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Young children's tool innovation across culture: Affordance visibility matters

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ABSTRACT

Young children typically demonstrate low rates of tool innovation. However, previous studies have limited children's performance by presenting tools with opaque affordances. In an attempt to scaffold children's understanding of what constitutes an appropriate tool within an innovation task we compared tools in which the focal affordance was visible to those in which it was opaque. To evaluate possible cultural specificity, data collection was undertaken in a Western urban population and a remote Indigenous community. As expected affordance visibility altered innovation rates: young children were more likely to innovate on a tool that had visible affordances than one with concealed affordances. Furthermore, innovation rates were higher than those reported in previous innovation studies. Cultural background did not affect children's rates of tool innovation. It is suggested that new methods for testing tool innovation in children must be developed in order to broaden our knowledge of young children's tool innovation capabilities.

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1. Introduction

The extent to which humans innovate with tools remains unparalleled within the animal kingdom (Carr, Kendal, & Flynn, 2016; Vaesen, 2012). Yet the capacity for tool innovation appears curiously absent in young children, with multiple studies showing that prior to 8 years of age children struggle to innovate even simple tools on their own (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Beck, Williams, Cutting, Apperly, & Chappell, 2016; Cutting, 2013; Cutting, Apperly, Chappell, & Beck, 2014; Nielsen, 2013). This is curious, as from a young age children are adept tool users (Brown, 1990; Connolly & Dalgleish, 1989; Harris, 2005). However, previous studies may have limited children's performance by presenting tools with opaque affordances. In addition, the vast majority of testing to date has been conducted using the same methodology, and tested almost exclusively children from Western cultural backgrounds (Nielsen, Tomaselli, Mushin, & Whiten, 2014). These factors may individually or in combination lead to apparent tool innovation failure that may not accurately portray children's true capacities.

Children are driven to explore and utilize the material world around them (Bakeman, Adamson, Konner, & Barr, 1990; Bock, 2005; Gaskins, 2000; Kaye, 1982; Keller et al., 2009; Little, Carver, & Legare, 2016; Piaget & Cook, 1952; Rogoff et al., 1993). By the age of four months, infants from Western and traditional societies demonstrate a sustained interest in objects, and by 8–11 months begin to engage in relational play with objects (Belsky & Most, 1981; Bjorklund & Gardiner, 2011; Bourgeois, Khawar, Neal, & Lockman, 2005; Konner, 1976). This interest persists well into the early childhood years, manifesting as object play, construction and manipulation (Bakeman et al., 1990; Belsky & Most, 1981; Bock & Johnson, 2004; Little et al., 2016; Smith & Simon, 1984), as children examine the causal relationships existing between objects and the environment (Bjorklund & Gardiner, 2011; Lockman, 2000; Pepler & Rubin, 1982; Piaget & Cook, 1952). At the age of nine months children begin to use tools to reach for objects far away from them (Willatts, 1984), and by two years they can competently use tools such as spoons and rakes (Brown, 1990; Connolly & Dalgleish, 1989; Harris, 2005; McCarty, Clifton, & Collard, 2001). They can even invent simple tool-use behaviors independently by three years (Reindl, Beck, Apperly, & Tennie, 2016). Young children are also capable of tool manufacture: constructing or modifying tools after watching an adult manipulate relevant materials (Barr & Hayne, 1999; Bauer,

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Hertsgaard, & Wewerka, 1995; Beck et al., 2011; Cutting, Apperly, & Beck, 2011). While tool manufacture occurs following observation or instruction on how to make the ideal tool (Cutting et al., 2011; Shumaker, Walkup, & Beck, 2011), tool innovation necessitates the construction of a novel tool that is designed by the individual without previously witnessing a demonstration of the means to do so (Cutting et al., 2011). This is a cognitively demanding feat: first the child must generate an ideal tool shape that might solve a task, then they must develop an action plan for creating that ideal tool shape, and finally execute that to an adequate degree to ensure success. It is perhaps unsurprising, then, that children of 4–5 years of age struggle to innovate new tools (Beck et al., 2011; Cutting, 2013; Cutting et al., 2014).

However, by this age children demonstrate developing capabilities in means-end reasoning, working memory, inhibitory control and causal understanding, which are purported to be involved in such multi-step problem solving (Bechtel, Jeschonek, & Pauen, 2013; Brown, 1990; Chappell, Cutting, Apperly, & Beck, 2013; Chappell et al., 2015; Gardiner, Bjorklund, Greif, & Gray, 2012; Garon, Bryson, & Smith, 2008; Miyake et al., 2000; Pauen & Bechtel-Kuehne, 2016; Pauen & Wilkening, 1997; Reader, Morand-Ferron, & Flynn, 2016; although see Beck et al. (2016) for a lack of relationship between tool innovation and executive function). They have an appreciation of affordances: the relation between an object and an actor, and object and the environment, which provides the actor with an opportunity to perform an action, should they recognise it (Gibson, 1969, 1979; Norman, 2013). This begins in infancy with an exploration of object properties such as pliability, flexibility and rigidity (Bourgeois et al., 2005; Fontenelle, Kahrs, Neal, Newton, & Lockman, 2007; Geary, 2005), and progresses to investigations into object relations between form and function in the second year (Bjorklund & Gardiner, 2011; Brown, 1990; Madole, Oakes, & Cohen, 1993; Pauen & Bechtel-Kuehne, 2016). In this way children learn that an object's form affords action: a spoon affords scooping, and a hook affords pulling (Bjorklund & Gardiner, 2011; Gibson, 1969). Given the sophisticated cognitive toolkit young children are developing, it is reasonable to expect them to be better at tool innovation, yet they appear not to be.

To date, almost all studies examining children's tool innovation have employed the same basic methodology. The task, which was first administered to New Caledonian crows (Weir, Chappell, & Kacelnik, 2002), involves retrieving a bucket and reward from a long, vertical tube using some form of pliable material. For children, the reward consists of a toy and sticker, which are placed into the bucket, and lowered to the base of the narrow tube. Children are presented with a straight pipecleaner and some distractor items (e.g., a string and some match sticks), and told that these things might help them in retrieving the toy from the tube. Children are then given one minute to retrieve the toy. In order to be successful on the task, children must innovate a novel tool from the materials provided. Without seeing a demonstration of how to do so, they must select the straight pipecleaner and bend its end into a hook-shape, so that it may be placed down the tube and hooked onto the bucket's handle to lift it up.

Young children find this task extremely challenging: Across a number of studies, only 8–20% of 4–5 year-olds spontaneously make a hook with the pipecleaner (Beck et al., 2011; Chappell et al., 2013; Cutting et al., 2014; although see Sheridan, Konopasky, Kirkwood, and Defeyter (2016) for performance of 44% in 4–5 year-olds). It is only at about 8–9 years of age that 60–65% of children innovate the ideal hooked tool (Beck et al., 2011). When compared with high innovation rates of over 90% in adult samples, it appears that young children are particularly poor at innovating in this task.

What, then, might make this task so difficult for young children? One reason may be its "ill-structured" nature (Chappell et al., 2013). In ill-structured problems, key information necessary for the successful solving of the problem is omitted from the available stimuli (Goel & Grafman, 2000; Wood, 1983). This information must therefore be internally generated by the individual in order for the task to be solved. For example, in the pipecleaner task previously described, children are provided with information about the starting material state (use a pipecleaner, string or matchstick), and the goal state (retrieve the bucket from the tube), but no information is given about how the starting materials might be transformed in order to successfully achieve this end. Instead, the child must independently determine two things: an ideal tool shape to use on the task (a hooked tool), and a strategy on how to construct that shape from the available materials (bend the pipecleaner; Bongers, Smitsman, & Michaels, 2003; Cox & Smitsman, 2006).

Consequently, one reason why children may fail to generate the ideal tool shape is because they may not detect the appropriate affordance existing within the material. There is much evidence to show that perceptual information incongruent with the causal properties of a tool will lower overall tool performance (Bates, Carlson-Luden, & Bretherton, 1980; Gardiner et al., 2012; Gentner & Markman, 1997; Pierce & Gholson, 1994; Rattermann & Gentner, 1998; Winner, Rosenstiel, & Gardner, 1976). A hooked pipecleaner has a "visible" affordance: its ability to complete the action of 'hooking' onto the bucket is perceptually obvious. In contrast, in the classic tube problem, the straight pipecleaner offered has a "hidden" affordance: although it has the potential to be bent into a hook, this cannot be perceived in its current state. By providing a hooked pipecleaner, children are given clear information about how the tool might effectively be used to achieve the goal of retrieving the bucket. The straight pipecleaner, however, could have any number of uses or the potential for multiple transformations within the task, and success relies on the child arriving on this hook shape on his or her own in order for it to be used effectively.

Similarly, children perform best at tool-use tasks when the causal link between a tool's form and its function is highlighted (Bechtel et al., 2013; Gardiner et al., 2012; Goswami & Brown, 1990; Pierce & Gholson, 1994; Winner et al., 1976). Indeed, children's success on the pipecleaner task elevates if they are given an indication of the ideal tool shape required. Beck et al. (2011) gave children the choice between using a hooked pipecleaner or a straight pipecleaner, and children reliably selected the hooked pipecleaner and used it on the task. This suggests that children can recognise a hook-shape as providing the necessary affordance needed to solve the task, but that they struggle to generate this tool shape on their own.

Alternatively, children might be able to generate the idea of a hooked tool, but struggle to develop an action plan that will transform the straight pipecleaner into that ideal tool (Bjorklund & Gardiner, 2011). Indeed, children will readily copy an adult's demonstration of how to make a hook – once they see how to bend the pipecleaner's end upwards, they copy this action and swiftly apply it to the tube problem (Beck et al., 2011; Cutting et al., 2011). This suggests again that children are able to recognise the value of a hooked tool and can readily map the action plan they observed onto their physical materials to create an adequate tool themselves.

Although such scaffolding procedures are valuable in verifying some of the cognitions that underlie children's tool use, by providing a hooked tool template, they also remove the 'innovative' element of the task. These studies have reduced the tube problem from one requiring tool innovation, in which no example of an

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