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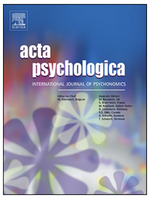

Functional fixedness in tool use: Learning modality, limitations and individual differences

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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

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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