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.

Keywords: cross-cultural, tool manufacture, tool innovation, innovation, affordance, cognitive development

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 behaviours 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, 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 to 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, & 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 and colleagues (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 ideal tool is provided, to one requiring tool manufacture (where a template tool is constructed for the child to copy) or tool use (where the appropriate tool must be selected from an array). It is still unknown whether adding information about the ideal tool shape needed *without* providing an example of the exemplar tool might see equal improvement in children's performance on the task.

The current study thus aimed to examine whether providing a pipecleaner that had its hooked affordance visible, but required innovation in another form, would see children's performance improve on the tube problem. We provided a hooked pipecleaner that had the non-hook end curled over and hence required unbending in order to create the ideal tool. Children thus needed to innovate on the non-hook end of the tool to make it long and straight. This was compared to the performance of children who received the straight pipecleaner as per the classic task, which required one end to be bent into a hook.[1] It was hypothesised that children provided with the focal affordance of the target tool (the hook shape) would select this tool more often against a distractor and correctly innovate on the tool at higher rates than children for whom the affordances remained invisible. Providing visual information would reduce the cognitive load inherent in the task, because children would only be required to recognize, rather than generate, the appropriate affordance (and therefore function) of the tool for the task.

Further, calls remain strong for data collection in psychology to move away from reliance on homogenous samples, and specifically those that are Westernised, Educated, Industrialised, Rich, and Democratic (WEIRD; Henrich, Heine, & Norenzayan, 2010; Legare & Harris, 2016; Legare & Nielsen, 2015; Nielsen & Haun, 2016; Rowley & Camacho, 2015). This issue is particularly pertinent here with only one study to date examining a non-WEIRD sample, finding poor tool innovation in Southern African Bushman children similar to that of Western children (Nielsen et al., 2014). However, a child's detection or interpretation of object affordances will be influenced by how they see others interacting with similar objects, and so may be culturally defined (Bakeman et al., 1990; Flynn, 2008; Little et al., 2016; Tennie, Call, & Tomasello, 2009; Tomasello & Call, 1997; Whiten & Flynn, 2010). The extent to which children's poor innovation capabilities are culturally-dependent or biologically universal thus remains largely uncharted. We therefore undertook data collection in two distinct cultural samples – children living in a typical WEIRD city

[1] Previous research examining children's tendency to bend and unbend materials in an innovation task found no difference in their ability to perform such actions (Cutting, 2013). Both actions are considered to fall under the manufacture mode of 'reshaping', and thus should be represented similarly (Kacelnik, Chappell, Weir, & Kenward, 2006). It is unlikely then that any elevated performance seen on the Hook Visible pipecleaner would be due to a difference in the difficulty required to construct the ideal tool shape.

and children living in a remote, Indigenous Australian community. Following recent approaches (Little et al., 2016), our goal here was not to emphasize the dichotomy between Western and Non-Western populations but rather to enable better articulation of the universality of young children's tool innovation abilities. Hence no hypotheses regarding potential differences between these two communities were generated.

Method

Participants

Thirty Indigenous Australian children (16 male, 14 female) aged between 3 and 5 years (M = 4 years 3 months, range = 3 years 2 months to 5 years 10 months) participated in this experiment. Four additional children were tested, but their data was excluded due to excessive shyness ($N = 3$) or recording failure ($N = 1$). These children were residents of the Borroloola and Robinson River Aboriginal communities in Northern Australia. Borroloola is a remote town of roughly 1500 inhabitants, with a predominantly Aboriginal population. Robinson River is situated approximately 150 kms Southeast of Borroloola, and consists of an Aboriginal community of about 250 residents. Aboriginal residents of Borroloola mostly identify as one of four language groups - Garrwa, Yanyuwa, Mara and Gudanji – while the residents of Robinson River are majorly Garrwa. These groups have co-existed for many generations, predating European incursion (Mushin, 2012a, 2012b). Both came into contact with European settlers in the late 19th century when the country was taken for cattle pasture. Many groups were decimated by this event, through disease, starvation and violence (Roberts, 2005). Over the first half of the 20th century, many of the residents worked on cattle stations as domestic workers and stockmen. Today, residents live in extended family groups in houses, but much of everyday life occurs outside in public areas (Baker, 1999). Traditional practices of hunting or foraging for traditional foods, as well as ceremonial rites such as initiation, still occur. Children have access to public schooling and preschools, playgroups and crèches. Here children interact with non-indigenous people and are taught the English language. However, everyday conversations between the children use a local vernacular language (a creole). Apart from Westernised schooling and exposure to television, children and the larger community have little contact with Western society.

Thirty children from Brisbane also participated in this study. They were matched for age and gender with the Aboriginal children to be within three months of their matched counterpart (N = 30, 16 male, 14 female, M = 4 years 4 months, range = 3 years 5 months to 5 years 6 months). The majority were Caucasian and from middle-class socioeconomic backgrounds. Brisbane is Australia's third most populous city, with a population of 2 million. Education is compulsory until the age of 15 years, and public and private schooling is available. The predominant language spoken is English. All children in both locations were presented with a thank you gift and certificate for their participation.

Materials/Apparatus

Children were presented with a vertical plexiglass tube (22 cm height x 5 cm width) that was positioned on a wooden base. A small toy figurine and a sticker were placed inside a small plastic bucket with a wire handle. This bucket was lowered into the vertical tube by the experimenter. The tube was presented alongside two materials acting as potential tools for each condition: a thin rope (35 cm length), and a pipecleaner (30 cm in length). The rope was the same in each condition, and served as a distractor material that would not be effective in the tool innovation task. Only the pipecleaner served as an effective material in both conditions. In the Hook Visible condition, the pipecleaner was presented with a hook bent into one end, and its other end rounded over into a loop. This rendered it too short and wide to fit into the tube in its current state. The ideal action required to innovate this material effectively was to unbend the looped end to create a long and straight hooked tool (see Figure 1a). In the Hook Not Visible condition, the pipecleaner was presented straight (see Figure 1b). The ideal action required to innovate this material into an effective tool was to bend its end into a hook. Children in each sample were assigned to the Hook Visible (*N*= 16) or the Hook Not Visible (*N*= 14) condition.

a. b. c.

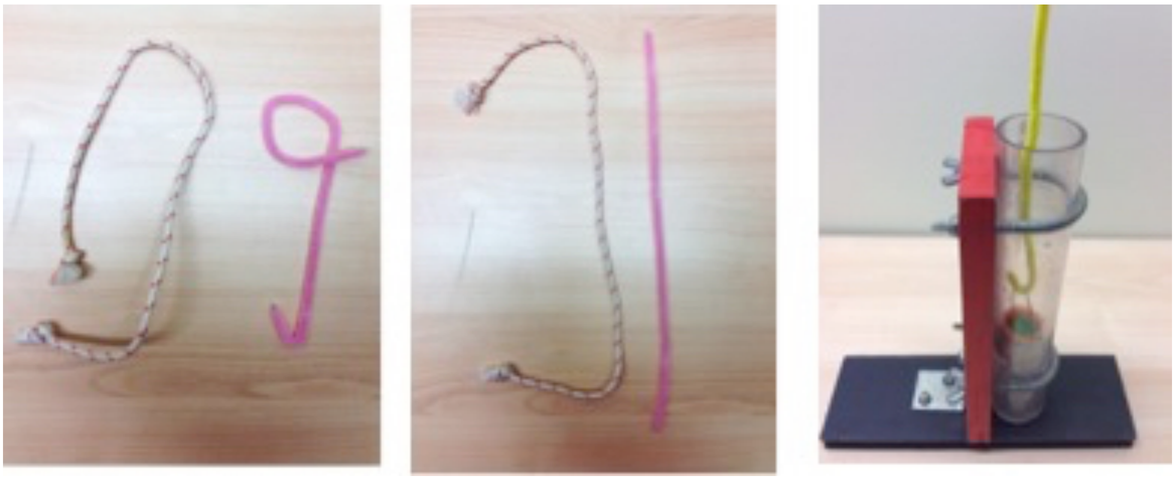

Figure 1. The a) Hook Visible and b) Hook Not Visible stimuli set, and c) the tube apparatus with the ideal tool shape displayed.

Procedure

The Borroloola children were recruited from playgroups, crèches or the public school. Parental permission was obtained through consent forms requesting a signature. Children were tested individually out of the view of other children, and were seated on a play mat directly across from an experimenter. The experimenter warmed children up to the testing scenario by playing another unrelated game with them before commencing the task. Children were often tested in the presence of a parent or teacher aide.

The Brisbane children were recruited from a database managed by the university. Children were first brought into a child-friendly warm-up room of the university for playtime with some unrelated toys. Then, children were tested in a child-friendly room of the university on a play mat on the floor, with the child facing the experimenter. Brisbane children were always tested in the presence of a parent.

Test phase. Children were shown a 'monster' figurine that was placed into a bucket 'spaceship'. Children were told that while the monster was going on an adventure, his spaceship fell down a well and got stuck. The experimenter then dropped the bucket and monster into the vertical tube out of the child's view. The experimenter brought the tube out to the front of the child, and told them that she didn't know how to get the monster out, and asked if the child could help her rescue him. The experimenter then presented the pipecleaner and rope materials and stated, "maybe these things could help you get the monster out". The child was given one minute to complete this goal to remain consistent with other innovation paradigms. The experimenter gave neutral encouragement such as "you can try anything" or "keep trying" if children hesitated on the task, but did not give any direct instruction on how to use the materials.

Demonstration phase. If children did not retrieve the toy within the time frame, the experimenter engaged in a tool-making demonstration. She pulled out another pipecleaner in the same state as that the child had received, and demonstrated the required action needed for that condition. In the Hook Visible condition, she unbent the loop to create a long, straight tool, leaving the hook present. In the Hook Not Visible condition, she bent the bottom end of the pipecleaner into a hook. She then inserted the tool into the tube, but did not scoop up the bucket. She removed this tool from the child and gave them another pipecleaner in its original form, and said, "you can have a turn". Children were given another 30 seconds to retrieve the figurine. If they were still unsuccessful, the experimenter assisted them by modifying their tool and helping them hook it onto the bucket. All children received praise when they retrieved the toy from the tube.

Coding

All coding of responses occurred from video. Our coding scheme differed slightly from that of previous innovation experiments (Beck et al., 2011; Cutting et al., 2011; Cutting et al., 2014). In previous experiments, success was coded as a correct innovation plus subsequent retrieval of the toy using the innovated tool. However we wished to separate this measure into two critical parts – first, to examine whether children actively made the ideal innovation on the tool, and separately, whether they successfully retrieved the toy from the tube. This is because we consider the construction of the novel tool to be the key measure indicating insightful innovation, and recognise that this could occur even without successful application of it to the task. We also included a measure of any innovations made by children, which was defined as any alteration in any material's form or structure occurring by deliberate action (ie. by curling or scrunching the pipecleaner, or tying the rope in knots or forming a circle with it). This was to ensure we had a measure of children's attempts to alter the states of both materials, as they may have arrived at alternative solutions than the hook to solve the task. Thus, the dependent variables recorded included: (1) which material was first touched by the child; (2) which material was first inserted into the tube; (3) whether the material was innovated upon in any way (4) whether the ideal innovation was done on the pipecleaner (bending it into a hook in the Hook Not Visible condition or unbending the loop to straighten it in the Hook Visible condition); (5) whether the ideal innovation occurred before the initial insertion into the tube or after and (6) success at retrieving the toy from the tube (either before or after a demonstration).

Inter-rater reliability tests were conducted on 10% of the videos, which were also coded by a second rater blind to the study aims and hypotheses. Coders reached agreement above .86 across all dependent measures (Cohen's kappa).

Baseline condition.

As part of the review process we were requested to provide a baseline condition to ensure any action on the test apparatus was unlikely to be attributable to children's spontaneous, non-goal-directed explorations. Thus a second sample of children who had not participated in the experiment was collected from the same Indigenous communities the following year (N = 18, 13 male, 5 female, M = 6 years 8 months, range = 4 years 10 months to 8 years 9 months), and an age-matched sample of children from the Brisbane community (N = 18, 13 male, 5 female, M = 6 years 8 months, range = 5 years 0 months to 8 years 0 months). Children were of an older age group because only the Borroloola school and preschool, but not the crèche, were available for recruiting at the time. Children received the Hook Not Visible or the Hook Visible pipecleaner alongside the rope from the experimental study. Children were simply asked to generate all the things they could do with 'these things' within a one-minute duration. Following this, they were presented with the other pipecleaner alongside the rope in a counterbalanced order for the same time.

The purpose of this condition was to examine what deliberate actions children would engage in on each material, and what overall shapes they would generate, when no direct goal was presented. This served to check whether children made the same actions on the materials habitually as they might do deliberately in an innovation task: 1) bending a hook into the Hook Not Visible pipecleaner or 2) straightening out the curled end of the Hook Visible pipecleaner and 3) straightening out the hook in the Hook Visible pipecleaner. Similarly it was recorded if 4) children would create the overall ideal Hook Not Visible (bending a hook only) and Hook Visible tool shapes (straightening out the curl while not straightening out the hook) in the absence of a goal. If children made these ideal shapes at similar rates in the baseline conditions, then the creation of these shapes could not be considered 'innovative' or goal-directed within the experimental conditions. However, if children made more ideal shapes in the experimental conditions than those made in the baseline condition, this would provide reassurance that children were making insightful innovations in the experimental task in order to achieve the goal.

Results

Chi-square tests were employed for all statistical comparisons between the Hook Visible and Hook Not Visible conditions. In comparisons with low expected cell frequencies, Fisher's exact tests were run and are reported instead. Exact McNemar tests were used to compare between children's use of each material, and binomial tests were used to assess the frequency of use against chance levels. Chance here was defined as 50% because there were only two binary outcomes available for these measures (ie. top end or bottom end of pipecleaner).

Test phase

Material choice: Children were just as likely to select and touch the pipecleaner first as the rope in both cultural groups (Borroloola: $p = .099$; Brisbane: $p = .585$, exact McNemar tests), and this did not differ between conditions (Borroloola:

χ^2 (1) = .07, p = .796, Brisbane: χ^2 (1) = .48, p = .491; see Table 1). Similarly, children were just as likely to insert the pipecleaner into the tube first as the rope in each culture (Borroloola: p = .856; Brisbane: p = 1.000; exact McNemar tests) indicating there was no immediate preference for either material in the task regardless of condition (Borroloola: χ^2 (1) = 1.16, p = .282, Brisbane: χ^2 (1) = .54, p = .464). The majority of children utilized both materials in the task during the one-minute test duration (77% of Borroloola children and 83% of Brisbane children). Therefore, perseveration with one material was rare for children of both cultures. Instead, children acted resourcefully, choosing to utilize all available materials when attempting to solve the task.

Tool innovation: Children in both cultures were more likely to innovate upon the pipecleaner than the rope by attempting to change its overall structure (Borroloola: p = .004; Brisbane: p = .004; exact McNemar tests), and this was the same regardless of condition (Borroloola: χ^2 (1) = 1.16, p = .282, Brisbane: χ^2 (1) = .62, p = .431). Notably, some children innovated the materials by combining them both together (20% of Borroloola children and 16% of Brisbane children).

Ideal Innovations: When looking at the ideal innovations required for the task: unbending the curled end of the Hook Visible pipecleaner or bending the Hook Not Visible pipecleaner, the Borroloola children were significantly more likely to make the ideal innovation on the Hook Visible pipecleaner by straightening it out than on the Hook Not Visible pipecleaner by bending it into a hook, χ^2 (1) = 5.64, p = .042 (see Table 1). A non-significant trend was observed in the Brisbane children, χ^2 (1) = 4.29, p = .058, Fisher's exact test.

Because the pattern of ideal innovation rates between each cultural group was statistically the same (p = .633, Fisher's exact test), and because sample sizes for each condition in each culture were relatively small, children's ideal tool innovation rates were compared collapsed across cultural groups. Within the combined sample, children were significantly more likely to correctly innovate on the Hook Visible pipecleaner than the Hook Not Visible pipecleaner, χ^2 (1) = 9.39, p = .002. An odds ratio indicated that the probability of children correctly innovating a tool in the Hook Visible condition (n = 13) was 9.4 times higher than in the Hook Not Visible condition (n = 2). This indicates that children were much more effective at making an ideal innovation if that innovation occurred on a tool that had its hooked affordance visible than one that did not. Further, most children that innovated the ideal tool in either condition were more likely to place it in the correct orientation (hook-end down) than not, binomial test: 13/17, p = .018.

First insertions. In both cultural groups, a number of children made the ideal innovation on their pipecleaner before inserting it into the tube for the first time, however this only occurred in the Hook Visible condition within each sample (Borroloola: 2/5 = 40%; Brisbane: 4/8 = 50%; refer Table 1). This indicates that some children could innovate in this condition from observation of the materials alone, without requiring haptic experience.

Success: Although the rate of ideal innovations made by children differed between conditions, successful retrieval of the toy and bucket by children in the test phase was similarly very low (Borroloola: p = 1.000, Fisher's exact test; Brisbane: p = 1.000). In both the Borroloola and Brisbane groups, 6% of children (1 out of 16) were able to retrieve the toy independently from the Hook Visible condition, and no child successfully retrieved the tool from the Hook Not Visible condition in either cultural group (see Table 1).

Table 1

Tool innovation as a function of cultural group and condition

Cultural Group	Condition	*n*	First Material Touched		First Material Inserted		Innovation		Ideal Innovation on Pipecleaner (%) [b]			Ideal Innovation Before First Insert		Success (%)		
			Pipecleaner	Rope	Pipecleaner	Rope	Pipecleaner	Rope	Before Demonstration	After Demonstration	With Assistance	Yes	No	Before demonstration	After Demonstration	With Assistance
Borroloola	Hook Visible	16[a]	11	5	10	6	10	3	5 (33%)	9 (60%)	1 (6%)	2	3	1 (6%)	5 (31%)	10 (63%)
	Hook Not Visible	14	9	5	6	8	6	3	0 (0%)	13 (93%)	1 (7%)	-	-	0 (0%)	8 (57%)	6 (43%)
Brisbane	Hook Visible	16	6	10	9	7	8	2	8 (50%)	7 (44%)	1 (6%)	4	4	1 (6%)	7 (44%)	8 (50%)
	Hook Not Visible	14	7	7	6	8	5	2	2 (14%)	12 (86%)	-	0	2	0 (0%)	7 (50%)	7 (50%)

[a] The Hook Visible condition in the Borroloola sample *n* = 16 for all measures except the Ideal Innovation and Ideal Innovation Before First Insert conditions (*n* = 15) due to loss of visibility in video for one participant.

[b] Hook Visible pipecleaner unbent at its top end; Hook Not Visible pipecleaner bent into a hook at its bottom end.

Demonstration phase

The children that progressed to the demonstration phase reliably imitated the experimenter's actions and constructed an ideal tool shape with the pipecleaner (Borroloola: 90%, Brisbane: 93%, collapsed across condition). This was no longer classed as an innovation but a modification, as it occurred following a demonstration. However, often this modified tool was not able to effectively reach all the way down the tube – either the tool was not straightened out to its full extent, or the hook that was bent into it was too wide to fit. Of the 14 Borroloola children and 15 Brisbane children who made these errors, 21% of Borroloola children and 58% of Brisbane children adjusted their modification by reconstructing it. Children in both cultures inserted their modified tools in the correct manner (hooked-end down) at rates significantly higher than would be expected by chance (Borroloola: 13/14, $p = .002$, binomial test; Brisbane: 11/12, $p < .001$, binomial test).

Related to these difficulties, only 41% of Borroloola children, and 48% of Brisbane children who saw a demonstration successfully retrieved the bucket without aid from the demonstrator. This level of success did not differ between the conditions, Borroloola: χ^2 (1) = 1.80, $p = .180$; Brisbane: χ^2 (1) = .032, $p = .858$. It appears then that young children found retrieving the toy and bucket using an ideal tool considerably difficult, both before and following a demonstration.

Baseline condition

Actions: The presence or absence of a goal within the task had no significant effect on how often children bent a hook into the Hook Not Visible pipecleaner for either culture, indicating that children can engage in bending actions regardless of whether they have a goal or not (Borroloola: $p = .238$; Brisbane: $p = .183$; Fisher's exact tests; see Table 2). Similarly, children in both cultures were just as likely to unbend the curl in the Hook Visible pipecleaner in the experimental and baseline conditions (Borroloola: p = .418; Brisbane: p = .291; Fisher's exact tests), and straighten out the hook (Borroloola: p = .607; Brisbane: p = .180; Fisher's exact tests), indicating that straightening actions occur regardless of whether a specific goal is present or not.

Ideal shapes: Children in both cultures were equally likely to create the ideal tool shape in the Hook Not Visible pipecleaner regardless of whether they were assigned to the baseline or experimental condition, indicating that the presence or absence of a goal was not important for its creation (Borroloola: p = 1.000; Brisbane: p = .183; Fisher's exact tests). However, this occurred at low rates in both conditions, making comparisons difficult (see Table 2).

In contrast, the presence or absence of a goal was significantly associated with how often children generated the ideal tool shape in the Hook Visible pipecleaner, with both cultural samples producing more ideal tools in the experimental condition (Borroloola: p = .013; Brisbane: p = .001; Fisher's exact tests). This suggests that this ideal tool shape was created most when the task required a tool to extract a bucket from a tube, compared to when no direct goal was provided.

Table 2

Actions and shapes constructed on the materials as a function of cultural group and condition

			Hook Not Visible Pipecleaner				Hook Visible Pipecleaner					
Cultural Group	Condition	*n*	Bend Hook?		Make Ideal Shape (%)		Unbend Curl?		Unbend Hook?		Make Ideal Shape (%)	
			Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Borroloola	Baseline	18	3	15	1 (6%)	17 (94%)	3	15	3	15	0 (0%)	18 (100%)
	Experimental	14[a], 15[b]	0	14	0 (0%)	14 (100%)	5	10	1	14	5 (33%)	10 (67%)
Brisbane	Baseline	18	0	18	0 (0%)	18 (100%)	5	13	5	13	0 (0%)	18 (100%)
	Experimental	14[a], 16[c]	2	12	2 (14%)	12 (86%)	8	8	1	15	8 (50%)	8 (50%)

[a] Total *n* for the Hook Not Visible condition for both cultural samples.
[b] Total *n* for the Hook Visible condition for the Borroloola sample.
[c] Total *n* for the Hook Visible condition for the Brisbane sample.

Discussion

Previous research has highlighted the difficulties young children experience when innovating novel tools. While children are extremely good at copying the tool-making actions they see (Beck et al., 2011; Cutting et al., 2011), or selecting adequate tools for a task (Beck et al., 2011), they struggle to design and make tools on their own (Beck et al., 2011; Beck et al., 2016; Cutting, 2013; Cutting et al., 2014). The current study sought to examine whether young children could perform better on the tube problem if they were provided with a tool that had its focal hooked affordance visible, but still required another innovation before it could become an effective tool. By comparing the performance of children who received the Hook Visible pipecleaner to those who received the Hook Not Visible pipecleaner, inferences could be made about whether children's particular struggle in such tasks originate from difficulties in generating the idea of a hooked tool. It was predicted that providing visual information about the tool's affordance would reduce the overall cognitive load involved in the problem-solving process, as children would only be required to recognize, rather than generate, the appropriate affordance required. This would lead to greater innovation performance. In addition, by testing children from two distinct cultural backgrounds, more information could be gained about the universality or specificity of children's tool innovation capacities.

The results of the current study support the notion that young children are better innovators when using tools with visible affordances. Children were nine times more likely to correctly innovate on a pipecleaner when its hook shape was made visible, compared to when it was not visible. Furthermore, the rate at which they did so was higher than in previous studies – increasing to 45% of 3-5 year-olds in comparison to typical rates of below 10% (Beck et al., 2011; Cutting et al., 2011; Cutting et al., 2014) and that of the 14% who did so in the Hook Not Visible condition. In addition, just under half of the children that received this pipecleaner were able to make the ideal innovation on it before their first insertion of it into the tube, while no child did so in the Hook Not Visible condition. This indicates that some children could perceive the affordances inherent in this material from observation alone, without requiring haptic feedback from the tool's interaction with the object before arriving on the innovation solution. This suggests that children gain greater insight into how a tool can be innovated upon to solve a task if they are provided with information on how it could be used effectively. This finding supports past research demonstrating that providing a template of the ideal hook-shape elevates children's performance (Beck et al., 2011; Cutting et al., 2014), and that children are best at problem-solving with tools that have congruent perceptual and causal information (Bechtel et al., 2013; Gardiner et al., 2012; Goswami & Brown, 1990; Pierce & Gholson, 1994; Winner et al., 1976). Conversely, children's struggle on tool innovation tasks appears to be in part due to the need to generate the ideal tool shape, and confirms that children determine the affordances of objects in part from the physical properties they can perceive (Brown, 1990; Gardiner et al., 2012; van Leeuwen, Smitsman, & van Leeuwen, 1994; Vingerhoets, Vandamme, & Vercammen, 2009).

Furthermore, this pattern of results persisted across two diverse cultural samples. Children from a rural, Indigenous community, and those from an urban, Western sample, benefitted equally from being shown a hooked tool that required innovation over a non-hooked tool that required innovation. Despite distinct differences in the family structure, cultural activities and socioeconomic standing of each community, the children's performance was similar. This provides additional support for the notion that young children, regardless of cultural upbringing, can share similar tool-related innovation abilities (Nielsen et al., 2014).

While significantly more children did recognize that the Hook Visible pipecleaner was the appropriate tool to use in the current task, this recognition was not immediate. In contrast with hypotheses, children did not select the hooked pipecleaner at higher rates than the rope in the first instance. This suggests that children may not have been perceptive to how the hooked affordance could solve the task on first presentation. Nielsen and colleagues (2014) also reported that children did not select a hooked pipecleaner over a straight pipecleaner when placed amongst multiple distractor materials. These findings contrast that of the original tool innovation study, where children chose a hooked pipecleaner significantly more often amongst two distractors (Beck et al., 2011). It is possible that children learned over the task's duration that the more pliable pipecleaner was better suited for use in the task, but that this could only occur with the experience of manipulating the materials during the task (Vaesen, 2012). Indeed, previous research has demonstrated that children's performance on such tasks is enhanced if they are shown the properties of the materials beforehand (such as their malleability; Bechtel et al., 2013; Cutting et al., 2014). This is because this provides functional information about how the material might provide the means to achieve the goal (Bechtel et al., 2013). Future research could provide children with free time to play with either pipecleaners or distractor materials before beginning the innovation task to see just how much individual exploration of the material might elevate performance.

It is curious that despite children's marked improvement in innovating ideal tools in the Hook Visible condition, their success rates at retrieving the toy were not similarly elevated. It is possible that children were not modifying the Hook Visible pipecleaner insightfully. Perhaps their straightening out of the curled end of the pipecleaner was a habitual action that they performed without thinking of how it might apply to the problem, and thus their creation of the ideal tool did not correspond with an understanding of how to solve the task. However, the baseline condition demonstrates that while children will habitually engage in the same actions of straightening either end of the Hook Visible pipecleaner in the absence of a goal, they do not habitually create the same ideal tool that children do in an innovation task – indicating that when children focus on innovating on the curled end of the hooked pipecleaner while keeping the hook intact, they are doing so insightfully and in a goal-directed manner. Furthermore, in the experimental conditions children were more likely to insert their straightened out pipecleaner in the correct orientation needed for success, with the hook component down, than not. These findings suggest children were applying their innovated tool to the task appropriately in an active attempt to retrieve the toy.

Instead, it appears that children's success suffered due to a failure to integrate the perceptual feedback of their tool manipulation to the target object (Gardiner et al., 2012; van Leeuwen et al., 1994), or a lack of fine motor skills (Bechtel et al., 2013), rather than due to a limitation of their affordance understanding. This reflects previous research demonstrating that young children are better at selecting or constructing a tool appropriate for a task than they are at successfully using it to achieve a goal (Gardiner et al., 2012; Remigereau et al., 2016). Many children on the current task made an ideal innovation on their pipecleaner, but often this action was not finalized to an adequate degree to make it long enough or straight enough to go cleanly down the tube and reach the bucket. Although a fair portion of children attempted to recalibrate their innovation, often this did not lead to subsequent success. Even following the demonstration phase, when children saw exactly how to execute an ideal innovation, less than half of children who attempted to construct the template tool did so to an appropriate degree that they succeeded. The other half required assistance from the experimenter to ensure their constructed tool could lift the bucket out of the tube. This may be in part due to the highly malleable properties of the pipecleaner: very deliberate action was required in order to construct and maintain a rigid shape within it. Perhaps then future innovation tasks could utilise a paradigm containing rigid materials more suited to young children's current level of dexterity. Similarly, a longer test time may allow children to further explore the material, and success rates may elevate as a result.

While children's innovation on tools with visible affordances was markedly higher than previously reported for 3-5 year-olds on tools with invisible affordances, their performance did not reach rates typical of 8-9 year olds (65% of children), nor the ceiling rates observed in adults (Beck et al., 2011). Just under half of the 3-5 year-olds were able to generate the solution of straightening out the hooked pipecleaner for use. This suggests that while innovative ability is certainly present in 3-5 year olds, it is still developing. It emphasizes that innovation is a skill that is refined throughout childhood and on into adulthood (Beck et al., 2011; Carr et al., 2016; Chappell et al., 2013; Cutting et al., 2011; Cutting et al., 2014; Nielsen et al., 2014). While this certainly occurs due to improvements in executive functioning and causal reasoning (Beck et al., 2016; Cutting et al., 2011; Gardiner et al., 2012; Miyake et al., 2000; Monsell, 1996), it may also occur due to increased experience in using tools and exploring their affordances first-hand. Nevertheless, the fact that innovation is inherently an ill-structured problem, in which an individual must generate and execute a method for transforming an incomplete material into an effective tool independently, means it remains a particularly challenging problem to solve (Chappell et al., 2013).

The results from the current study are encouraging, because they highlight that young children may have a greater understanding of how materials can be innovated upon to solve new problems than current literature suggests. They suggest that children's ability to innovate may indeed span across cultures (Nielsen et al., 2014). However, they also demonstrate how task difficulty may mask or limit children's intrinsic tool innovation abilities. There is great need for the development of new paradigms for testing children's tool innovation across diverse contexts (Caldwell, Cornish, & Kandler, 2016; Carr et al., 2016). Moving away from tasks that omit key information about focal tool shape, and towards tasks that provide tools with clear affordances, is one such way in which future research could provide a favorable platform for children to display innovative behavior. Similarly, providing children with opportunities to explore the materials' affordances beforehand, with longer test times, might see their performance improve. The settings in which human adults have demonstrated and implemented tool innovations are boundless. It seems at odds then that our investigation into this critical ability in development has thus far been restricted to just a couple of paradigms.

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