and each attempt included a planning phase and an execution phase. Participants were videotaped during both phases.

At the beginning of each testing trial, the experimenter showed a colored picture of the corresponding puzzle and verbally described the problem to be solved to the participants. The experimenter then handed them the 3 tools linked to each puzzle, one by one. Participants in all conditions were therefore given the chance to briefly touch and see each tool before being presented with the real 3D puzzles. We did this to ensure that our results were not explained by simple familiarity with the physical structure of the tools. Immediately after a 3D puzzle was positioned on top of the table, the planning phase began.

Each planning phase lasted up to 30 s (maximum set by experimenter). During this time, participants came up with a strategy to solve the puzzles. Participants were instructed to plan a solution as fast as possible, and to notify the experimenter as soon as they were done. Participants were also instructed to use this planning time to rotate the puzzle tray, so that they could observe the puzzle from different perspectives. However, they were not allowed to touch or manipulate the puzzles. The experimenter verified that participants followed these instructions and reinforced these rules whenever it was needed. To make sure that the strategy designed during each planning phase was specific enough, the experimenter asked participants to describe her/his plan in detail, and to be as specific as possible.

Participants were then given up to 60 s to solve the puzzle by following the strategy they designed during the planning phase. Again, they were instructed to execute their plan as fast as possible, and to notify the experimenter as soon as they were finished. If participants failed at solving the puzzle during their 1st attempt, they were given another chance to solve it. The 2nd attempt included new planning and new execution phases. Participants moved onto the next puzzle regardless of success or failure after two attempts at solving a puzzle. Participants were given no verbal feedback on their performance.

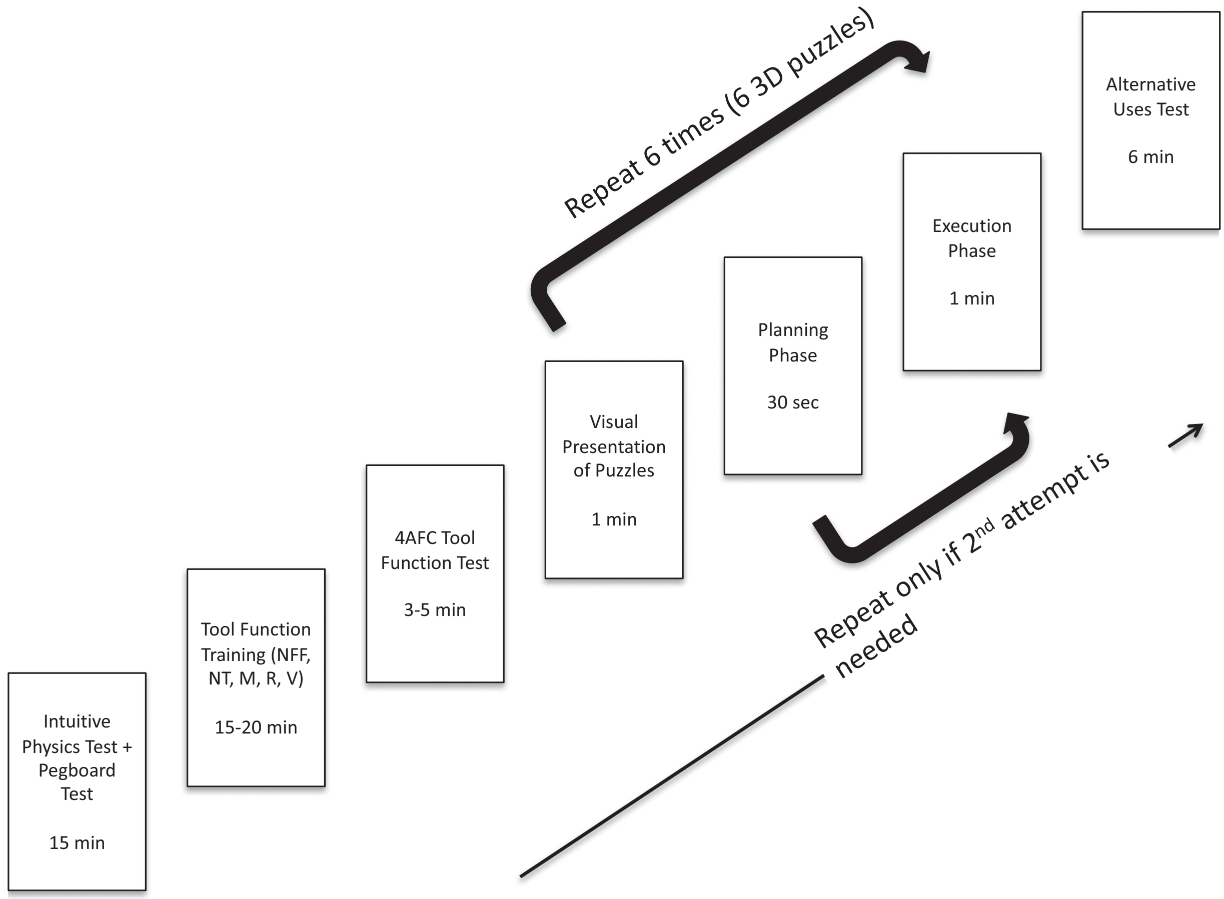

Fig. 3. Experimental design.

Following completion of all six puzzles, participants completed the Alternative Uses Test.

2.3.5. Statistical analyses

To answer our research questions, we focused on 4 outcome variables: puzzle solution accuracy, total time during the 1st attempt (planning + execution time), planning time, and execution time.

To calculate solution accuracy, each trial was scored separately. Participants received 1 point if they solved a puzzle during their 1st attempt, 0.5 points if they solved it on the 2nd attempt, and 0 points if they were unable to solve it. Planning and execution times were recorded directly by the experimenters and checked subsequently by another blind researcher from the videotapes. The values recorded by the experimenters and the blind researcher for the 4 variables (planning 1st attempt, planning 2nd attempt, execution 1st attempt, execution 2nd attempt) was highly congruent as estimated by both Pearson's correlation coefficients and Spearman's rank correlation coefficients (range Pearson's r: 0.942–0.962; range Spearman's rho: 0.939–0.963).

We first used Fisher's exact test to evaluate differences in solution accuracy among conditions, after collapsing across puzzles. We then used several Fisher's exact tests to evaluate differences in solution accuracy among conditions for each puzzle individually. These analyses were supplemented with two multilevel logistic regressions. These regressions were used to analyze trials that resulted in successfully solving the puzzles during the 1st attempt or 2nd attempt, respectively. These models included fixed predictors for condition (experimental groups), intuitive physics scores, pegboard times, and alternative uses scores. They also included a random intercept to account for the different levels of difficulty among the puzzles.

Total, planning, and execution times were analyzed with mixed-effects ANCOVAs. For each of these dependent variables, we used 3 ANCOVA models. The first ANCOVA considered all trials, regardless of whether they resulted in solving the puzzles or not. This model included fixed predictors for condition, puzzle, interaction condition/puzzle, intuitive physics scores, pegboard times, and alternative uses scores. They also included a random intercept to account for the different levels of performance among participants. While the 2nd ANCOVA considered only trials that resulted in puzzle solution during the 1st attempt, the 3rd ANCOVA considered only trails that resulted in puzzle solution during the 2nd attempt. This was done to evaluate whether functional fixedness was found only during an initial encounter with a puzzle.

For all ANCOVAs, post-hoc multiple comparisons were conducted using Tukey *p*-value adjustments. We also calculated an Ω^2 for each model as a measure of effect size (Xu, 2003). The R programming language (R Core Team, 2016) was used to implement all statistical procedures and to create the figures. We used the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) to fit both multilevel logistic models and multilevel linear models. We then used the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2016) to summarize these multilevel linear models into mixed-effects ANCOVAs.

3. Results

3.1. Puzzle difficulty

We used a bootstrap method with resampling to calculate 95% Confidence Intervals (CIs) for each puzzle's solving accuracy. We first artificially generated 1000 data sets from our original data set, and then estimated each puzzle's solving accuracy for each of these simulated matrices. Subsequently, we constructed 95% CIs by recovering the values corresponding to the 2.5% and 97.5% quantiles of the distribution

Table 1
This table shows the 5 experimental conditions, as well as the type of information that participants received in each of these groups. The last column shows whether the knowledge received by the participants was accurate (A) and would therefore help them solve the subsequently presented puzzles, or if it was inaccurate (I) and would therefore lead to functional fixedness during puzzle solution.

Conditions	Functional knowledge	Passive manipulation knowledge	Active manipulation knowledge	Accurate knowledge (A)/ inaccurate knowledge (I)
Reading	X			I
Video	X	X		I
Manual	X		X	I
No functional fixedness	X			A
No training				

of estimates. According to its median solution value, Marble Push was the most complicated mechanical puzzle (median = 11.6%, CI = [6.7%, 18.3%]), followed by Weight Wheel (median = 28.7%, CI = [21.7%, 36%]), PVC Pipe (median = 45.9%, CI = [33.7%, 60%]), Box Flap (median = 47.2%, CI = [35.5%, 63.4%], Scale Prop (median = 47.3%, CI = [35.6%, 61.8%], and Scale Balance (median = 73.6%, CI = [56.24%, 93.9%]. Four levels of puzzle difficulty were thus created: very difficult (Marble Push), difficult (Weight Wheel), easy (PVC Pipe, Box Flap, Scale Prop), and very easy (Scale Balance). This information was used to study whether functional fixedness was present across puzzles, regardless of their difficulty.

3.2. Solution accuracy

We used Fisher's exact test to assess whether solution accuracy during either the 1st or 2nd attempts differed across conditions. Results suggested a relationship between condition and solving accuracy during the 1st attempt ($p = .014$) (see Table 1). Unlike other conditions, the NFF group showed a solution proportion greater than 50% during the 1st attempt. Conversely, results did not suggest an association between condition and solving accuracy during the 2nd attempt ($p = .200$) (Table 2).

We also used Fisher's exact test to evaluate whether solving accuracy during the 1st attempt differed across conditions and puzzle difficulty. Results did not suggest an association between condition and solving accuracy for the Marble Push ($p = .407$), Weight Wheel ($p = .902$), PVC Pipe ($p = .496$), and Box Flap ($p = .942$) puzzles. However, results indicated an association between these variables for both the Scale Prop ($p = .002$) and Scale Balance ($p < .001$) puzzles; an easy and a very easy puzzle, respectively. For both mechanical problems, the NFF condition showed higher solving accuracy than any other group (see Fig. 4).

3.3. Only trials resulting in puzzle solution during the 1st attempt

We then used a multilevel logistic model considering only performance during the 1st attempt. We added predictors for the conditions, intuitive physics scores, pegboard times, and creativity scores. This was done to supplement the results of Fisher's exact test and to account for variables related to individual differences. Consistent with Fisher's exact test's results, the model suggested that the NT, R, V, and M conditions were associated with lower odds of outcome than the NFF group (No Training: $\beta = -0.66$, Odds Ratio: 0.52, $Z = -2.8$, $p = .005$; Reading: $\beta = -0.79$, Odds Ratio: 0.45, $Z = -3.4$, $p < .001$; Video: $\beta = -0.73$, Odds Ratio: 0.48, $Z = -3.1$ $p = .002$; Manual: $\beta = -0.63$, Odds Ratio: 0.54, $Z = -2.7$, $p = .007$). Post hoc multiple comparisons based on Tukey contrasts did not show differences among these four conditions (all $p > .982$). Additionally, higher intuitive physics scores were associated with higher odds of puzzle solution ($\beta = 1.92$, Odds Ratio: 6.88, $Z = 3.5$, $p < .001$) and longer pegboard times were associated with lower odds of outcome ($\beta = -0.02$, Odds Ratio: 0.98, $Z = -2.2$, $p = .033$). Creativity scores did not show a statistically significant association with the response variable ($\beta = 0.01$, Odds Ratio: 1.01, $Z = 1.7$, $p = .086$).

Table 2
Number of solutions for each experimental condition.

Conditions	No Solution	Solution	Total
Reading	118 (63.4%)	68 (36.6%)	186
Video	107 (59.4%)	73 (40.5%)	180
Manual	105 (58.3%)	75 (41.7%)	180
No functional fixedness	90 (46.9%)	102 (53.1%)	192
No training	109 (60.6%)	71 (39.4%)	180

3.4. Only trials resulting in puzzle solution during the 2nd attempt

The second multilevel logistic model included the same predictors. Again, results suggested that higher intuitive physics scores were associated with higher odds of puzzle solution ($\beta = 1.78$, Odds Ratio: 5.94, $Z = 2.5$, $p = .012$), while longer pegboard times were associated with lower odds of outcome ($\beta = -0.02$, Odds Ratio: 0.98, $Z = -2.2$, $p = .026$). No other predictor was statistically significant (all $p > .250$).

3.5. Summary (solution accuracy)

Taken together, our results indicated that the NFF group was better at solving the mechanical puzzles than any other group. While the R, V, and M groups showed signs of functional fixedness compared to the NFF group, results for the NT group indicate that lack of familiarity can also negatively affect mechanical problem solving.

Differences between the NFF group and the remaining groups were observed in both an easy (Scale Prop) and a very easy (Scale Balance) puzzle, suggesting that the effect of functional fixedness is restricted to low difficulty problems. Differences with respect to NFF were observed only during the 1st attempt. This indicates that functional fixedness does not bias mechanical problem solving after an initial solving strategy results in failure. Additionally, intuitive physics scores were connected to higher solving accuracy and longer pegboard times were connected to lower solving accuracy.

3.6. Total time during the 1st attempt

We used a mixed-effect ANCOVA to study differences among conditions, regardless of whether the trials resulted in puzzle solution or not. This model had an Ω^2 of 0.4, a moderate-to-strong effect size. Results indicated a main effect of puzzle ($F(5, 740) = 42.74$, $p < .001$), an interaction between condition and puzzle ($F(20, 740) = 1.76$, $p = .021$), and a main effect of intuitive physics scores ($F(1, 145) = 6.17$, $p = .014$). After reshaping the ANCOVA model in the form of a multilevel regression model, we observed that higher intuitive physics scores were associated with shorter total times ($\beta = -15.06$, $t(145) = -2.48$, $p = .014$). The remaining predictors were not significantly associated with this outcome variable. Post-hoc multiple comparisons suggested that participants in the NFF group were faster than participants in the R group while solving the Scale Prop puzzle (Estimated difference = −13.33, $t(777.67) = -2.8$, $p = .038$), an easy mechanical problem. These comparisons also revealed that participants in the NFF group were faster than participants in the NT (Estimated difference = −13.52, $t(778.43) = -2.9$, $p = .036$) and R groups (Estimated difference = −14.85, $t(777.67) = -3.2$, $p = .014$) while solving the Scale Balance puzzle, a very easy mechanical problem (see

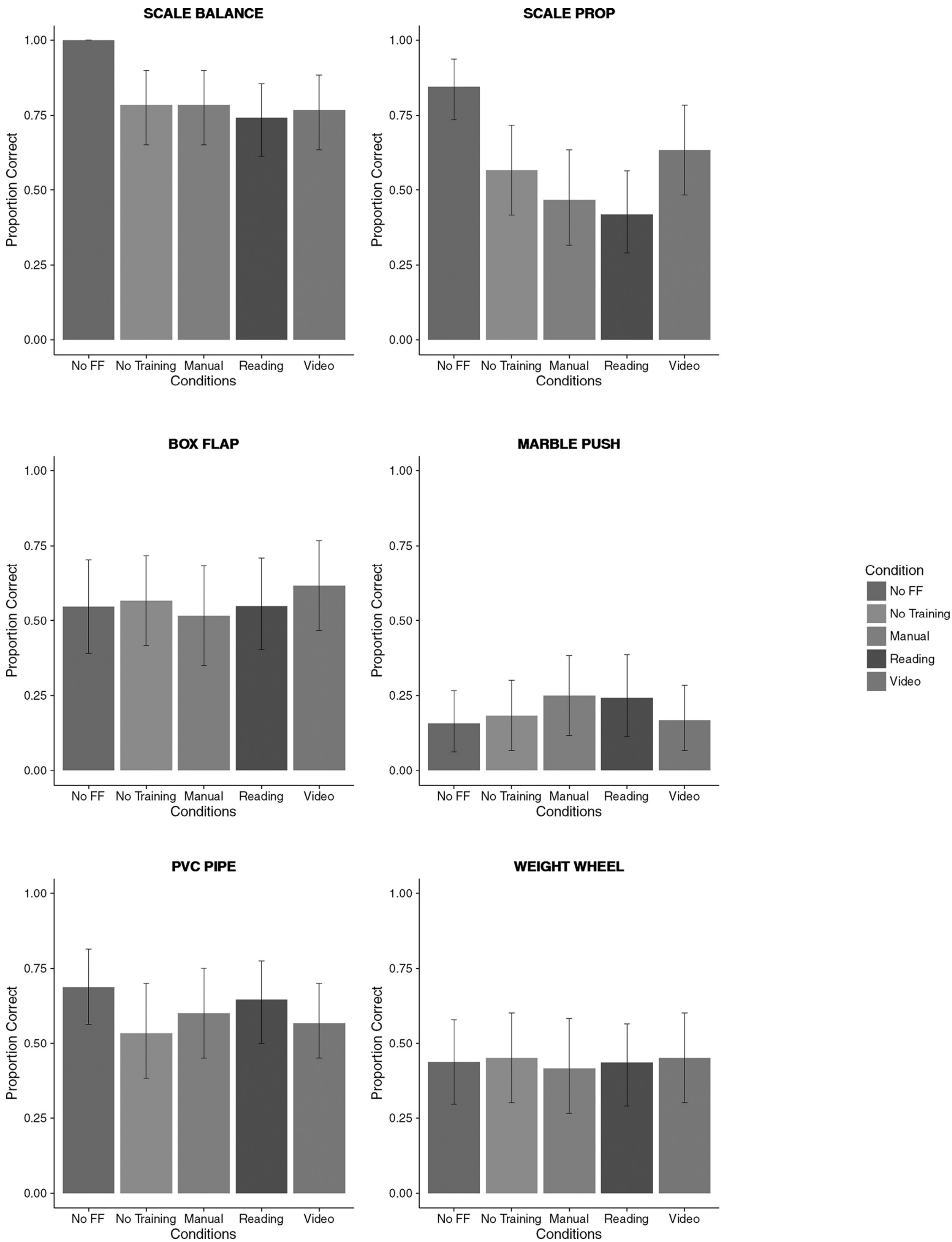

Fig. 4. Differences in solution for each puzzle. In the "Scale Balance" and "Scale Prop" puzzles, the NFF groups show a higher solution proportion than the remaining groups. The figure includes bootstrap 95% CIs for each group.

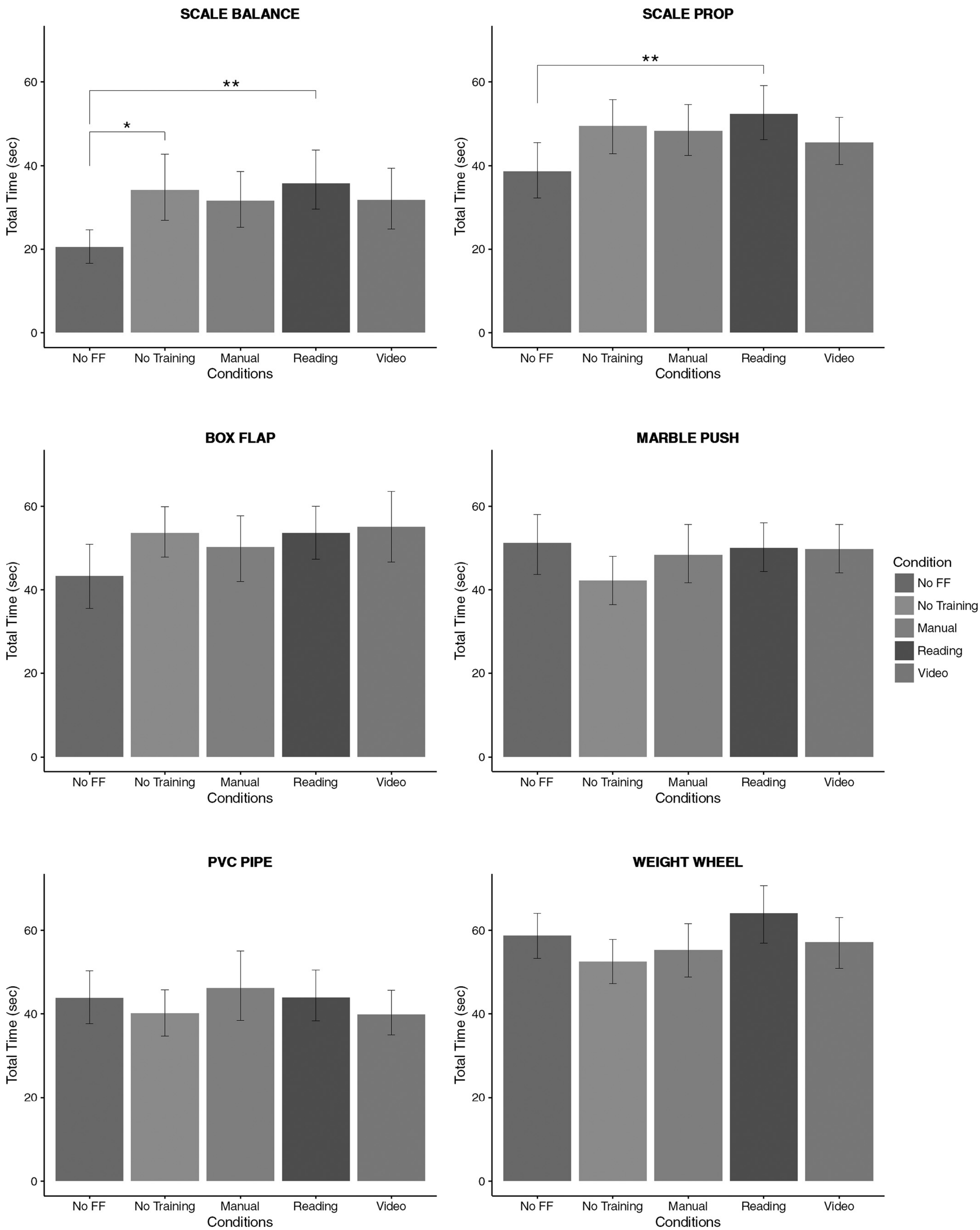

Fig. 5. Differences in total time for each puzzle during the 1st attempt. In the "Scale Balance" puzzle, the NFF group showed shorter total times than both the NT and R groups. In "Scale Prop" puzzle, the NFF group showed shorter total times than the R group. In the remaining puzzles, our results did not show statistically significant differences among the conditions.

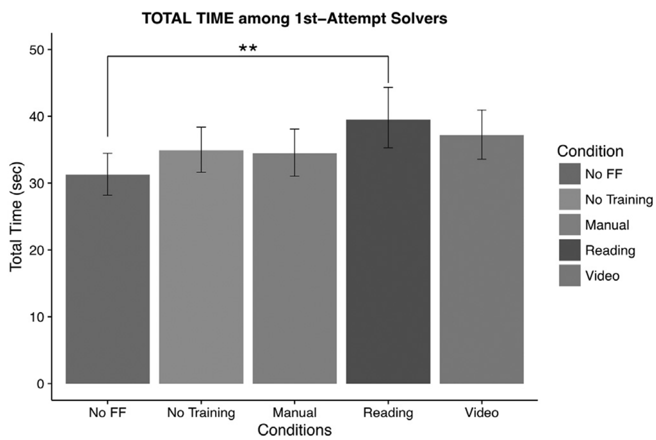

Fig. 6. Total time for trials that were solved during the 1st attempt. Results suggest that the NFF group showed shorter total times than the R group.

Fig. 5).

3.7. Only trials resulting in puzzle solution during the 1st attempt

The mixed-effect ANCOVA model had an Ω^2 of 0.34, a moderate effect size. Results indicated a main effect of condition (F(4, 376.48) = 3.53, p = .008) and a main effect of intuitive physics scores (F(1, 376.28) = 3.93, p = .048). Remaining predictors were not significantly associated with this outcome variable. Post-hoc multiple comparisons suggested that participants in the NFF group were faster than participants in the R group (Estimated difference = −7.97, t (376.88) = −3.56, p = .004) (see Fig. 6).

3.8. Only trials resulting in puzzle solution during the 2nd attempt

The mixed-effects ANCOVA model had an Ω^2 of 0.35, a moderate effect size. No predictor was significantly associated with the outcome variable.

3.9. Summary (total time)

Taken together, these results indicate that the NFF group was faster during the 1st attempt than the NT and R groups. The NFF group also showed shorter total times than the R group, when only considering trials that resulted in puzzle solution during the 1st attempt. Additionally, higher intuitive physics scores were associated with shorter total time.

3.10. Planning time

A mixed-effect ANCOVA evaluated differences in planning time during the 1st attempt, regardless of whether the trials resulted in puzzle solution. This model had an Ω^2 of 0.43, a moderate-to-strong effect size. Results indicated a main effect of condition (F(4, 145) = 3.57, p = .008) and a main effect of puzzle (F(5, 740) = 16.31, p < .001). No other predictor was significantly associated with this outcome variable. Post-hoc multiple comparisons showed that the NFF group planned faster than the NT group during the Box Flap (Estimated difference = −6.52, t(627.40) = −2.98, p = .025) and the Scale Balance puzzles (Estimated difference = −6.44, t(627.40) = −2.94, p = .028); faster than the R group during the Box Flap (Estimated difference = −7.50, t(626.43) = −3.46, p = .005) and the Scale Balance puzzles (Estimated difference = −6.46, t(626.43) = −2.98, p = .025); and faster than the V group during the Box Flap puzzle (Estimated difference = −6.01, t(620.26) = −2.74, p = .050) (see Fig. 7).

3.11. Only trials resulting in puzzle solution during the 1st attempt

The mixed-effects ANCOVA had an Ω^2 of 0.16, a small effect size. Results indicated a main effect of condition (F(4, 377.69) = 6.73, p < .001) and a main effect of intuitive physics scores (F(1, 377.08) = 3.9, p < .050). After reshaping the ANCOVA model in the form of a multilevel regression model, we observed that higher intuitive physics scores were associated with shorter planning times (β = −6.49, t(377.1) = −1.97, p = .050). Post-hoc multiple comparison indicated that the NFF group planned faster than the NT (Estimated difference = −4.96, t(377.18) = −3.68, p = .003); R (Estimated difference = −6.23, t(378.93) = −4.5, p < .001); V (Estimated difference = −4.32, t(377.47) = −3.17, p = .014); and M (Estimated difference = −5.15, t(378.57) = −3.87, p = .001) groups (see Fig. 8). Remaining predictors were not significantly associated with this outcome variable.

3.12. Only trials resulting in puzzle solution during the 2nd attempt

The mixed-effects ANCOVA had an R^2 or Ω^2 of 0.08, a small effect size. Results suggested an effect of intuitive physics scores (F(1, 195.63) = 4.14, p < .043), which were associated with shorter planning times (β = −9, t(195.63) = −2.03, p = .043). No other predictor was significantly associated with this outcome variable.

3.13. Summary (planning time)

Taken together, these results indicate that the NFF group planned faster than the R, V, and NT groups, when considering all trials. The NFF group also planned faster than the M, R, V, and NT groups, when only considering trials that resulted in puzzle solution during the 1st attempt. This effect was shown only for the easy (Box Flap) and a very easy (Scale Balance) puzzles, and only during the 1st attempt. Additionally, intuitive physics scores were linked to shorter planning times during both the 1st and 2nd attempts.

3.14. Execution time

A mixed-effects ANCOVA evaluated differences in execution time during the 1st attempt, regardless of whether the trials resulted in puzzle solution or not. This model had an Ω^2 of 0.27, a small-to-moderate effect size. Results indicated a main effect of puzzle (F(5, 740) = 35.86, p < .001), but neither a main effect of condition (F(4, 145) = 1.27, p = .287) nor an interaction between condition and puzzle (F(20, 740) = 1.43, p = .1). Results also suggested an effect for intuitive physics scores (F(1, 145) = 5.76, p = .018) and pegboard times (F(1, 145) = 3.8, p = .054), but not for creativity scores (F(1, 145) = 0.13, p = .724). Particularly, higher intuitive physics scores were associated with shorter execution times (β = −10.70, t (145) = −2.4, p = .018) and longer pegboard times were associated with longer execution times (β = 0.12, t(145) = 1.95, p = .054). Post-hoc multiple comparisons showed that the NT group was faster at executing than the NFF group during the Marble Push puzzle (Estimated difference = 12.56, t(867.69) = 3.05, p = .020).

3.15. Only trials resulting in puzzle solution during the 1st attempt

The mixed-effects ANCOVA had a Ω^2 of 0.34, moderate effect size. No predictor was statistically associated with this outcome variable.

3.16. Only trials resulting in puzzle solution during the 2nd attempt

The mixed-effects ANCOVA had an R^2 or Ω^2 of 0.24, a small-to-moderate effect size. Results suggested an effect of intuitive physics scores (F(1, 193.57) = 5.83, p = .017). After reshaping the ANCOVA model into a multilevel regression model, we observed that higher

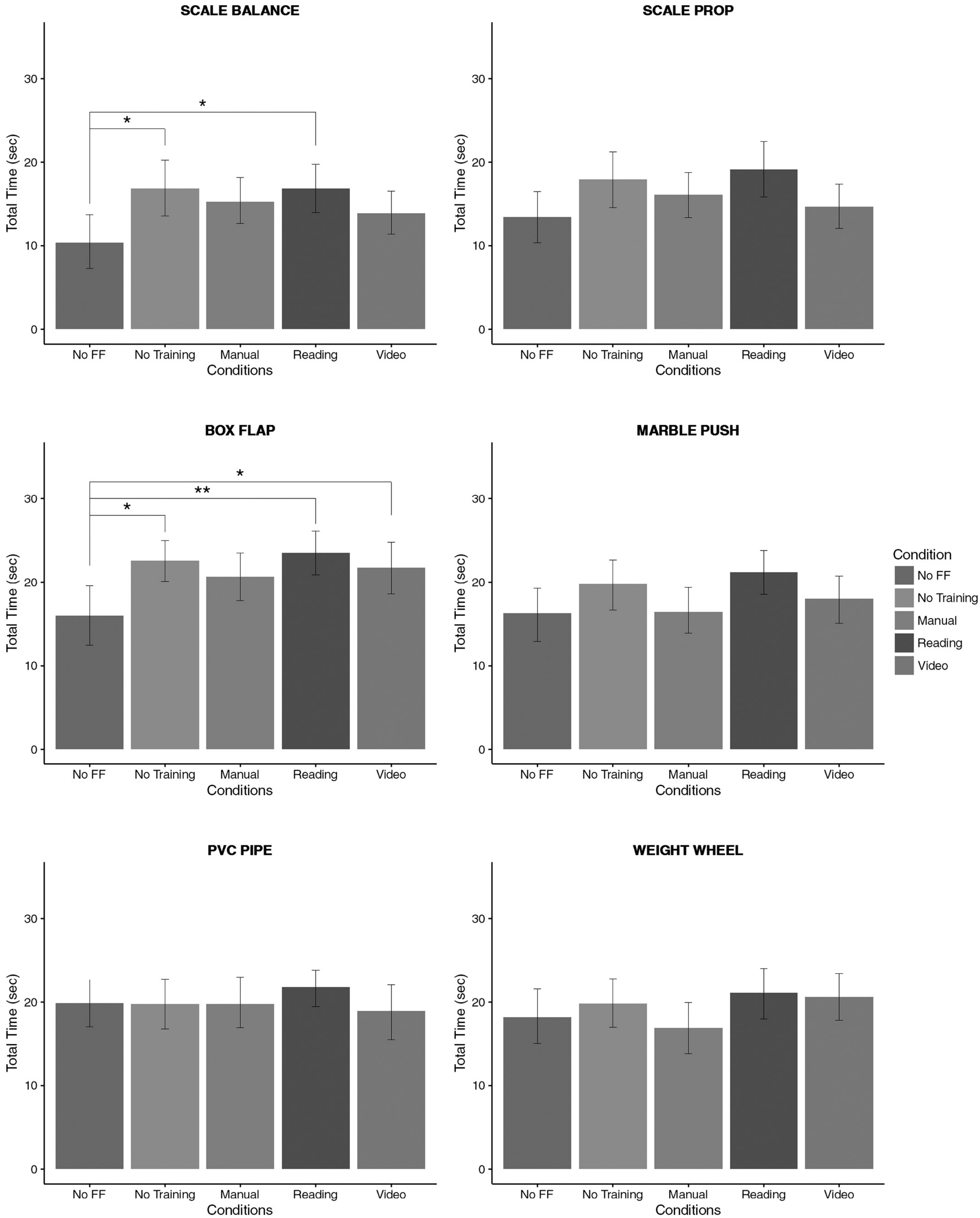

Fig. 7. Planning times for each puzzle. Differences among conditions were only found in the "Scale Balance" and "Box Flap" puzzles.

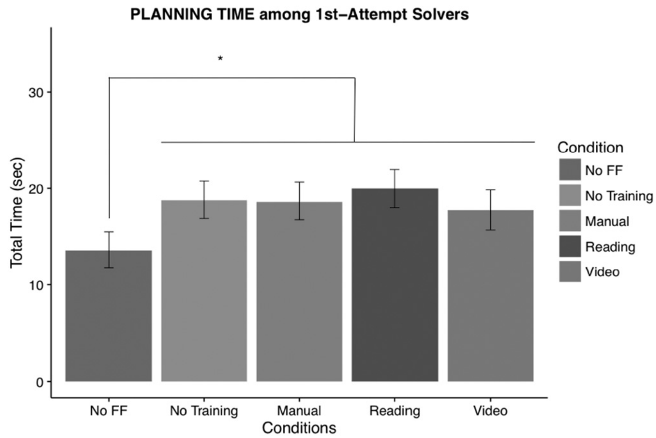

Fig. 8. Planning time for trials that were solved during the 1st attempt. Results suggest that the NFF group showed shorter planning times than the remaining groups.

intuitive physics scores were associated with shorter execution times during the 2nd attempt ($\beta = -17.58$, $t(193.58) = -2.4$, $p = .017$). No other predictor was significantly associated with this outcome variable.

3.17. Summary (execution time)

These results indicated that the NT group showed shorter execution times than the NFF group in a very difficult task (Marble Push), when considering all trials. Additionally, higher intuitive physics scores were associated with shorter execution times, and longer pegboard times were associated with longer execution times.

4. Discussion

The current study demonstrated that: (A) the way we learn to use tools does not affect the occurrence of functional fixedness; (B) although functional fixedness generates cognitive impasses when we try to solve simple mechanical problems, it does not seem to play a role in those of higher difficulty; (C) the effects of functional fixedness disappear following initial failures to solve a problem; (D) emphasizing tool function during testing is not a pre-requisite to evoke functional fixedness; (E) individual differences in intuitive physics knowledge and motor skills affect the way functional fixedness interferes with tool use.

4.1. Different ways of learning about tool function can generate functional fixedness

Novel to the current experiment was the inclusion of different ways of learning to use tools. Our results suggested that participants in the R, V, and M groups experienced functional fixedness, indicating that this cognitive bias is generated regardless of learning modality. Participants in these groups received the same misleading functional information during training. Nonetheless, they differed on whether they also received misleading passive (V) or active manipulation information (M). The fact that these three groups showed signs of functional fixedness is consistent with previous research indicating that inaccurate functional information is at the core of the functional fixedness of tool use (German et al., 2008; German & Barrett, 2005; German & Defeyter, 2000).

Our results also suggested slight differences among these three groups. For instance, the NFF group showed shorter total and planning times than the R group, but not compared to either the V or M groups. One could be tempted to interpret this as suggesting that acquiring functional and manipulation information together tends to lessen functional fixedness, but because there were no differences when directly comparing the R, V, and M groups, such an interpretation must be considered with caution. Although a decision we deemed necessary given the five goals of the present experiment, it is possible that the direct comparison between the R group and the V and M groups did not show differences due to our decision to restrict the maximum possible amount of planning and execution time. By restricting such time, we reduced potential variations in the results and combined all participants that did not figure out answers before the deadline, regardless of whether they would have done so within the next 10 or 60 s.

Our results also showed that the V and M groups experienced similar levels of functional fixedness. Although passive (V) and active (M) object engagement have been shown to differentially affect visual object recognition (Harman et al., 1999) and modulate the creation of sensory-motor systems in the brain (Butler & James, 2013; James & Bose, 2011), we found that these learning strategies did not differ in the generation of functional fixedness. This difference in result could be due to the task itself, as learning an object for subsequent recognition is quite different from learning how to use it. The lack of difference in the present work could also be due to the brief learning exposure. In previous work that found differences between passive and active learning, participants spent considerable time learning an object's structure, whereas in the present project, participants only learned how to use the objects for about 2 min.

Another contribution of the current experiment was the use of a No Training (NT) condition. Results indicated that the NT group did worse than the NFF group in terms of solution accuracy, total time, and planning time. Nevertheless, in general, the NT group's performance was not significantly different to that of the R, V, and M groups, suggesting that the training that promoted functional fixedness was no worse than no exposure to the tools at all. A future study could investigate the influence that the tools used in this study had on the differences observed between these groups. Particularly, future studies could investigate whether similar results are obtained when participants in the NT group solve the puzzles with more neutral objects (e.g., rocks and sticks), as this would better inform us about the differences between strategies based on pure mechanical knowledge (NT) and based on mechanical knowledge interfered by functional fixedness (R, V, and M).

4.2. Functional fixedness is only present during simple mechanical problem solving

Although functional fixedness is a well-established phenomenon (Coon & Mitterer, 2015; Goldstein, 2011; Reed, 2013), previous literature has mostly forgotten about studying its range of effect. Our results suggested that functional fixedness is not a widespread phenomenon and is not always behind the inception of cognitive impasses, as we only observed signs of this cognitive bias when participants attempted to solve simple mechanical puzzles. Additionally, our results did not appear to be a function of solvability because the individuals who successfully solved the more difficult puzzles did not show any signs of functional fixedness. These results restrict the role that functional fixedness plays in the origination of cognitive impasses and indicate that other factors, probably more important than functional fixedness, can be behind their generation. Given that it is only through the resolution of complicated mechanical tasks that we conceive new technology and achieve novel solutions to novel problems, future studies will have to go beyond functional fixedness to understand how we come to experience cognitive impasses.

4.3. The effect of functional fixedness is limited to first attempts of problem solving

Our results support the idea that the initial cognitive impasse generated by functional fixedness dissipates following a failure and favors a dynamic role for the misleading functional information driving this bias. This is consistent with a context-dependent perspective of concept activation, where the information accessed changes depending on current task goals and is modified by different experiences.

4.4. Emphasizing tool function is not a requisite to evoke functional fixedness

Limited exposure to functional information promoted functional fixedness, suggesting that a tool's function does not have to be highly familiar or highlighted during testing to produce the adverse effects of functional fixedness. Participants in the R, V, and M groups solved fewer puzzles, took more total time to solve puzzles, and more time to plan answers than participants in the NFF group. This pattern of results suggests that recent learning experiences with tools can bias the search process for alternatives uses in the context of novel tasks, regardless of whether tool function is emphasized or not. Different from Maier's study (1931), we did not assume the functional information that participants had about each tool, but we instead experimentally manipulated the specific information we wanted them to have.

These results are consistent with studies that have been conducted in the context of other cognitive tasks (Chrysikou et al., 2016), as they have also shown that there is no need to emphasize the function of a known object to generate functional fixedness.

4.5. Individual differences affect functional fixedness

Our results suggested that knowledge of intuitive physics and fine motor skills influenced how functional fixedness interfered with mechanical problem solving. Namely, better knowledge of intuitive physics and better fine motor skills were associated with greater solution accuracy. Intuitive physics scores were also related to other outcome variables, such as total, planning, and execution times. In contrast, our results did not suggest a role for creativity in the generation of functional fixedness.

The fact that higher intuitive physics scores were linked to lower functional fixedness suggests that a better understanding of how objects interact can be a protective factor against the detrimental effects of receiving misleading functional information. Interestingly, this type of knowledge protected against functional fixedness across all the outcome variables measured in this study. Future experiments will be needed to investigate whether intuitive physics knowledge is always a protective factor against functional fixedness or whether its effects are only restricted to contexts of mechanical problem solving.

Fine motor skills were associated with higher solution accuracy and shorter execution times, but not with total or planning times. These results raise the question of why individuals with better motor skills suffered less functional fixedness than their counterparts with lower abilities. Fine motor skills have been found to promote object exploration (Wiesen et al., 2016) and thus it is possible that these participants were able to extract valuable information via manual object exploration to discern alternative uses for tools. Given the correlational nature of our data, future studies will be needed to disentangle the exact contribution of this variable to the modulation of functional fixedness.

Our results with respect to creativity scores are consistent with a recent study suggesting that divergent thinking does not necessarily predict innovative problem solving in children (Beck et al., 2016), but are at odds with adult studies indicating that creativity plays a role in problem solving (DeYoung et al., 2008). This discrepancy is probably linked to the test we used to assess creativity (i.e. Alternative Uses Task), as it required participants to freely indicate alternative uses for objects without stipulating conditions circumscribed by physical limitations. In contrast to the Alternative Uses Task, mechanical problem solving requires the search process for alternative uses to be constrained by the physical properties of the mechanical puzzles, as well as by the need to achieve a well-defined goal. Additionally, these results are also consistent with neuropsychological literature indicating that while mechanical problem solving is associated with the left inferior parietal cortex but not with the frontal cortex (Goldenberg & Hagmann, 1998; Goldenberg & Spatt, 2009), unbound creativity is linked to activity in the frontal and prefrontal cortices (Carlsson, Wendt, & Risberg, 2000; Heilman, Nadeau, & Beversdorf, 2003).

5. Conclusion

The current study focused on different aspects related to the generation of functional fixedness. Consistent with previous studies (Defeyter & German, 2003; German et al., 2008; German & Barrett, 2005; German & Defeyter, 2000), our experimental manipulation indicated that misleading functional knowledge is at the core of this cognitive bias. Specifically, when dealing with novel mechanical problems, learned, misfit functional information can adversely affect performance. Our data also suggested that different modalities of learning do not change the amount of functional fixedness that affects performance; that the influence of functional fixedness is confined to simple mechanical problems and dissipates after an initial encounter with a problem; further, it showed that individual differences in performance exist and may be due to prior intuitive physics knowledge and fine motor skills.

Contrary to the previously held assumption that functional fixedness is a widespread phenomenon that always interferes with problem solving, our results indicated that this bias is confined to easy problems. This significantly reduces the importance of this cognitive bias in the explanation of cognitive impasses.

Acknowledgements

Felipe Munoz-Rubke would like to thank Fulbright and CONICYT for financial support provided through an academic scholarship. The authors would also like to thank Rick Moore and Jesse Goode, who are part of the Technical Support Group of the Department of Psychological and Brain Sciences at Indiana University, for their invaluable help in the creation of the mechanical puzzles used in this study.

Declaration of interest statement

The authors declare no competing financial interests.

Research involving human participants

All procedures performed in studies involving human participants were in accordance with the ethical standards of the Indiana University Bloomington Institutional Review Board.

Appendix A

1. *Scale Balance*: In this puzzle, there is a wooden bar with 3 weights hung asymmetrically on it, such that one side is heavier than the other. The goal is to balance the bar so that it is parallel to the wooden tray the task is on. The solution is to introduce a cylindrical tool underneath the bar, off-center towards the heavier side, to balance the bar parallel
2. *Scale Prop*: In this puzzle, there is a wooden scale and 3 different weights. The first weight is made of metal, the second is made of wood, and the third is made of styrofoam. The goal is to balance this scale parallel to the wooden tray the task is on. The solution is to introduce a wooden rectangular tool underneath any side of the scale to prop the scale to parallel. The weights can then be put on the same side as the wooden rectangular tool.
3. *Box Flap*: In this puzzle, one marble is located on top of the bottom surface of a transparent plastic structure. The goal is to remove the marble from the box. The plastic structure has 2 holes, but only one

of them can be used to successfully solve the problem. The solution is to introduce a hook-like tool through the correct hole to push a plastic flap located within the plastic structure, which in turn will move a mechanism (visible to the participant) that will lift the floor of the plastic structure. This movement brings the marble to the entrance of the correct hole such that it can be easily retrieved.

4. *Marble Push*: In this puzzle, a marble is located within a hollow rubber circle that is itself positioned on the floor of a transparent plastic cube. Underneath the rubber circle there is a PVC structure connecting the floor of the transparent structure with the wooden tray. The goal is to get the marble out of the box. There is one hole in superior face of the cube and two holes on one of the sides. The solution is to introduce a spiral-like tool through the correct lateral hole and push the marble down the hole.
5. *PVC Pipe*: In this puzzle, there is a tube that contains a metal platform. The tube is attached to a wooden tray. The metal platform is located halfway up the tube and has a marble atop it. There is a hole located on the top of the tube and a hole at the base of the tube. Additionally, there is a vertical slit that is adjacent to the metal platform. The goal is to remove the marble from the tube. The solution is reached by using a short rod to rotate the metal platform through the slit. The marble will fall and roll out the hole at the base of the tube.
6. *Weight Wheel*: In this puzzle, there is a large, elevated wheel that contains a string within crevices of the wheel. The string is attached to a reel on one side of the wheel and a weight on the other side, making up a pulley mechanism. The string is attached to the reel through a hole in the center and contains an arm that can be rotated to spin the string. The goal is to make the weight remain elevated at the base of the wheel. The solution is achieved by using an s-shaped tool to hook one end around the string and insert the other end of the s into a hole in the reel.

Appendix B

Scale Balance (Solution = Circle Tracer)

1. Architect's Right Angle Triangle: This object is a wooden triangle, thicker at the base and narrowing to its top point. Its function is to provide a stencil for easily and rapidly drawing 90-degree angles.
2. Circle Tracer: This object is a section of PVC pipe. Its function is to provide a stencil for easily and rapidly drawing a circle.
3. Compass: This object is a wooden cylinder with a wooden rectangle attached to the top. A pencil is attached to the end of the rectangle opposite from the cylinder. Its function is to draw a large circle, with the cylinder in the middle as the center of circle.

Scale Prop (Solution = Field Scale):

1. Field Scale: This object is a small rectangular wooden block, spray-painted green with a ruler scale added. Its function is to provide reference size in pictures of plants and insects.
2. Go-Bar: This object is a thin sheet of metal, with rounded edges forming a flat hook on either side of the bar. Its function is to act a smaller version of a crowbar, providing leverage for tasks such as opening lids.
3. Paperweight: This object is a small square plastic block. Its function is to hold papers down so they do not blow away in a breeze.

Box Flap (Solution = Hook):

1. Bottle Opener: This object is a white plastic piece with a curved edge at the end and middle of the object. Its function is to take the caps off bottles.
2. Hook: This object is a thin metallic cylinder, with a curved end making a hook. Its function is to hang objects off its hook.
3. Vertical Paintbrush: This object is a small wooden cylinder with a foam paintbrush head attached at a 90-degree angle. Its function is to paint thick and thin lines, in a vertical, rather than normal horizontal, fashion.

Marble Push (Solution = Drink Mixer):

1. Drink Mixer: This object has a spiral structure that is used to combine different liquids into one. It is composed of a flexible material that is relatively firm. The tool is spun and stirred to efficiently combine drinks.
2. Hammer: This object is made up of a rectangular wooden handle attached perpendicularly to a rubber cylinder. The wooden handle is wider at the bottom and gets narrower towards the part attached to the cylinder. Participants used the hammer by gripping the handle and striking objects with the flat face of the cylinder. It is typically used to drive in nails.
3. Medicine Container: This object is made up of an expandable tube and a lid that plugs the end of the tube. It is used as a portable medicine container. Medicine is poured into the tube, which is then sealed with the lid. The flexible structure of the container allows the medicine to be taken anywhere.

PVC Pipe (Solution = Dowel Rod):

1. Dowel Rod: This object is a small wooden rod that is used to connect elements together. The dowel rod can connect objects through inserting it into holes that have the same circumference as the rod.
2. Paint Mixer: This object is a wooden stick that has a wider section that makes up the handle. The narrower portion of the stick is used to mix together various paint colors. The tool is stirred in different paints to create new colors.
3. Wallet Wrench: This object is a plastic, rounded-rectangle that has a slit on one side, which allows it to be used as a wrench. Screws are placed tightly within the slit and the wrench is rotated to tighten or loosen the screws.

Weight Wheel (Solution = S-Tracer):

1. S-Tracer: This object is an s-shaped metal rod that is used to assist in drawing the letter ‘S.’ The tool is traced on either side of the ‘S’ to help produce a legible letter. The tool aids children to learn the alphabet and trauma patients to produce neat letters.
2. Sewing Spool: This object is a wooden cylinder that contains a smaller cylinder extruding from a larger cylinder. The larger cylinder has grooves along it that are intended to keep thread in place. The thread is wrapped around the larger cylinder and the sewing needle can be safely stored by stabbing it into the end of the smaller cylinder.
3. Wire-Installation Wedge: This object is a metal rectangle that contains a hole on the top half of the wide face. The tool provides support and elevates wires during the installation process. The wire is run through the holes of various wedges for an accurate and easy installation.

References

Baber, C. (2003). *Cognition and tool use: forms of engagement in human and animal use of tools.* London, New York: Taylor & Francis.

Baron-Cohen, S., Wheelwright, S., Spong, A., Scahill, V., & Lawson, J. (2001). Are intuitive physics and intuitive psychology independent? A test with children with Asperger Syndrome. *Journal of Developmental and Learning Disorders, 5*(1).

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), http://dx.doi.org/10.18637/jss.v067.i01.

Battaglia, P. W., Hamrick, J. B., & Tenenbaum, J. B. (2013). Simulation as an engine of physical scene understanding. *Proceedings of the National Academy of Sciences, 110*(45), 18327–18332. http://dx.doi.org/10.1073/pnas.1306572110.

Beck, S. R., Apperly, I. A., Chappell, J., Guthrie, C., & Cutting, N. (2011). Making tools isn't child's play. *Cognition, 119*(2), 301–306. http://dx.doi.org/10.1016/j.cognition.2011.01.003.

Beck, S. R., Williams, C., Cutting, N., Apperly, I. A., & Chappell, J. (2016). Individual differences in children's innovative problem-solving are not predicted by divergent thinking or executive functions. *Philosophical Transactions of the Royal Society, B: Biological Sciences, 371*(1690), 20150190. http://dx.doi.org/10.1098/rstb.2015.0190.

Boronat, C. B., Buxbaum, L. J., Coslett, H. B., Tang, K., Saffran, E. M., Kimberg, D. Y., & Detre, J. A. (2005). Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging. *Cognitive Brain Research, 23*(2–3), 361–373. http://dx.doi.org/10.1016/j.cogbrainres.2004.11.001.

Bryden, P. J., & Roy, E. A. (2005). A new method of administering the Grooved Pegboard Test: Performance as a function of handedness and sex. *Brain and Cognition, 58*(3), 258–268. http://dx.doi.org/10.1016/j.bandc.2004.12.004.

Butler, A. J., & James, K. H. (2013). Active learning of novel sound-producing objects: Motor reactivation and enhancement of visuo-motor connectivity. *Journal of Cognitive Neuroscience, 25*(2), 203–218. http://dx.doi.org/10.1162/jocn_a_00284.

Buxbaum, L. J. (2014). Moving the gesture engram into the 21st century. *Cortex, 57*, 286–289. http://dx.doi.org/10.1016/j.cortex.2014.01.006.

Buxbaum, L. J., & Saffran, E. M. (2002). Knowledge of object manipulation and object function: Dissociations in apraxic and nonapraxic subjects. *Brain and Language, 82*(2), 179–199. http://dx.doi.org/10.1016/S0093-934X(02)00014-7.

Buxbaum, L. J., Veramontil, T., & Schwartz, M. F. (2000). Function and manipulation tool knowledge in apraxia: Knowing "what for" but not "how.". *Neurocase, 6*(2), 83–97. http://dx.doi.org/10.1080/13554790008402763.

Canessa, N., Borgo, F., Cappa, S. F., Perani, D., Falini, A., Buccino, G., ... Shallice, T. (2008). The different neural correlates of action and functional knowledge in semantic memory: An fMRI study. *Cerebral Cortex, 18*(4), 740–751. http://dx.doi.org/10.1093/cercor/bhm110.

Carlsson, I., Wendt, P. E., & Risberg, J. (2000). On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects. *Neuropsychologia, 38*(6), 873–885.

Carr, K., Kendal, R. L., & Flynn, E. G. (2016). Eureka!: What is innovation, how does it develop, and who does it? *Child Development, 87*(5), 1505–1519. http://dx.doi.org/10.1111/cdev.12549.

Chrysikou, E. G., Motyka, K., Nigro, C., Yang, S.-I., & Thompson-Schill, S. L. (2016). Functional fixedness in creative thinking tasks depends on stimulus modality. *Psychology of Aesthetics, Creativity, and the Arts, 10*(4), 425–435. http://dx.doi.org/10.1037/aca0000050.

Colzato, L. S., Ozturk, A., & Hommel, B. (2012). Meditate to create: The impact of focused-attention and open-monitoring training on convergent and divergent thinking. *Frontiers in Psychology, 3*. http://dx.doi.org/10.3389/fpsyg.2012.00116.

Coon, D., & Mitterer, J. (2015). *Introduction to psychology: gateways to mind and behavior.* Boston, MA: Cengage Learning.

Defeyter, M. A., & German, T. P. (2003). Acquiring an understanding of design: Evidence from children's insight problem solving. *Cognition, 89*(2), 133–155. http://dx.doi.org/10.1016/S0010-0277(03)00098-2.

DeYoung, C. G., Flanders, J. L., & Peterson, J. B. (2008). Cognitive abilities involved in insight problem solving: An individual differences model. *Creativity Research Journal, 20*(3), 278–290. http://dx.doi.org/10.1080/10400410802278719.

Duncker, K. (1945). On problem-solving. *Psychological Monographs, 58*(5), i–113. http://dx.doi.org/10.1037/h0093599.

Fischer, J., Mikhael, J. G., Tenenbaum, J. B., & Kanwisher, N. (2016). Functional neuroanatomy of intuitive physical inference. *Proceedings of the National Academy of Sciences, 113*(34), E5072–E5081. http://dx.doi.org/10.1073/pnas.1610344113.

Frey, S. H. (2007). What puts the how in where? Tool use and the divided visual streams hypothesis. *Cortex, 43*(3), 368–375. http://dx.doi.org/10.1016/S0010-9452(08)70462-3.

German, T., Truxaw, D., & Defeyter, M. (2008). The role of information about "convention", "design", and "goal" in representing artificial kinds. *New Directions for Child and Adolescent Development,* 69–81.

German, T. P., & Barrett, H. C. (2005). Functional fixedness in a technologically sparse culture. *Psychological Science, 16*(1), 1–5. http://dx.doi.org/10.1111/j.0956-7976.2005.00771.x.

German, T. P., & Defeyter, M. A. (2000). Immunity to functional fixedness in young children. *Psychonomic Bulletin & Review, 7*(4), 707–712.

Gilhooly, K. J., Fioratou, E., Anthony, S. H., & Wynn, V. (2007). Divergent thinking: Strategies and executive involvement in generating novel uses for familiar objects. *British Journal of Psychology (London, England: 1953), 98*(Pt 4), 611–625. http://dx.doi.org/10.1348/096317907X173421.

Goldenberg, G. (2013). *Apraxia: The cognitive side of motor control* (1st ed.). Oxford: Oxford University Press.

Goldenberg, G., & Hagmann, S. (1998). Tool use and mechanical problem solving in apraxia. *Neuropsychologia, 36*(7), 581–589. http://dx.doi.org/10.1016/S0028-3932(97)00165-6.

Goldenberg, G., & Spatt, J. (2009). The neural basis of tool use. *Brain, 132*(6), 1645–1655. http://dx.doi.org/10.1093/brain/awp080.

Goldstein, E. B. (2011). *Cognitive psychology: connecting mind, research, and everyday experience* (3rd ed.). Australia: Belmont, CA: Wadsworth Cengage Learning.

Guilford, J. P., Christensen, P. R., Merrifield, P. R., & Wilson, R. C. (1978). *Alternate uses: Manual of instructions and interpretations.* Orange, CA: Sheridan Psychological Services.

Gupta, N., Jang, Y., Mednick, S. C., & Huber, D. E. (2012). The road not taken: Creative solutions require avoidance of high-frequency responses. *Psychological Science, 23*(3), 288–294. http://dx.doi.org/10.1177/0956797611429710.

Harman, K. L., Humphrey, G. K., & Goodale, M. A. (1999). Active manual control of object views facilitates visual recognition. *Current Biology, 9*(22), 1315–1318. http://dx.doi.org/10.1016/S0960-9822(00)80053-6.

Hegarty, M. (2004). Mechanical reasoning by mental simulation. *Trends in Cognitive Sciences, 8*(6), 280–285. http://dx.doi.org/10.1016/j.tics.2004.04.001.

Heilman, K. M., Nadeau, S. E., & Beversdorf, D. O. (2003). Creative innovation: Possible brain mechanisms. *Neurocase, 9*(5), 369–379. http://dx.doi.org/10.1076/neur.9.5.369.16553.

Hespos, S. J., & vanMarle, K. (2012). Physics for infants: Characterizing the origins of knowledge about objects, substances, and number. *Wiley Interdisciplinary Reviews: Cognitive Science, 3*(1), 19–27. http://dx.doi.org/10.1002/wcs.157.

James, K. H., & Bose, P. (2011). Self-generated actions during learning objects and sounds create sensori-motor systems in the developing brain. *Cognition, Brain, Behavior: An Interdisciplinary Journal, 15*(4), 485–503.

Jarry, C., Osiurak, F., Delafuys, D., Chauviré, V., Etcharry-Bouyx, F., & Le Gall, D. (2013). Apraxia of tool use: More evidence for the technical reasoning hypothesis. *Cortex, 49*(9), 2322–2333. http://dx.doi.org/10.1016/j.cortex.2013.02.011.

Kaiser, M. K., Proffitt, D. R., & McCloskey, M. (1985). The development of beliefs about falling objects. *Perception & Psychophysics, 38*(6), 533–539. http://dx.doi.org/10.3758/BF03207062.

Knoblich, G., Ohlsson, S., Haider, H., & Rhenius, D. (1999). Constraint relaxation and chunk decomposition in insight problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(6), 1534–1555. http://dx.doi.org/10.1037/0278-7393.25.6.1534.

Kuznetsova, A., Brockhoff, P., & Christensen, R. (2016). LmerTest: Tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package). Retrieved from https://cran.r-project.org/web/packages/lmerTest/index.html.

Macgregor, J. N., & Cunningham, J. B. (2008). Rebus puzzles as insight problems. *Behavior Research Methods, 40*(1), 263–268. http://dx.doi.org/10.3758/BRM.40.1.263.

Macgregor, J. N., Ormerod, T. C., & Chronicle, E. P. (2001). Information processing and insight: A process model of performance on the nine-dot and related problems. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 27*(1), 176–201.

Maier, N. R. F. (1931). Reasoning in humans. II. The solution of a problem and its appearance in consciousness. *Journal of Comparative Psychology, 12*(2), 181–194. http://dx.doi.org/10.1037/h0071361.

McCaffrey, T. (2012). Innovation relies on the obscure: A key to overcoming the classic problem of functional fixedness. *Psychological Science, 23*(3), 215–218. http://dx.doi.org/10.1177/0956797611429580.

Mccaffrey, T. (2016). A visual representation to quantitate, diagnose, and improve creativity in insight problem solving. *Journal of Creative Behaviour, 52*(1), 52–65. https://doi.org/10.1002/jocb.132.

McCloskey, M. (1983). Intuitive physics. *Scientific American, 248*(4), 122–130.

McCloskey, M., Washburn, A., & Felch, L. (1983). Intuitive physics: The straight-down belief and its origin. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 9*(4), 636–649. http://dx.doi.org/10.1037/0278-7393.9.4.636.

Ohlsson, S. (1984a). Restructuring revisited.: I. Summary and critique of the Gestalt theory of problem solving. *Scandinavian Journal of Psychology, 25*(1), 65–78. http://dx.doi.org/10.1111/j.1467-9450.1984.tb01001.x.

Ohlsson, S. (1984b). Restructuring revisited.: II. An information processing theory of restructuring and insight. *Scandinavian Journal of Psychology, 25*(2), 117–129. http://dx.doi.org/10.1111/j.1467-9450.1984.tb01005.x.

Öllinger, M., Jones, G., & Knoblich, G. (2014). The dynamics of search, impasse, and representational change provide a coherent explanation of difficulty in the nine-dot problem. *Psychological Research, 78*(2), 266–275. http://dx.doi.org/10.1007/s00426-013-0494-8.

Osiurak, F. (2014). What neuropsychology tells us about human tool use? The four constraints theory (4CT): Mechanics, space, time, and effort. *Neuropsychology Review, 24*(2), 88–115. http://dx.doi.org/10.1007/s11065-014-9260-y.

Osiurak, F., Aubin, G., Allain, P., Jarry, C., Richard, I., & Le Gall, D. (2008). Object utilization and object usage: A single-case study. *Neurocase, 14*(2), 169–183. http://dx.doi.org/10.1080/13554790802108372.

Osiurak, F., & Badets, A. (2016). Tool use and affordance: Manipulation-based versus reasoning-based approaches. *Psychological Review*. http://dx.doi.org/10.1037/rev0000027.

Osiurak, F., Jarry, C., Allain, P., Aubin, G., Etcharry-Bouyx, F., Richard, I., ... Le Gall, D. (2009). Unusual use of objects after unilateral brain damage. The technical reasoning model. *Cortex, 45*(6), 769–783. http://dx.doi.org/10.1016/j.cortex.2008.06.013.

Patrick, J., & Ahmed, A. (2014). Facilitating representation change in insight problems through training. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*(2), 532–543. http://dx.doi.org/10.1037/a0034304.

R Core Team (2016). *R: A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical Computing.

Reed, S. K. (2013). *Cognition: Applications and theories.* Belmont, CA: Wadsworth, Cengage Learning.

Reed, S. K. (2016). The structure of ill-structured (and well-structured) problems revisited. *Educational Psychology Review, 28*(4), 691–716. http://dx.doi.org/10.1007/s10648-015-9343-1.

Sellaro, R., Hommel, B., de Kwaadsteniet, E. W., van de Groep, S., & Colzato, L. S. (2014). Increasing interpersonal trust through divergent thinking. *Frontiers in Psychology, 5*. http://dx.doi.org/10.3389/fpsyg.2014.00561.

Sirigu, A., Duhamel, J.-R., & Poncet, M. (1991). The role of sensorimotor experience in object recognition: A case of multimodal agnosia. *Brain, 114*(6), 2555–2573. http://dx.doi.org/10.1093/brain/115.2.645-a.

Sperber, D., Premack, D., & Premack, A. J. (Eds.). (2002). *Causal cognition: a multidisciplinary debate*Oxford: Clarendon Press.

van Elk, M., van Schie, H., & Bekkering, H. (2014). Action semantics: A unifying conceptual framework for the selective use of multimodal and modality-specific object knowledge. *Physics of Life Reviews, 11*(2), 220–250. http://dx.doi.org/10.1016/j.plrev.2013.11.005.

Wiesen, S. E., Watkins, R. M., & Needham, A. W. (2016). Active motor training has long-term effects on infants' object exploration. *Frontiers in Psychology, 7*. http://dx.doi.org/10.3389/fpsyg.2016.00599.

Xu, R. (2003). Measuring explained variation in linear mixed effects models. *Statistics in Medicine, 22*(22), 3527–3541. http://dx.doi.org/10.1002/sim.1572.

Yancosek, K. E., & Howell, D. (2009). A narrative review of dexterity assessments. *Journal of Hand Therapy, 22*(3), 258–270. http://dx.doi.org/10.1016/j.jht.2008.11.004.

Zago, M., & Lacquaniti, F. (2005). Cognitive, perceptual and action-oriented representations of falling objects. *Neuropsychologia, 43*(2), 178–188. http://dx.doi.org/10.1016/j.neuropsychologia.2004.11.005.