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Brief article

Making tools isn't child's play

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ABSTRACT

Tool making evidences intelligent, flexible thinking. In Experiment 1, we confirmed that 4- to 7-year-olds chose a hook tool to retrieve a bucket from a tube. In Experiment 2, 3- to 5-year-olds consistently failed to innovate a simple hook tool. Eight-year-olds performed at mature levels. In contrast, making a tool following demonstration was easy for even the youngest children. In Experiment 3, children's performance did not improve given the opportunity to manipulate the objects in a warm-up phase. Children's tool innovation lags substantially behind their ability to learn how to make tools by observing others.

1. Introduction

Anyone who watches a three-year-old use a computer mouse or a drinking straw can see that human children are extremely competent tool users. Children use simple tools such as hooks and rakes in the second year of life (Brown, 1990). Two-year-olds learn how tools work by watching others (McGuigan & Whiten, 2009) and make inferences about intended functions and design (Casler & Kelemen, 2005). However, psychologists have neglected a fundamental aspect of children's tool use: can children *make* tools?

Historically, tool use has been seen as a mark of intelligence, but more recently tool making, potentially involving flexibility, planning, and imagination, has been judged more important (see Emery & Clayton, 2004, 2009). Non-human primates make some tools (Povinelli, 2000; Sanz, Call, & Morgan, 2009; St Amant & Horton, 2008), but it is the corvids who offer the most striking evidence. A New Caledonian crow (*Corvus moneduloides*) made a hook from a straight piece of wire to retrieve a bucket containing food from a transparent tube (Weir, Chappell, & Kacenik, 2002). Similar behavior has been observed in rooks (*Corvus frugilegus*), a species that does not use tools in the wild (Bird & Emery, 2009). Importantly, in both cases, the birds had seen and used a pre-made hook tool before, giving them an opportunity for learning that we will return to discuss below. Evidence for tool manufacture in non-human animals fuels the debate on the evolution of intelligence and whether capacities such as tool making result from domain-general intelligence or domain-specific adaptation (Kacelnik, 2009).

Despite the interest in the evolution of tool use and making in non-human animals (phylogenetic development), we are largely ignorant about the ontogeny of tool making in humans (i.e. development within an individual's lifespan). Is children's tool making comparable to their understanding and use of pre-made tools? Perhaps children's ability to use the tools that adults demonstrate is grounded in a full understanding of the physics and function of the tool. In this case, one might expect simple tool making, such as making a hook, to be relatively easy. On the other hand, making a novel tool is likely to involve problem solving, which may pose a challenge for young

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children. In fact, there seem to be two rather distinct aspects to tool making. Necessarily, tool-making requires the physical transformation of materials. But often it also requires the prior step of imagining the type of tool suitable for the task. We call these two aspects of tool making "tool manufacture" and "tool innovation" respectively. In the comparative literature this distinction has not been explicitly addressed. The crow in Weir et al.'s (2002) study had seen a wire hook in the context of the bucket retrieval task before she needed to make her own tool, and so she was required to manufacture but not innovate. In Bird and Emery's (2009) study the rooks had not seen a wire hook before, so their task did involve tool innovation. However, they had previously seen and used a hook tool made from wooden components to solve the task, so one might describe them as innovating the means of creating a tool (i.e. bending a wire), but not innovating the hook tool itself as a solution to the task. Although young children have no doubt encountered hooks before, it is very unlikely that they will have seen the target tool in our task, a pipecleaner hook (despite experience with pipecleaners, a common craft material in schools) or used a hook tool to solve a bucket retrieval problem like this one.

There has been one previous study that examined children's tool making. Mounoud (1996) gave 4–9 year old children a task in which they had to push a block from one location to another within a box. The block could not be moved by hand but had to be accessed through a small gap in the side of the box. Children were given Lego blocks to construct a tool. Children's strategies developed from a trial-and-error approach to construction of a complete tool before trying to solve the problem and children were 7 years old before they successfully constructed a complete tool in anticipation. The objects children were given to make the tool lent themselves to combination, and it is likely that children would have viewed this task as a tool making game, particularly over repeated trials. On the other hand, the physical demands of the task were quite complicated and there was no way to check whether children understood what the best solution to the problem was. Thus, although this study hints that tool making is not trivially easy for young children, we are left unsure as to whether this is because of the tool manufacture or tool innovation demands. Since Mounoud's study the comparative literature had provided us with the simple hook making task and so we decided to use this to investigate both aspects of children's tool making ability: manufacture and innovation.

In our first experiment, we confirmed that children understood the physical demands of the task. Having demonstrated this, we explored tool manufacture and innovation in Experiments 2 and 3.

2. Experiment 1

2.1. Method

2.1.1. Participants

Children aged 3–7 years old were recruited from and tested at primary schools serving working and middle classes of the UK. In all three experiments presented here children were grouped for analysis by their school class to reflect the number of formal years of education they had experienced. There were 16 3- to 4-year-olds (Mean = 4 -years 3 months (4;3), range 3;10–4;8), 28 4- to 5-year-olds (range 4;10–5;9, individual dates of birth were not available for this class), 26 5- to 6-year-olds (M = 6;3, range 5;10–6;9), and 27 6- to 7-year-olds (M = 7;3, range 6;10–7;9).

2.1.2. Procedure

Participants saw a vertically positioned plastic cylinder (22 cm length; opening 5 cm in diameter) too narrow to reach into using a hand. At the bottom was a bucket containing a sticker, with a handle that afforded retrieval with a hook. A 29 cm straight pipecleaner and a 29 cm pipecleaner bent to make a hook at one end were placed on the table. Participants were told, "If you can get the sticker out of here you can keep it". We coded which pipecleaner the child used first. Children had a minute to complete the task, during which they were given neutral prompts by the experimenter.

2.2. Results and discussion

The number of children choosing the straight or bent pipecleaner first is shown in the Table 1. 4- to 5-year-olds were significantly more likely than chance to select the bent pipecleaner (binomial test $p = .013$). 5- to 6-year-olds and 6- to 7-year-olds also performed better than chance ($p = .004$ and $p < .001$ respectively). The youngest group did not perform better than chance although this may have been due to our small sample size.

Our criterion for passing this test was strict in that we looked at which tool the children used first. It is notable that only five children (three 3- to 4-year-olds and two 4- to 5-year-olds) failed to retrieve the bucket, and only one of these 4- to 5-year-olds never used the hook. Overall, this experiment gave us confidence that children from at least 4–5 years could identify a hook as the best tool to solve the tube task.

We progressed to our main research question of whether children could make tools. We tested their ability to innovate a hook tool by simply presenting them with the problem and the material to make a functional tool

Table 1
Performance in Experiment 1.

Age group (years)	Chose straight pipecleaner	Chose hooked pipecleaner	Significantly different to chance using binomial test?
3–4	4	11	Not significant
4–5	7	21	$p = .013$
5–6	5	21	$p = .004$
6–7	4	23	$p < .001$

(a straight pipecleaner). We also tested children's ability to manufacture a tool: children who failed to innovate a hook spontaneously saw a demonstration of hook making. We then examined whether they adopted this technique to solve the task.

3. Experiment 2

3.1. Method

3.1.1. Participants

Children aged 3–11 years old were recruited from and tested at primary schools serving working and middle classes of the UK. The four younger age groups were recruited from the same school as the children in Experiment 1, but no child participated in more than one experiment. There were 26 3- to 4-year-olds (M = 4;5, range 3;10–4;9), 28 4- to 5-year-olds (range 4;10–5;9, as in Experiment 1 individual dates of birth were not available for this class), 22 5- to 6-year-olds (M = 6;3, range 5;10–6;9), 24 6- to 7-year-olds (M = 7;3, range 6;10–7;9), 32 7- to 8-year-olds (M = 7;7, range 7;2–8;1), 30 8- to 9-year-olds (M = 8;6, range 8;2–9;1), 36 9- to 10-year-olds (M = 9;8, range 9;3–10;1), and 35 10- to 11-year-olds (M = 10;7, range 10;1–11;1). Due to the timing of our testing in the school year there was some overlap between the chronological ages of children in the 6- to 7-year-old and 7- to 8-year-old groups. We also tested a 'mature' comparison group of 13 16- to 17-year-olds (M = 17; 5, range 16; 11–17;9) recruited from a local college.

3.1.2. Procedure

Participants saw the same tube and bucket apparatus as in Experiment 1. A 29 cm pipecleaner, a 29 cm piece of string, two 5 cm sticks were placed on the table (there was no bent pipecleaner). As in Experiment 1, participants were told, "If you can get the sticker out of here you can keep it" and for 1 min they were given neutral prompts. We coded whether participants made a hook or other functional tool (the only alternative functional tool made was an inverted "T" combining pipecleaner and a stick). This formed the tool innovation test. If after a minute a participant had not succeeded, we tested their tool manufacture ability. The experimenter instructed the participant to watch, took another pipecleaner, demonstrated how to bend it into a hook, and retained this hook herself. Participants then had another opportunity to use their own materials to retrieve the bucket.

3.2. Results and discussion

Children found the tool innovation task remarkably difficult (see Fig. 1). Very few 3- to 5-year-olds ever made a hook spontaneously and success on the task gradually increased from 5 to 10 years. The majority of successes occurred when participants bent the pipecleaner into a hook (the dark bars on the graph). However, in a small number of cases in the older groups, participants created an alternative functional tool by combining the matchstick and pipecleaner in to an inverted 'T' (the light bars). Examples of child-made hooks are shown in Fig. 2.

We compared adjacent age groups' performance on the innovation task using Chi Square tests. 5- to 6-year-olds were significantly more likely to succeed than younger children $\chi^2(df = 1, N = 52) = 5.71$, $p = .017$, and 8- to 9-year-olds were more successful than 7- to 8-year-olds $\chi^2(df = 1, N = 62) = 4.99$, $p = .025$. Otherwise, the proportion of participants innovating a functional tool moved steadily toward 100% success in mature performance.

On the other hand, tool manufacture was remarkably easy. One hundred and twenty-four children progressed to this test, because they had failed to innovate a functional tool. After the experimenter's demonstration, only four of these remaining children did not make a hook.

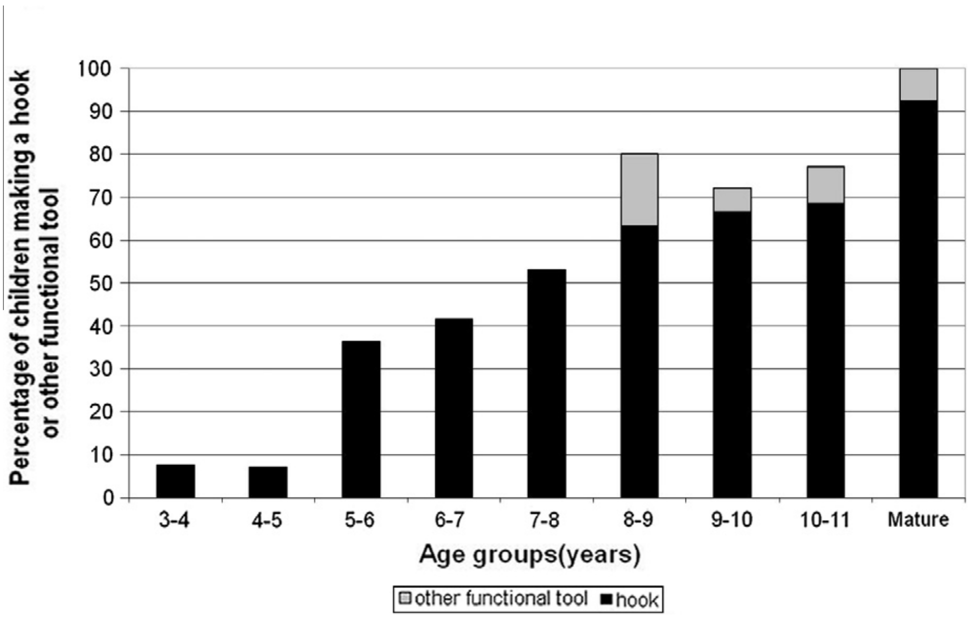

Fig. 1. Percentage of children innovating a hook (or other tool) in Experiment 2.

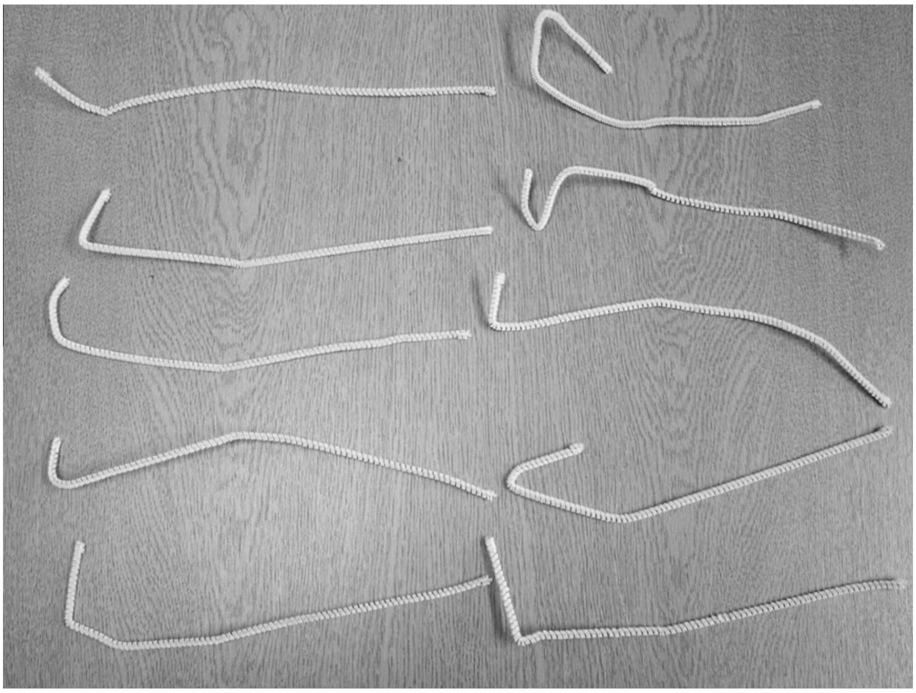

Fig. 2. Examples of hooks made by children. Pipecleaners were 29 cm long. N.b. We did not preserve the tools made in the experiments reported here. The tools depicted were created by children of the same age under a near-identical procedure.

Two of these children were from the 3- to 4-year-old group and two from the 4- to 5-year-old group. One 8-year-old made a hook, but did not put it into the tube.

Although the vast majority of children could manufacture a hook, it appeared that children under the age of about eight found the tool innovation task difficult and children under five found it near impossible. While this might reflect poor innovation abilities, an alternative explanation was that we had not communicated the task to the children appropriately. Perhaps children thought that they had to use the objects as they were presented to them and that they were not allowed to bend the pipecleaner. Another possible problem was that children did not know the functional property of the pipecleaner: i.e. that it was pliable. We checked for these alternative explanations in Experiment 3.

4. Experiment 3

4.1. Method

4.1.1. Participants

Children aged 4–5 years (n = 26, M = 4;7, range 4;2–5;2) and 6–7 years (n = 28, M = 6;7, range = 6;2–7;1) were recruited from a school serving a working and middle class population in the UK.

4.1.2. Procedure

Children were alternately allocated to either the Standard condition or the Demonstration condition, based on the order of the teacher's class list. Both groups followed the procedure from Experiment 2, however, the demonstration group also participated in a familiarization phase. Before the demonstration group saw the tube apparatus, the experimenter manipulated the other objects and the child copied the actions: a pipecleaner was curled around a pen, string was shaped into an 'S' to trace a printed shape on a piece of paper, four matchsticks were arranged in a square.

4.2. Results and discussion

None of the younger children spontaneously innovated a hook in either condition. The older children appeared slightly more likely to make a hook if they had manipulated the objects (6 of 14 children) than if they had no warm-up experience (1 of 14 children). This result did not reach statistical significance, p = .077. However, in neither condition did the older children's performance exceed the level observed in the same aged children in Experiment 2 (44%). When the experimenter later demonstrated hook manufacture (as per Experiment 2) 38 of 47 remaining children succeeded. Thus, once again, the manufacture of a hook was comparatively easy, yet the innovation of a novel tool was extremely difficult.

5. General discussion

Young children were remarkably poor at innovating a simple hook tool. It was not until 8 years of age that a majority of children succeeded at this task. Children's difficulties were apparent even when they had manipulated the objects (Experiment 3), and despite a strong preference to select a pre-made hook (Experiment 1), and despite the ability to manufacture a hook when prompted (Experiments 2 and 3). Our findings suggest that children's ability to innovate tools lags substantially behind their ability to learn about making tools from others and their causal understanding of tools.

In line with the broader literature on observational learning (e.g. McGuigan & Whiten, 2009), children found it easy to manufacture a tool once the process had been demonstrated to them by an adult. One possible reason why this ability should precede tool innovation is that human children may have a unique competence for social learning (e.g. Csibra & Gergely, 2009) and that this makes them less likely to seek their own solutions to novel tool making problems. In fact, it seems plausible that children's dependence on adults for an extended period of development may have resulted in selection pressure on children to avoid innovation: there is little to be gained by reinventing the wheel. One way to explore the role of social learning is to see if children find tool manufacture equally easy if the model tool is presented outside the social context, either by another person who is not demonstrating the technique to the child (see e.g. Nielsen, 2006) or when the child happens to have encountered a similar tool in the very recent past (as happened in the corvid studies). If children's precocious tool manufacture in the current studies is solely the result of their social learning ability then we would expect their performance at manufacturing to be worse in these new conditions, where ostensive cues to social learning were absent. Alternatively, children might benefit from these or other non-social manipulations, suggesting that precocious tool manufacturing abilities are not just the result of good social learning abilities.

Of course, this would leave open the question of what makes tool innovation particularly difficult for children. We suggest it is likely that being able to innovate a tool without a model or demonstration requires domain-general "executive" skills for flexible problem solving. For example, in order to come up with a new tool one may need to hold in mind the goal, inhibit incorrect but impulsive approaches (e.g. putting the straight pipecleaner in to the tube), and formulate a correct strategy. These kinds of skills develop substantially during early and middle childhood (e.g. Apperly & Carroll, 2009; Davidson, Amso, Anderson, & Diamond, 2006), making it plausible that such developments could be the limiting factor on tool innovation.

It might be thought that children's difficulty with tool innovation, and the proposition that tool innovation relies upon executive function, is incompatible with findings from non-human species that show evidence of tool use but are not generally thought to have high levels of executive function. However, this point is moot for two interesting reasons. First, we have already mentioned the fact that while non-human species may show impressive abilities to manufacture tools there is, as yet, very limited evidence of innovation of novel tools: the rooks in Bird and Emery's (2009) study innovated the means of making a tool but did not need to innovate the hook tool as a solution to the task because the solution had already been presented in a different form. In order to be clear about why tool innovation can be difficult for both humans and non-humans, we need to know whether rooks innovate tools without prior exposure to a model solution and whether children find innovation of the means difficult, even having seen a similar tool. Second, even if it turns out that some non-human animals are able to innovate solutions as well as innovating the means, it would remain important to find out whether non-human species innovated tools using analogous processes to those used by humans. We believe that both of these questions are ripe for further investigation.

This leads to a broader point arising from these studies, which is that the protracted development of children's tool making should lead us to question the assumption that all aspects of tool use are trivially easy for human beings. Recent comparative work has focused on whether tool use or making is 'unique' to humans (e.g. Bird & Emery, 2009). Developmental work on children's tool use has emphasized their competence learning from others (Hopper, Flynn, Wood, & Whiten, 2010) or focused on the intriguing observations that younger children are sometimes better at solving tool use tasks than older children who are influenced by their knowledge of the intended function of a tool (Defeyter & German, 2003). We argue that children's surprisingly poor performance on our simple hook making task clearly demonstrates limitations to human's tool competence. In the future, we need to be more precise about what elements of tool use and tool making are easy or difficult for children. Exploring the ontogenetic development of both tool manufacture and tool innovation is the obvious and much needed complement to the comparative literature's focus on phylogenetic development.

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