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The effect of prior experience on children's tool innovation

Clare L. Whalley [a,*], Nicola Cutting [b], Sarah R. Beck [a]

[a] School of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
[b] School of Psychological and Social Sciences, York St John University, Lord Mayor's Walk, York, YO31 7EX, UK

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ABSTRACT

Spontaneous tool innovation to solve physical problems is difficult for young children. In three studies, we explored the effect of prior experience with tools on tool innovation in children aged 4–7 years ($N = 299$). We also gave children an experience more consistent with that experienced by corvids in similar studies to enable fairer cross-species comparisons. Children who had the opportunity to use a premade target tool in the task context during a warm-up phase were significantly more likely to innovate a tool to solve the problem on the test trial compared with children who had no such warm-up experience. Older children benefited from either using or merely seeing a premade target tool prior to a test trial requiring innovation. Younger children were helped by using a premade target tool. Seeing the tool helped younger children in some conditions. We conclude that spontaneous innovation of tools to solve physical problems is difficult for children. However, children from 4 years of age can innovate the means to solve the problem when they have had experience with the solution (visual or haptic exploration). Directions for future research are discussed.

* Corresponding author.
E-mail address: cxw063@bham.ac.uk (C.L. Whalley).

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Introduction

Tool use is considered to be a hallmark of human cognition, with our substantial technological accomplishments unrivaled by any nonhuman animal species. Observations of infants and children demonstrate their impressive competence in terms of their tool use and knowledge. From around 2 years of age, children show insight into the function of tools (Casler & Kelemen, 2005) and anticipate the target of a tool use action (Paulus, Hunnius, & Bekkering, 2011). In addition, 3-year-olds reliably copy tool use from peers (Hopper, Flynn, Wood, & Whiten, 2010) and are capable of transmitting a tool use action across multiple generations (Flynn & Whiten, 2008; Hopper et al., 2010). It is surprising, then, that despite being proficient tool users, children appear to struggle to innovate tools (i.e., to make a novel tool to solve a task) without prior training (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; Cutting, Apperly, & Beck, 2011; Cutting, Apperly, Chappell, & Beck, 2014; Hanus, Mendes, Tennie, & Call, 2011; Nielsen, Tomaselli, Mushin, & Whiten, 2014; Sheridan, Konopasky, Kirkwood, & Defeyter, 2016; Tennie, Call, & Tomasello, 2009).

Recent research into children's tool innovation was motivated by studies with corvids. "Betty," a captive New Caledonian crow, spontaneously manufactured a hook from a straight piece of wire to retrieve a wire-handled bucket from a transparent tube (Weir, Chappell, & Kacelnik, 2002). Researchers were investigating whether crows could choose the correct tool to solve a task and, on a task requiring a hook, had given them a hooked piece of wire and a straight piece of wire. When one crow flew off with the hooked tool, Betty bent the straight piece of wire to make her own hook despite not being shown how to make tools previously. In a later experiment, Betty continued to make functional hooks on the majority of trials when given only straight pieces of wire. New Caledonian crows have been directly observed making and using tools in the wild (Hunt & Gray, 2004; Rutz, Sugasawa, van der Wal, Klump, & St Clair, 2016), although not from wire or wire-like materials. However, similar findings have been replicated by Bird and Emery (2009) with captive rooks, a species that does not use tools in the wild. They were also able to select and manufacture the correct tool to solve the hook-making task used by Weir et al. (2002). Thus, it is even more surprising that children younger than 8 years demonstrate difficulty with similar problems requiring tool innovation.

In a paradigm adapted from the corvid literature, children were able to choose the appropriate tool to solve a problem requiring a hook (Beck et al., 2011). From 4 years of age, children were significantly more likely to pick up a hooked pipe cleaner than to pick up a straight one when their goal was to retrieve a handled bucket containing a sticker reward from a tube. However, when other children were given a straight pipe cleaner that required bending into a hook shape to retrieve the bucket, children younger than 5 years rarely solved the task. Performance improved with age, and it was not until 8 years that approximately half of children passed the task. Interestingly, most children found manufacturing a tool (making a tool following adult demonstration) comparatively easy. This finding appears consistent across cultures. Western and Bushman children show a similar pattern of tool innovation performance; innovating a tool independently to solve a physical problem is difficult for children aged 3–5 years, whereas manufacturing a tool following an adult demonstration is significantly easier (Nielsen et al., 2014).

Beck et al. (2011) noted that children's knowledge of tool function and ability to manufacture tools emerges significantly earlier than their ability to innovate tools. Given the findings from tasks involving corvids, children's difficulty with tool innovation has been met with curiosity. Given that many nonhuman species are known to use tools (Seed & Byrne, 2010), it is the human propensity for tool *innovation,* and the complex technologies that have arisen because of it, that sets us apart from nonhuman species. Findings such as these raise bigger questions surrounding human cognitive architecture. It is important to better understand those processes that we might share with nonhuman animals and those that may demonstrate human uniqueness (Shettleworth, 2012).

Cross-species comparisons between human children and nonhuman animals are often made (e.g., Beck et al., 2011; Cheke, Loissel, & Clayton, 2012; Engelmann, Herrmann, & Tomasello, 2012; Taylor et al., 2014). However, caution is required. To truly understand how human children differ from other species, in this case corvids, it is vital that studies are methodologically sound and fair to both species (Boesch, 2007; Shettleworth, 2012). When experimental procedures systematically differ, the value of cross-species comparisons is compromised. To date, the experiences of children and corvids on versions of the hook-making task have not been consistent.

Specifically, the experiences of the corvids and children prior to attempting the hook-making task were inconsistent. Corvids had already seen and had the opportunity to use a premade hook—made either from the same material as was available for tool making (wire; Weir et al., 2002) or from a different material (wood; Bird & Emery, 2009). Some children had not seen a pipe-cleaner hook previously within the task (Beck et al., 2011), and others had seen a hook but did not have the opportunity to use it (Cutting et al., 2014). The effect and potential advantage that such an experience might have on subsequent tool innovation in children is yet to be determined.

Cutting et al. (2014) suggested that certain pretest experiences can promote tool innovation on the hook-making task. In their study, 4- to 6-year-olds were shown a premade example of a pipe-cleaner hook (target tool demonstration). Half of the children also had the pliable nature of the test material (pipe cleaners) highlighted to them via "bending practice." It was found that 5- and 6-year-olds were significantly more likely to solve the hook-making task if they received both a target tool demonstration and bending practice compared with those who saw only a target tool demonstration. This suggests that seeing the correct tool required to solve a problem does not make tool innovation problems trivially easy for children. Unlike the corvids, children in these studies were not permitted to use the premade target tool prior to attempting the hook-making task.

The purpose of the current series of experiments was twofold. First, we sought to further explore the effect of prior experience on children's tool innovation. Second, we aimed to draw fairer cross-species comparisons of tool innovation between corvids and children. In three studies, the role of prior experience in children's ability to innovate a hook tool to solve the hook-making task was investigated.

In Study 1, we explored how children performed on the hook-making task given the same pretest conditions as corvids, that is, the opportunity to use a premade pipe-cleaner hook. Children, but not corvids, have previously been presented with nonfunctional distracter materials during the hook-making task such as string (Beck et al., 2011; Cutting et al., 2014). Therefore, no distracter items were included in these studies and children were presented only with pipe cleaners. Some corvids were also given multiple trials at the hook-making task, although performance was not observed to improve or deteriorate over time. Still, it seems important that the possibility of improved or changed performance over time is explored in children. Therefore, the first study included 3 trials to explore this possibility and to match more closely the experimental methodology of corvids. We did not give children the full 17 trials used in the original corvid study because we judged this as too many for children to cope with. Before attempting the hook-making task, half of the children completed a hook-using phase, where they were given the opportunity to use a premade pipe-cleaner hook on the bucket and tube apparatus. The hook-using phase emulates the condition used by Weir et al. (2002) where corvids were given a hooked piece of garden wire and a straight one.

Study 1

Method

Participants

The participants were 28 children aged 4 or 5 years (*M* = 4 years 6 months [4;6], range = 4;2–5;1) and 30 children aged 6 or 7 years (*M* = 6;7, range = 6;3–7;1) recruited from a mainstream school in the United Kingdom. The ethnic composition of the sample was 85% Caucasian, 10% Black, and 5% Asian. An additional 2 children were excluded from analysis due to retrieving the bucket without making a hook or other functional tool.

Materials

The apparatus was a transparent plastic tube (22 cm length, opening 5 cm in diameter) attached to a cardboard base (Fig. 1). At the bottom of the tube, there was a small bucket containing a sticker. The

Fig. 1. Apparatus for hook-making task.

bucket had a wire handle that required a hook in order to retrieve it from the tube. Tool-making materials were 30-cm pipe cleaners.

Procedure

The study comprised a hook-using phase and an innovation phase. Children were systematically assigned to either the experimental condition or the control condition by their class list. They were told by their class teacher that they would be playing a game and must not discuss the game in the class because it would spoil the surprise for the other children. Children completed the experiment in a quiet area of the school library with a female experimenter. A second female coder (the second author) was present during 1 or 4 testing days to ensure reliability of coding success/failure on the hook-making task. There was 100% interobserver agreement.

Children in the experimental condition first completed the hook-using phase. A 30-cm straight pipe cleaner and a 30-cm pipe cleaner bent at one end to form a hook were placed next to the apparatus in front of the children. They were told, "If you are able to get the sticker out of the tube, then you can keep it." Children were allowed up to 1 min to complete this phase, and neutral prompts were given by the experimenter where necessary.

All children completed the innovation phase. This followed the hook-using phase for those in the experimental condition and was the only phase for those in the control condition. During the innovation phase, children were presented with the same bucket/tube apparatus and a 30-cm straight pipe cleaner only. They were told, "If you can get the sticker out of the tube, then you can keep it." All children received three trials. In the first trial, children were allowed up to 1 min to attempt the task. The experimenter then reset the task for two further 30-s trials. If children failed to innovate a hook after the third trial, the experimenter provided a demonstration of how to make a hook and kept it herself. Children were then encouraged to make another attempt to retrieve the sticker using their own materials. Only 2 children failed to make a hook following an adult demonstration. In these cases, children were given the experimenter's premade hook and used this to retrieve the bucket.

Results and discussion

Criteria for success on the innovation phase, here and in all further experiments, were making a hook tool and using it to retrieve the bucket from the tube. All children who made a hook were able to retrieve the bucket from the tube. There were no significant effects of gender on performance in

Trial 1, 2, or 3, Fisher's exact test, lowest $p = .267$. Therefore, data were combined across gender for all analyses.

First, we analyzed whether the hook-using phase was successful in changing children's experience in the experimental condition. In other words, did children use the hook prior to attempting the innovation phase? The 4- and 5-year-olds were significantly more likely than chance to pick up the hooked pipe cleaner first, with 15 of 15 children choosing the hook first, binomial test, $p < .001$. A binomial test revealed the same pattern for 6- and 7- year-olds, with 12 of 15 children choosing the hook first, $p = .035$. The 3 children who picked up the straight pipe cleaner first went on to use the hooked pipe cleaner afterward. Therefore, children in the hook-using phase did indeed use the hook before attempting innovation.

Second, the effect of age group on performance during the innovation phase was analyzed. The 6- and 7-year-olds in the control condition were significantly more likely to pass the innovation phase than the 4- and 5-year-olds, Fisher's exact test, $p = .018$. However, in the experimental condition there was no significant difference in performance related to age, Fisher's exact test, $p = .080$.

Of most interest was whether condition affected performance during the innovation phase and, therefore, the likelihood to innovate a functional hook tool. Because a significant effect of age was found in the control group, age groups were analyzed separately when comparing performance by condition. The percentage of children who passed each trial is shown in Table 1. Condition had a significant effect in Trial 1: 4- and 5-year-olds, Fisher's exact test, $p = .001$; 6- and 7-year-olds, $\chi^2_{\text{Yates}}(df = 1, N = 30) = 7.350$, $p = .007$. In Trial 2, condition had a significant effect on performance of 4- and 5-year-olds, Fisher's exact test, $p = .006$, but the effect marginally failed to reach significance for 6- and 7-year-olds, $\chi^2_{\text{Yates}}(df = 1, N = 30) = 3.750$, $p = .053$. In Trial 3, condition had a significant effect on performance of 6- and 7-year-olds, Fisher's exact test, $p = .002$, but the effect marginally failed to reach significance for 4- and 5-year-olds, Fisher's exact test, $p = .055$. However, considering the significant results across all other trials, this borderline finding is treated as if it were significant.

To determine whether performance changed over time, McNemar tests were used to compare success levels between trials for each age group (Trial 1 vs. Trial 2, 4- and 5-year-olds, $p > .999$; 6- and 7-year-olds, $p > .999$; Trial 2 vs. Trial 3, 4- and 5-year-olds, $p > .999$; 6- and 7-year-olds, $p = .500$; Trial 1 vs. Trial 3, 4- and 5-year-olds, $p > .999$; 6- and 7-year-olds, $p = .500$). Therefore, children's performance appeared to neither improve nor deteriorate over time.

Finally, tool manufacture was easy for children. Of those children who failed to innovate a hook independently in any of the three test trials, 26 of 28 went on to successfully make a hook following an adult demonstration.

The results from Study 1 demonstrated that children who had been given the opportunity to use a hook tool prior to being required to make one of their own were at a significant advantage over those children who had no such experience. Therefore, using a hook tool facilitated children's subsequent tool innovation, so much so that younger children performed as well as older children. These results suggest that, like corvids, children are able to succeed on the hook-making task after having used a hook previously.

Next, we aimed to disentangle what aspect of the warm-up phase was facilitating subsequent innovation. There are at least two obvious factors that could be independently or collaboratively facilitating innovation. Children first need to *choose* the hook as the correct tool and reject the straight pipe cleaner. Second, they *use* the hook on the hook-making task. We designed a second experiment to

Table 1
Performance across trials in Study 1 test phase.

Age group (years)	Condition	n	Number of children succeeding		
			Trial 1 (%)	Trial 2 (%)	Trial 3 (%)
4–5	Experimental	15	9 (60)	9 (60)	8 (53.33)
	Control	13	0 (0)	1 (7.69)	2 (15.38)
6–7	Experimental	15	14 (93.33)	13 (86.67)	15 (100)
	Control	15	9 (60)	7 (46.67)	7 (46.67)

investigate whether choosing the hook and rejecting the straight pipe cleaner was an important element of the warm-up phase or whether simply using a premade pipe-cleaner hook was sufficient. It might be that being able to contrast two tools (a straight pipe cleaner and hooked one) helps children to identify what is functional about the target tool. We know that children from 4 years successfully choose a hooked tool over a straight one to solve this task (Beck et al., 2011). If this is the case, we expect children who choose a hook to outperform children who are just given a hook to use on the hook-making task. Alternatively, the additional demand of needing to choose between two tools may be more taxing for children (perhaps through working memory demands), and this may reduce performance on the subsequent hook-making task.

Study 2

Method

Participants

In total, 28 children aged 4 or 5 years (M = 4;9, range = 4;5–5;4) and 23 children aged 6 or 7 years (M = 6;10, range = 6;5–7;4) were recruited from the same school as in Study 1 and made up the final sample. None of these children had taken part in the first experiment. The ethnic composition of the sample was 78% Caucasian, 10% Black, 8% Asian, and 4% other/unknown. An additional 9 children were excluded from analysis due to retrieving the bucket without making a hook or other functional tool.

Procedure

All participants were presented with the plastic tube and bucket apparatus used in Study 1. Children were systematically allocated by their class list to one of two conditions. In the Hook Use condition, a premade pipe-cleaner hook only was placed next to the tube apparatus (Fig. 2). In the Tool Choice condition, a 30-cm straight pipe cleaner and a premade pipe-cleaner hook were placed next to the tube apparatus (Fig. 3). In both conditions, children were then given up to 1 min to try to retrieve the bucket from the tube.

Having completed either the Hook Use or Tool Choice phase, all participants then completed the same test phase as used in Study 1. Because no difference in performance across trials was observed in Study 1, children were given only one attempt at the test phase.

Fig. 2. Apparatus for Tool Choice condition in Study 2.

Fig. 3. Apparatus for Hook Use condition in Study 2.

Results and discussion

All children successfully used a premade hook tool in both conditions. There was no significant effect of gender on performance in either condition or age group, Fisher's exact test, lowest $p = .236$. Therefore, data were combined across gender for subsequent analysis.

Age group did not have a significant effect on performance during the test phase in either the Tool Choice condition, Fisher's exact test, $p > .999$, or the Hook Use condition, $\chi^2(df = 1, N = 26) = 1.330$, $p = .249$.

Finally, Table 2 shows the percentage of children who passed the test phase in each condition. Analyses were run to investigate whether condition affected innovation. First, an analysis was run for each age group separately. Condition did not affect performance on the test phase for younger children, Fisher's exact test, $p > .999$, or for older children, Fisher's exact test, $p = .214$. Because age did not affect performance in this sample, a chi-square analysis was also conducted with age groups combined; however, condition still showed no significant effect on innovation, $\chi^2(df = 1, N = 51) = 1.797$, $p = .249$.

Study 2 sought to explore what it was about the warm-up phase in Study 1 that facilitated tool innovation. Regardless of whether they chose and used a pipe-cleaner hook or used a pipe-cleaner hook only during their first phase, children were just as likely to innovate a hook during the test phase. This suggests that it is using the hook, rather than the choosing element of the warm-up phase, that improves children's tool innovation. In other words, rejecting the nonfunctional tool (straight pipe cleaner) during the choice phase does not seem to improve children's likelihood of innovating a hook during the test phase. Rather, the opportunity to use a functional hook tool on the hook-making task seems to promote children's tool innovation.

Table 2
Performance in Study 2 test phase.

Age group (years)	Condition	*n*	Number of successful children (%)
4–5	Tool choice	14	10 (71.43)
	Hook use	14	9 (64.29)
6–7	Tool choice	11	8 (72.73)
	Hook use	12	5 (41.67)

The findings from Studies 1 and 2 are especially interesting because Cutting et al. (2014) found that showing children a pipe-cleaner hook was not sufficient to help them innovate one of their own afterward. In their study, Cutting and colleagues showed children a premade pipe-cleaner hook only if they failed to innovate a hook on the hook-making task and then allowed them another go at the task. Half of these children were given pipe-cleaner bending practice, whereas the other half were not. It was found that only older children, who were also given the opportunity to manipulate the materials beforehand, benefited from a target tool demonstration.

Cutting et al. (2014) focused on children's performance after different aspects of the hook-making task were highlighted to children as well as how they could retrieve and coordinate this information to solve the task. As such, the analysis focused on performance between conditions rather than stages. However, it is possible that for some children, seeing a target tool drove their subsequent innovation.

This leaves open the question of whether seeing a target tool is as helpful as the opportunity to use a target tool in terms of likelihood of going on to solve the hook-making task. Children aged 3 or 4 years have been shown to demonstrate different strategies of exploration of materials for different tasks. For example, they used visual exploration to determine which spoons were the correct size to transport sweets, but they chose haptic exploration to decide which sticks, of varying rigidity, were suitable to stir sugar and gravel (Klatzky, Lederman, & Mankinen, 2005). It is yet to be made clear whether or not children find visual or haptic exploration of premade tools equally useful in the context of tool innovation or the hook-making task. If the key information that children extrapolate from a hook demonstration is regarding its shape, we would expect visual demonstration to be sufficient. However, if the information children require is regarding some other physical property of the pipe cleaner (e.g., flexibility, rigidity), we might expect that haptic exploration would be more beneficial.

In Study 3, we sought to compare the effects of seeing versus using a premade hook on performance on the hook-making task. In Studies 1 and 2, children were given the opportunity to use a hook before attempting the task.

Another factor is whether children benefit more from being given solution-relevant information before or after they encounter the problem to be solved. In Studies 1 and 2, children had only used a pipe-cleaner hook before they attempted the hook-making task, which proved to be beneficial to both younger and older children. In a previous study, children (and apes) were shown the location of tools they could choose to use to solve a problem either before or after they had seen the task they were going to solve (Martin-Ordas, Atance, & Call, 2014). Younger children found it easier to locate the tools to solve the problem after they had seen the task they would need to solve. These findings suggest that children are sensitive to the timing of relevant information when engaging in tool use tasks, and the same may be true of tool innovation tasks. Given the findings of Martin-Ordas et al. (2014), we might predict that younger children would benefit more from being given solution-relevant information after already attempting the hook-making task. Hence, in Study 3, we also manipulated the timing of the experience children were given (before or after having attempted the task).

Study 3

Method

Participants

The participants were 94 children aged 4 or 5 years (M = 4;7, range = 4;3–5;2) and 96 children aged 6 or 7 years (M = 6;7, range = 6;3–7;2) from two mainstream schools in the United Kingdom. The same proportion of children from each school were present in each age group. The ethnic composition of the sample was 89% Caucasian, 5% Black, and 6% Asian. None of these children had taken part in either of the previous two studies.

Procedure

Children were presented with the same bucket and tube apparatus from the previous experiments. As per the 2×2 design, children were systematically assigned by class list to one of four conditions: See Before, See After, Use Before, or Use After. All children completed the standard test phase (hook-making task) from the previous experiments and were given the same instructions. The experimenter told them, "If you can get the bucket out of the tube, then you can keep the sticker." However, the experience that children had before and after attempting the test phase varied per condition.

In the See Before condition, children were presented with the bucket and tube apparatus. The experimenter then said "Look at this" and showed them a premade pipe-cleaner hook. The experimenter then removed this from sight, said "Here is something that might help you," and placed a straight pipe cleaner next to the apparatus. Children were then given 1 min to attempt the hook-making task.

In the See After condition, children first attempted the hook-making task (pre-demonstration phase). Children who failed to innovate a pipe-cleaner hook and retrieve the bucket were encouraged to put down their materials. The experimenter then showed them a premade pipe-cleaner hook, said "Look at this," and gave children a new straight pipe cleaner if necessary. Children then attempted the hook-making task for a second time.

In the Use Before condition, children were presented with the bucket and tube apparatus and a premade pipe-cleaner hook. They were allowed up to 1 min to attempt the task with the materials given. All children successfully retrieved the bucket using the premade pipe-cleaner hook. Children then attempted the hook-making task.

In the Use After condition, children first attempted the hook-making task (pre-demonstration phase). Children who failed to innovate a pipe-cleaner hook and retrieve the bucket were encouraged to put down their materials. Pipe cleaners were removed. The experimenter then gave children a premade pipe-cleaner hook and said "Here is something that might help you." Children were encouraged to have another go at the task for up to 1 min. Once more, all children successfully retrieved the bucket using the premade pipe-cleaner hook. Children then attempted the hook-making task for a second time.

As noted previously, if children failed to make a hook on their second attempt at the hook-making task (After conditions: Use After and See After) or their only attempt at the task (Before conditions: Use Before and See Before), the experimenter demonstrated how to make a pipe-cleaner hook and allowed them to have another go at the task.

Results and discussion

There was a significant overall effect of gender on performance in 4- and 5-year-olds, with girls performing better than boys, $\chi^2_{\text{Yates}}(df = 1, N = 94) = 4.115$, $p = .042$, $\phi = 0.231$. However, there was no significant effect of gender on performance in 6- and 7-year-olds, $\chi^2_{\text{Yates}}(df = 1, N = 96) = 0.686$, $p = .408$. Because no previous effects of gender were observed on these tasks, and this difference was present in only one age group, the result is not discussed further here.

Older children performed significantly better than younger children in the Use After condition, Fisher's exact test, $p = .030$, and the See Before condition, $\chi^2(df = 1, N = 47) = 6.139$, $p = .013$, $\phi = 0.006$. However, there were no significant differences in performance related to age in either the See After condition, $\chi^2(df = 1, N = 48) = 2.521$, $p = .112$, or the Use Before condition, $\chi^2(df = 1, N = 48) = 1.137$, $p = .286$.

Table 3
Performance across conditions in Study 3.

Age group (years)	*n*	Condition	Number of successful children on test phase (%)
4–5	24	Use before	17 (70.83)
	23	Use after	15 (65.22)
	23	See before	7 (30.43)
	24	See after	14 (58.33)
6–7	24	Use before	21 (87.50)
	24	Use after	22 (91.67)
	24	See before	17 (70.83)
	24	See after	20 (83.33)

Of most interest was whether condition affected performance. Table 3 shows performance across conditions for each age group. Children in the After conditions who passed during the pre-demonstration phase were included in the analysis. This is to match children in the Before conditions who may have passed regardless of the opportunity to see or use a hook and could not be identified. In total, 8 children in the Use After condition (2 4- and 5-year-olds and 6 6- and 7-year-olds) passed during the pre-demonstration phase, and 10 children in the See After condition (2 4- and 5-year-olds and 8 6- and 7-year-olds) passed during the pre-demonstration phase.

We first looked at whether the timing of when information relevant to the hook-making task was given affected performance on the hook-making task. There were no significant differences between performance in Before and After conditions in 4- and 5-year-olds, $\chi^2_{\text{Yates}}(df = 1,\ N = 94) = 0.692$, $p = .405$, or in 6- and 7-year-olds, $\chi^2(df = 1, N = 96) = 0.675$, $p = .411$. Second, we looked at whether there was any difference in performance on the hook-making task related to whether children were in a Use or See condition. There were no significant differences in performance of 6- and 7-year-olds between the Use and See conditions, $\chi^2_{\text{Yates}}(df = 1, N = 96) = 1.875$, $p = .171$. However, 4- and 5-year-olds performed significantly better in the Use conditions compared with the See conditions, $\chi^2(df = 1, N = 94) = 4.326$, $p = .038$, $\phi = -0.236$. We then looked at what was driving the difference between these conditions in 4- and 5-year-olds using a Bonferroni-adjusted alpha level of .025 (.05/2). A continuity-corrected chi-square test indicated no significant difference in success between the Use After and See After conditions, $\chi^2_{\text{Yates}}(df = 1, N = 47) = 0.034$, $p = .853$. However, children in the Use Before condition performed significantly better than those in the See Before condition, $\chi^2_{\text{Yates}}(df = 1, N = 47) = 6.139$, $p = .013$, $\phi = -0.404$.

Study 3 revealed no clear indication overall that either using or seeing a target tool is more beneficial than the alternative. Likewise, the timing of clues or information relating to transformation from the start state to the end goal does not appear to be important. In other words, being given tool shape prior to attempting innovation is no more useful than being told the information having already had one failed attempt at the hook-making task.

However, younger children performed significantly better in the Use Before condition compared with the See Before condition, being more than twice as likely to succeed in the Use Before condition. This suggests that the Use Before condition was particularly beneficial for 4- and 5-year-olds in terms of facilitating innovation of a hook tool on the hook-making task. This complements the findings from Studies 1 and 2, in which younger children performed at similar levels as older children when they had the opportunity to use a premade hook tool prior to attempting the hook-making task. This can also be related to the findings of Cutting et al. (2014), who concluded that 4- and 5-year-olds experienced less benefit from seeing a target tool than 5- and 6-year-olds.

Older children performed well across conditions, with success levels greater than what might be expected given performance in the control condition of Study 1. The results suggest that using and seeing a premade target tool is useful for children of this age regardless of whether this is before or after first attempting innovation. Younger children also performed well across conditions when compared with performance in previous studies and in the control condition of Study 1. This suggests that some younger children were able to coordinate knowledge highlighted to them in order to innovate a hook tool.

General discussion

Spontaneous tool innovation remains a difficult problem for many children aged below 8 years (e.g., Study 1 control group). Previous studies demonstrate that choosing the correct tool and tool manufacture following an adult demonstration is relatively easy for children from as early as 4 years (Beck et al., 2011). The current studies contribute to our understanding of what children find especially difficult about tool innovation. In Study 1, when children were given the opportunity to use a premade hook tool, making a hook of their own on subsequent trials was significantly more likely. Study 2 suggested that the *using* element of the pretest experience in Study 1, rather than choosing/rejecting tools, seemed to be what was driving better performance on the hook-making task. Using a premade hook made it easier to solve the innovation problem in the future. This suggests that fundamental to children's success on the hook-making task was first interacting with the solution. This provides more evidence that the most difficult aspect of the hook-making task for children is bringing to mind the solution to the problem for themselves. However, it also demonstrates that children do not lack the understanding of how to transform the straight pipe cleaner to a functional hook tool without being explicitly shown how to do so in an action demonstration.

Finally, Study 3 provided further insight into children's performance on the hook-making task. Children across age groups and conditions performed better than expected on the hook-making task compared with previous studies (Beck et al., 2011; Cutting et al., 2014) and children in the control group of Study 1. Younger children were most successful when they could use a premade tool before their first innovation trial. For older children, there was no significant difference between trials. In two conditions (Use Before and See After), there was no significant difference in success levels between younger and older children. These results highlight the benefit that younger children experience by being given information about the target solution. The results also suggest that the same information (e.g., seeing a hook before attempting the task) is not equally helpful for all children.

The results from Study 3 may reflect individual differences in children's learning preferences. For example, Flynn, Turner, and Giraldeau (2016) recently suggested that 5-year-olds could choose a learning strategy (social or asocial) for themselves that was effective for them. Children could choose to either attempt a task for themselves or watch an experimenter attempt it first and then had their learning strategy choice either met or violated. Although children showed a strong preference overall to learn socially, unlike 3-year-olds, 5-year-olds were also efficient at solving the task under asocial conditions, when this strategy matched their indicated preference. In the context of Study 3, one might hypothesize that, similarly, children show preferences for the types of information or opportunity for exploration offered (visual or haptic) and the timing of this information (before or after attempting the task).

In Study 3, we concluded that using or seeing a premade tool was beneficial for older children in terms of solving the hook-making task later, with no single condition being significantly better than another. For younger children, using a hook was more beneficial than seeing a hook before attempting the hook-making task, but this difference was not present when the information was presented after their first attempt at innovation. This finding provides some support to the claims of Cutting et al. (2014), who concluded that older children benefited from a target tool demonstration (alongside bending practice), whereas younger children did not. However, the focus of Cutting and colleagues was on performance between conditions rather than stages. On closer inspection, younger children in their study did appear to benefit from seeing a target tool demonstration, albeit not to the extent of the older children. Following a target tool demonstration, a further 23% (no bending practice) and 37% (bending practice) of children went on to innovate a hook tool of their own. In the current investigation, seeing a hook increased tool innovation from near floor (Study 1) to 30%–58% (see Table 3). This suggests that, for a significant number of 4- and 5-year-olds, seeing a premade hook facilitated their future hook tool innovation.

Cutting et al. (2014) concluded that 4- and 5-year-olds struggle to innovate both the solution (a hook) and the means (bending the pipe cleaner) to solve the hook-making task. It was also concluded that although 5- and 6-year-olds were better at innovating the means to solve the task following a target tool demonstration and bending practice, spontaneous innovation of the hook tool solution remained difficult for the majority. Here, we suggest that Cutting and colleagues' conclusions may have been slightly pessimistic regarding younger children's capabilities. The majority of 4- and 5-year-olds in Studies 1 and 2 could innovate the means to solve the hook-making task, having had the chance to use (rather than just see) a premade tool. Younger children were also helped by seeing a target tool where performance was improved from near floor to 30% to 58% (see Table 3). We suggest that it is especially difficult for children aged 4–7 years to independently generate the solution to the problem—that they need a hook.

The current series of experiments allows us to comment for the first time on how the performance of children on the hook-making task compares with that of the corvids. When children were faced with similar pretest experiences as that of the New Caledonian crow in the Weir et al. (2002) version of the task, they too were able to innovate a hook to solve the hook-making task. It would now be interesting to see how corvid species perform on tool tasks such as the hook-making task without prior exposure to or experience with the target tool. Rooks had a different pretest experience from that of children and crows (Bird & Emery, 2009). They were exposed to wooden hook tools prior to needing to make a wire hook of their own. In sum, they transferred the solution from the wooden hook tool and transferred this to a new material when they made a wire hook on subsequent trials. Considering recent findings, this seems remarkable. Beck et al. (2014) found that 4- to 7-year-olds do not transfer their knowledge of manufacturing a pipe-cleaner hook when they are later required to make a hook from dowel (or vice versa) to solve a similar task.

In line with previous findings (Beck et al., 2011; Nielsen et al., 2014), we noted children's difficulty with spontaneous innovation of a tool to solve the hook-making task. None of the 4- and 5-year-olds, and only a minority of the 6- and 7-year-olds, innovated a hook tool on their first attempt at the hook-making task without prior experience of a premade tool. Betty the crow demonstrated innovation of the means to solve the task but not innovation of the solution itself, due to her experience with a premade wire hook (Weir et al., 2002). However, spontaneous tool innovation has been reported in "Figaro" the cockatoo (Auersperg, Szabo, von Bayern, & Kacelnik, 2012). Given impressive reports of the abilities of certain nonhuman animal species, it remains intriguing that young children should experience such difficulty in innovating tools to solve problems independently.

It is important to bear in mind that reports of tool innovation in nonhuman animal species are often individual cases. For example, although Figaro the cockatoo could innovate a tool, other individuals either failed to use tools at all or showed components of tool-making behavior, which may have been the result of shared social experience with Figaro. Although this does not make the achievements of Figaro any less impressive, this does resonate with the literature examining children's propensity for tool innovation. It appears, at least in the case of younger children (4- to 7-year-olds), that some children have the capacity for innovation, whereas others do not. A recent study has suggested that individual differences in divergent and creative thinking are not associated with tool innovation (Beck, Williams, Cutting, Apperly, & Chappell, 2016). Future research efforts might explore whether the ability to innovate tools is related to other personal characteristics, personality traits, or a set of cognitive abilities that promote innovative behavior.

Within the animal literature, it is noted that to unravel the potential underlying cognitive mechanisms that support innovative tool manufacture, it will be necessary to control the developmental histories and experiences of participants (Auersperg et al., 2012). This presents a challenge to the study of tool innovation in children who come from a wide range of backgrounds with varied experiences. When studying children's performance on such tasks, it is important to consider the wider sociocultural context. Children at this age are likely to have received varied influence from parents and caregivers, including opportunity for exploration, feedback, and availability of objects. This is especially true of the youngest children, who have spent less time in full-time state education. These factors may greatly influence a child's likelihood to display innovative behavior, both its onset and its frequency (Tomasello, 1999). Future studies may find ways in which we can manipulate experience with objects and materials to explore its effect on tool innovation.

Holyoak, Junn, and Billman (1984) argued that analogical reasoning is an important mechanism for cognitive development because analogy permits the transfer of knowledge and information from domains that are understood to those that are not. We propose that the hook-making task may require children to employ analogical reasoning because they are required to make inferences about novel experiences, identify the relevant and useful information from target tool demonstrations, and transfer what they have learned to the innovation phase (for further discussion, see Beck et al., 2014). It may be that those children with superior analogical reasoning abilities find it easier to use the information highlighted to them to pass the hook-making task. Future studies may seek to investigate whether children's analogical reasoning is related to their tool innovation ability.

Because one of the main aims of these studies was to draw comparisons with the corvid literature, the current findings are restricted to the results from one innovation task (hook making). However, children's difficulty with spontaneous innovation has been demonstrated on tool innovation tasks such as the Floating Object Task (Hanus et al., 2011; Nielsen, 2013) and the Loop Task (Tennie et al., 2009). Here, children found it especially difficult to innovate the solution to the hook-making task—that they require a hook to retrieve the bucket from the tube. However, when given the opportunity to use the solution to the hook-making task, they could innovate the means to solve the task without prior training; they transformed the straight pipe cleaner into a pipe-cleaner hook. It remains unclear why some children find tool innovation difficult, whereas others do not. A more complete picture of the developmental trajectory of tool innovation should be built, with further investigation into the levels of scaffolding required and conditions that might facilitate children's independent innovation on a wide range of innovation tasks.

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