Observational learning of tool use in children: Investigating cultural spread through diffusion chains and learning mechanisms through ghost displays

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A B S T R A C T

In the first of two experiments, we demonstrate the spread of a novel form of tool use across 20 “cultural generations” of child-to-child transmission. An experimentally seeded technique spread with 100% fidelity along twice as many “generations” as has been investigated in recent exploratory “diffusion” experiments of this type. This contrasted with only a single child discovering the technique spontaneously in a comparable group tested individually without any model. This study accordingly documents children’s social learning of tool use on a new, population-level scale that characterizes real-world cultural phenomena. In a second experiment, underlying social learning processes were investigated with a focus on the contrast between imitation (defined as copying actions) and emulation (defined as learning from the results of actions only). In two different “ghost” conditions, children were presented with the task used in the first experiment but now operated without sight of an agent performing the task, thereby presenting only the information used in emulation. Children in ghost conditions were less successful than those who had watched a model in action and showed variable matching to what they had seen. These findings suggest the importance of observational learning of complex tool use through imitation rather than only through emulation. Results of the two experiments are compared with those of similar experiments conducted previously with chimpanzees and are discussed in relation to the wider perspective of
Introduction

Interest in the observational learning abilities of infants and children has a long history (Bandura, Ross, & Ross, 1961; Meltzoff & Moore, 1977; Meltzoff & Prinz, 2002; Piaget, 1962). Only recently, however, has serious effort been devoted both to experimentally testing whether observational learning between children allows the spread of behaviors among them (Horner, Whiten, Flynn, & de Waal, 2006) and how such learning occurs, with researchers aiming to tease apart different forms of observational learning (Gleissner, Meltzoff, & Bekkering, 2000; Huang & Charman, 2005; McGuigan, Whiten, Flynn, & Horner, 2007; Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009). In the first experiment presented here, we assessed how well children would learn a complex tool-use task via observational learning and how far such socially learned behaviors would spread along a series of “cultural generations” or transmission episodes.

Positive results in this first experiment were followed up in a second experiment where we went on to assess which forms of observational learning could explain the social transmission observed. In part through integration with work in comparative psychology, a number of observational learning mechanisms, or underlying cognitive processes, have been distinguished (Want & Harris, 2002; Whiten, Horner, Litchfield, & Marshall-Pescini, 2004). Recent studies have begun to focus on whether children replicate the actions of others (imitation) or, instead, the environmental changes that occur as a result of actions (emulation). Several studies have concluded that young children are primarily imitators (Bornstein & Bruner, 1989; Horner & Whiten, 2005; Meltzoff & Moore, 1977; Meltzoff & Prinz, 2002; Zentall & Galef, 1988), even blindly imitating actions that are visibly ineffective, recently labeled “overimitation” (Lyons, Young, & Keil, 2007; McGuigan et al., 2007). However, few studies have yet tested the emulation alternative directly in the manner we do here. In the following, we offer overviews of the research literature relevant to each of our two experiments in turn.

Extending social learning experiments to multiple cultural transmissions

A limitation of many social learning studies with children is that they have focused on only dyadic learning scenarios, often with an (unfamiliar) adult as the demonstrator (e.g., Gergely, Bekkering, & Kiraly, 2002; Tennie, Call, & Tomasello, 2006; Thompson & Russell, 2004). Yet culture is, by its nature, a group-level phenomenon that requires fidelity across a series of social transmission events (Mesoudi & Whiten, 2004; Mesoudi & Whiten, 2008). In real life, this may be intergenerational, notably between parent and child (Guglielmino, Viganotti, Hewlett, & Cavalli-Sforza, 1995), but many day-to-day learning experiences for children are also through interactions with other children, such as siblings or friends, offering the prospect of “horizontal” transmission. Experimental studies have shown that children can be reliable models for their peers (Flynn & Whiten, 2008a; Hanna & Meltzoff, 1993; Hopper, Lambeth, Schapiro, & Whiten, 2008; Horner et al., 2006). Such child–child interactions, the focus of our first experiment, may be multiple and additive, in contrast to the dyadic designs of most prior experimental studies. Recognizing this contrast between dyadic tests and the richer nature of group-level traditions, comparative psychologists have begun to employ a method of “serial reproduction” derived from the early work of Bartlett (1932); see also Bangerter, 2000; Kashima, 2000; Mesoudi & Whiten, 2004, 2008). One version of this paradigm, called “diffusion chains,” initially is arranged so that one individual (B) observes another individual (A) perform a target act. Then, going beyond this first dyad, B becomes the model for a third individual (C), who in turn is the model for a fourth individual (D) and so on. Such a method offers new ecological validity insofar as it relates readily to real-life situations in which information spreads through a community, family, or friendship group and may lead to the establishment of a tradition.
In comparative research, this diffusion chain method was pioneered to investigate the transmission of predator mobbing behavior in birds (Curio, Ernst, & Vieth, 1978), and more recently diffusion chains have been used to study how other behaviors, such as foraging techniques, spread among varied species (Whiten & Mesoudi, 2008), including human children (Flynn, 2008; Flynn & Whiten, 2008a; Horner et al., 2006), human adults (Baum, Richerson, Efferson, & Paciotti, 2004; Mesoudi & Whiten, 2008), and chimpanzees (Horner et al., 2006). Mesoudi and Whiten (2004) concluded that the results of such an approach illustrated that “the value of the transmission chain method over standard single-generation memory experiments and confirms that the effect is genuinely ‘cultural’” (p. 18).

Diffusion chain studies have recently been extended to children, showing that they may copy their peers with a level of faithful replication that can be maintained along multiple transmissions or “generations” (Flynn & Whiten 2008a; Horner et al., 2006). Horner and colleagues (2006) seeded two chains with different techniques to retrieve a reward from a puzzle box and reported that each seeded method spread along its respective chain of children with 100% fidelity. The authors reported comparably high levels of matching along diffusion chains with chimpanzees operating on the same task.

More recently, Flynn (2008) conducted a diffusion chain study with both 2- and 3-year-olds in a series of experimental conditions where children saw both irrelevant and relevant actions performed in a tool-use task in chains of six children (see also Horner & Whiten, 2005; Lyons et al., 2007; McGuigan et al., 2007). Flynn reported not only that children were more likely to solve the task after having seen a demonstration than those in a no-demonstration control, but also that those children in later positions along the chains performed fewer of the irrelevant actions than those in the first position in the chain. However, like Horner and colleagues (2006), Flynn reported that children copied the relevant actions with fidelity and that these behaviors were transmitted along the chains of children. In a parallel study, McGuigan and Graham (2009) reported similar findings.

The first experiment presented here allowed for an extension to previous studies of the social learning of tool use during childhood (Want & Harris, 2002) through such a diffusion chain paradigm. We asked whether the observational learning employed by children in such a context is robust enough to sustain multiple transmission events and create different traditions in different chains. We tested across 20 transmission episodes, twice as many as had been examined previously and, thus, more representative of the complexity of cultural transmission in real life.

Our second aim was to discriminate among potential learning mechanisms that may underlie any such transmission. In an influential review, Want and Harris (2002) concluded that children between 18 months and 4 years of age “are best characterized as learning by imitation . . . [whereas emulation] may arise at a still later stage” (p. 11). In contrast, Bauer (1992) provided evidence that 20-month-olds use both imitation and emulation, suggesting that a linear development of observational learning processes, as outlined by Want and Harris, is too simplistic. Further research has confirmed that children are flexible in their use of imitation and emulation, with the application of these social learning strategies depending on circumstances such as the children’s understanding of intentionality (Behne, Carpenter, & Tomasello, 2005; Biro, Csibra, & Gergely, 2007; Carpenter, Akhtar, & Tomasello, 1998), the form of presentation (McGuigan et al., 2007; Nielsen, Simcock, & Jenkins, 2008; Strouse & Trosset, 2008), the context in which a behavior is produced (Gergely et al., 2002), and the processing demands of the behavior (Bekkering, Wohlschlager, & Gattis, 2000; Flynn & Whiten, 2008b).

**Examining observational learning processes using “ghost” conditions**

One method that has begun to be employed to untangle the observational learning mechanisms evidenced by children is the “ghost” method (for a review, see Hopper, in press). In the ghost method, the pertinent parts of an apparatus are moved discreetly by the experimenter (e.g., through the use of fishing line) so that the device is not explicitly acted on by a human agent and appears to move by itself. This preserves only the components of a demonstration on which emulation should be based, omitting the model required for imitation. Such a display corresponds to the definition of emulation offered by Tomasello (1999) as “learning that focuses on the environmental events involved—the changes of state in the environment that the other produced—not on a conspecific’s behavior or behavioral strategy” (p. 29). To date, we know of just five studies that have used the ghost method with children (Hopper et al., 2008; Huang & Charman, 2005; Subiaul et al., 2007; Tennie et al.,...
Thompson and Russell (2004) used the ghost method to compare emulation and imitation in the observational learning of infants and to provide insights into the potential role of mimicking (copying an action with no recognition of its goal) and stimulus enhancement (having one’s attention drawn to a task and/or its key elements). Children could retrieve a toy in one of two conditions. In the first condition, a toy on a mat could be retrieved by pushing the mat away, whereas in the second condition, the toy on the mat could be reached by pulling a second mat toward children. For both tasks, providing a human demonstration resulted in more successful retrievals of the toy than during a no-demonstration baseline period. Surprisingly, however, in the condition where a single mat was moved, children retrieved significantly more toys not only in comparison with the baseline but also in comparison with the human demonstration. Accordingly, in this condition, emulation was shown to be more influential than imitation. The same was not true for the two-mat condition. Thompson and Russell suggested that the ghost display was not so influential in the two-mat condition because this test “did not present a single, unambiguous, movement ... [and did] not show a unique contingency between pulling the empty mat and the toy coming within reach” (p. 886).

Huang and Charman (2005) presented 17-month-olds with one of four forms of demonstration of a simple object manipulation action presented on a video monitor. Infants saw either (a) a full demonstration by an unfamiliar adult, (b) a ghost condition (which the authors termed an “object movement” condition) in which the human was digitally removed from the images, (c) a “body movement” condition in which the part of the object with which the adult interacted was digitally removed from the footage, or (d) a control (“baseline”) condition in which infants saw only a video of the initial state of the objects with no manipulation. Huang and Charman reported that infants were just as likely to perform the target acts after having seen a ghost display as in the full demonstration condition and, furthermore, that infants in both of these conditions performed significantly more target acts than those in the body movement and control conditions. That infants were more likely to reproduce the outcome in the object movement condition than in the body movement condition was suggested to be due to “object movement reenactment” (OMR), a form of emulative learning (Custance, Whiten, & Fredman, 1999).

Tennie and colleagues (2006) presented 12-, 18-, and 24-month-olds with a “bidirectional” task consisting of a box that had an opaque hinged door that could be either pulled out toward the operator or pushed inward to retrieve a reward inside. Children were provided with either a demonstration by an adult human or a ghost display in which the door was moved discretely using fishing line. It was found that 18- and 24-month-olds matched the human demonstration, whereas 12-month-olds did not. However, only 24-month-olds matched the ghost display. Like Thompson and Russell (2004), Tennie and colleagues demonstrated that young children can learn from ghost displays, implicating emulation. However, the developmental progression of this ability remains unclear because Thompson and Russell found that both their 14- to 20-month-old group and their 20- to 26-month-old group showed similar levels of ability, whereas in Tennie and colleagues’ study only the oldest group (24-month-olds) was able to learn from the ghost display.

Subiaul and colleagues (2007) conducted the only study with a ghost display that has compared the responses of typically developing children and individuals with autism. Individuals with autism between 8 and 20 years of age (the mean “socialization” age was 3.94 years, whereas the mean “communication” age was 4.79 years) and two groups of children (3 and 4 years of age) were presented with a “simultaneous chaining paradigm.” Images were presented concurrently at random locations on a touch-screen monitor, and participants were required to select the images in order. Participants saw either (a) a “social human demonstration,” (b) a “nonsocial computer-only condition” with each correct response paired with a sound (comparable to a ghost display), or (c) a “social-plus-computer condition” in which participants observed an adult select the images in the correct order along with sound cues from the computer. A fourth group was tested in a no-information control. Subiaul and colleagues aimed to test for “cognitive imitation” by removing physical ability as a confound that may impair children’s ability to imitate (Barr, 2002). All participants were significantly more successful in the three experimental conditions than those in the no-information baseline condition. Although children responded successfully in the computer-only condition, Subiaul and colleagues concluded...
that emulation could not explain what they termed “cognitive imitation” because the images needed to be selected in the correct order and there was not an alternative way to reach the same end state. However, participants did repeat the actions shown in the absence of a demonstrator, indicative of some form of emulation.

Hopper and colleagues (2008) employed a bidirectional task. In this case, a door on an apparatus could be slid to the left or right with equal ease to gain a reward, replicating a previous study conducted with pigeons (Klein & Zentall, 2003). Children (3- and 4-year-olds) observed one of three forms of “demonstration”: (a) a child moving the door to either the left or the right, (b) a ghost display in which the door was moved to either the left or the right discretely using fishing line, or (c) an “enhanced ghost” condition in which the child saw a ghost display as described but another child was present and acted as a passive “demonstrator” not touching the door but collecting the reward. Hopper and colleagues found that all children who observed a fellow child perform the behavior matched the demonstration with 100% fidelity. Furthermore, it was found that in both ghost conditions children displayed emulation by matching the direction that the door of the box had been moved with their first response, but that this pattern of matching continued across all of their responses only in the enhanced ghost condition.

None of these previous studies employing ghost conditions with children investigated how children learn a novel task involving a tool. This is an unfortunate omission given the current interest in the acquisition and transmission of children’s tool use (Flynn, 2008; Flynn & Whiten, 2008a; Flynn & Whiten, 2008b; Nielsen, 2006), and here we aim to fill this gap in the research literature.

The apparatus selected for the current study embodied a tool-use task, the “Pan-pipes” (Fig. 1), that we employed previously in a ghost condition experiment with chimpanzees (Hopper et al., 2007). Hopper and colleagues (2007) found that providing chimpanzees with a Pan-pipes ghost display

![Fig. 1. Pan-pipes viewed from the side. (A) Stick tool inserted under the T-bar for the lift method. (B) Stick tool inserted into the top hole for the poke method. (C) Stick tool pushing the T-bar back for the push–slide method. (D) Panpipes viewed from the child’s perspective, inside the clear plastic box with the access holes, with lift being demonstrated.](image-url)
was insufficient for them to learn how to operate the device even when the ghost display showed the action of the tool on the apparatus. This lack of response is especially marked when compared to those chimpanzees that saw a fellow chimpanzee operate the Pan-pipes, which had led to the establishment of distinct, socially learned traditions in chimpanzee communities (Whiten, Horner, & de Waal, 2005). Our third aim was to compare the responses of children with those of the chimpanzees when presented with comparable ghost displays of the Pan-pipes.

**Experiment 1: Diffusion chain study**

We aimed to discover whether observational learning was sufficiently robust to generate the beginnings of a cultural tradition of tool use in young children. To date, the small number of diffusion chain studies conducted with children have included no more than 10 children (Flynn & Whiten, 2008a; Horner et al., 2006). The high fidelity of transmission reported might depend on the small number of “generations,” which reduces the probability of corruption events arising. The current experiment ran a chain of 20 children to address this concern. This length of chain exceeds that in all other such studies we know of in either humans (for a review of 34 studies with adults, see Mesoudi & Whiten, 2008) or nonhuman animals (for a review of 33 studies, see Whiten & Mesoudi, 2008).

Previous diffusion studies with children have used tasks that have only one method of operation different from that demonstrated. In contrast, as shown in Fig. 1, there are three possible ways to extract a reward from the Pan-pipes and, therefore, more possible avenues for corruption from the initially seeded method. In Experiment 1, the diffusion chain was seeded with lift, and the subsequent children in the chain could use either the lift, poke, or push–slide method. The lift method was anticipated to be an unlikely spontaneous solution for children of this age, and this was checked in a no-model control condition.

**Method**

**Participants**

A total of 20 children (14 girls and 6 boys) with an age range of 3 years 6 months to 4 years 10 months (mean age = 3 years 7 months) were recruited from a nursery school in Fife, Scotland. A further 16 children (8 girls and 8 boys) with an age range of 3 years 3 months to 4 years 10 months (mean age = 3 years 11 months) were assigned to a no-information control group.

**Materials**

A tool-use task, the Pan-pipes, was used in this study (Fig. 1). The Pan-pipes have previously been used in social learning experiments and ghost conditions with chimpanzees (Hopper et al., 2007; Whiten et al. 2005) and were designed to approximately recreate the extractive tool use of chimpanzees in the wild (Boesch & Boesch, 1993; McGrew, 1974; Yamakoshi & Myowa-Yamakoshi, 2004).

The Pan-pipes (Fig. 1) consist of two short sloping pipes lying one on top of the other, forming a solid unit. A reward (a sticker in a plastic capsule) could be dropped by the experimenter into the upper of the two pipes, where it would be trapped by a cube-shaped block in the pipe. The reward could be retrieved using a number of techniques. One of three possible techniques, “lift,” was demonstrated to the first child in this experiment. To perform lift, a model placed a stick tool under a T-bar on top of the block. Raising the T-bar raised the block as well, allowing the reward to roll forward into the lower pipe, subsequently falling out of a front opening at the end of the lower pipe and allowing retrieval (Fig. 1A).

In addition to the lift technique, a child could retrieve the reward using one of two alternative methods: “poke” (Fig. 1B) or “push–slide” (Fig. 1C). Both lift and poke have been used as seeded methods in previous experiments (e.g., Hopper et al., 2007), but the third method, push–slide, was discovered by the children during testing and is described in more detail in the next section. To retrieve the reward using poke, a model inserted the stick tool through a small flap door over the entrance to the upper pipe and then used the tool to push the block back. Thus, the reward was pushed back as well until it reached the back of the upper pipe, where it dropped down into the lower pipe and rolled...
down and out through the opening at the front of the Pan-pipes (Fig. 1B). In both methods, the reward exited the Pan-pipes from the same hole.

In a previous experiment, when captive chimpanzees were presented with the Pan-pipes, the mesh of their caging formed a barrier between them and the Pan-pipes, so the tool needed to be used to release the food (Hopper et al., 2007). To prevent children from manipulating the Pan-pipes directly with their hands, and thus negating the use of the stick tool, the Pan-pipes were placed in a clear acrylic box (see Fig. 1D). Fifteen access holes arranged in a grid on the front panel of this box allowed insertion of the stick tool. Pilot work by us had shown that when children were presented with the Pan-pipes in such a box, it did not hinder their performance.

The clear acrylic box was designed to allow direct comparisons to be made between the responses of the children in the current study with those of chimpanzees tested previously using the same Pan-pipes apparatus (Hopper et al., 2007). The inclusion of the restricting box contrasts with the approach of Nielsen (2006), who also studied the interplay between imitation and emulation in infants. Nielsen presented infants with the option of replicating the tool-use actions demonstrated to open a box with either the tools provided (imitation) or their hands (emulation). In the current study, we were interested in the ability of the children to use the tool itself to replicate either the method shown (imitation) or one of two alternative methods (emulation) to retrieve the reward from the Pan-pipes.

Procedure

The experimental procedure followed the diffusion chain principle outlined in the Introduction. In addition, 16 children were presented with the Pan-pipes individually, without seeing a model, to ascertain whether they could learn how to operate the task asocially.

In this no-information control, the child was invited to sit in front of the Pan-pipes on a chair. The reward was placed into the Pan-pipes by the experimenter in full view of the child, and the stick tool was placed on the table in front of the Pan-pipes. The child was then told, “You can do anything you want. You can touch anything on the table. You cannot break it.” If after 1 min the child had not retrieved the reward from the Pan-pipes, the same verbal prompt was repeated. This control lasted for 5 min or until the child had completed 15 successful interactions with the Pan-pipes regardless of the method used. Only one child discovered the lift method. Therefore, the diffusion chain was seeded with this method to provide a robust test for serial social learning.

For the diffusion chain, the first child (Child A) was tested individually in a room familiar to him or her. The child was asked to sit in front of the Pan-pipes. The experimenter then showed the child how to retrieve the reward using the lift method. Once released, the reward was shown to the child and then placed back into the Pan-pipes. This demonstration was repeated five times. The child was then asked, “Would you like a go?” The child was presented with the tool, and the apparatus was rebaited with the reward. Child A was able to operate the Pan-pipes adeptly using the lift method after these five demonstrations and was considered to be a suitable model to seed the diffusion chain. A second child (Child B) was brought into the testing room and was asked to sit on a chair next to Child A. The experimenter then told Child B, “[Name of Child A] is going to have 15 goes at this new game, and then you can have a go, okay?” Child A was then given the stick tool and told that he or she could have a go. Child A was allowed to operate the Pan-pipes 15 times using the lift method, gaining a reward for each one, all in full view of Child B. At the end of this session, the experimenter rebaited the Pan-pipes and placed the tool on the table, and then Child A was asked to return to another nursery room. After the demonstration period, there was a “response period” during which the observing child was allowed to operate the Pan-pipes. The experimenter told Child B, “Now it’s your turn. You can have a go if you would like.” Note that no encouragement was given for Child B to copy Child A. Each child was allowed five turns with the Pan-pipes during this phase and was deemed to be proficient if he or she was able to retrieve the reward on all five occasions regardless of the method used. If the observing child was deemed to be proficient, he or she became the demonstrator and entered the next demonstration period. At this point, a third child (Child C) was brought into the room and Child B operated the Pan-pipes 15 times in front of him or her, as described above for Child A and Child B. This continued until all children had acted as an observer during a demonstration period and had operated the Pan-pipes during a response period.
If, after 1 min, the observing child during the response period did not interact with the tool or Pan-pipes, the child who had previously demonstrated to the nonresponsive child was brought back into the room and allowed to operate the Pan-pipes a further five times. A second response period was then provided to the observing child. However, if the observing child was still unable or unwilling to operate the Pan-pipes during his or her second response period, the observing child was removed from the chain and the demonstrating child (e.g., Child A) was brought back to operate the Pan-pipes in front of a second child (e.g., Child C) and the chain would continue.

All test sessions were video-recorded, and the children’s actions were coded. A poke was defined as “inserting stick tool through flap door into top pipe, pushing blockage completely backward; reward released and gained,” whereas a lift action was defined as “placing stick tool under T-bar to raise T-bar (and blockage); reward released and gained.” During the response period, some children employed a third alternative method in which the T-bar was pushed backward rather than the block. This is termed push–slide and was defined as “pushing T-bar (and blockage) completely backward using stick tool; reward released and gained” (Fig. 1C). The use of this push–slide method is discussed more fully in the Results and Discussion sections for this experiment. Due to the clear distinction among these three actions (poke, lift, and push–slide), the blind interrater reliability was in total agreement for each action coded.

Results

All but 2 of the 20 children in the chain were able to operate the Pan-pipes having seen the prior demonstrating child operating the Pan-pipes 15 times. All of these children used the lift method. The 2 exceptions involved only minimal departures from this state of affairs. The 17th child in the chain (Child Q) did not want to touch either the stick tool or the Pan-pipes during her first response period, so the child before Child Q in the chain (Child P) was brought back into the testing room to give a further five demonstrations. After this second demonstration period, Child Q happily completed the task using the lift method. In addition, the 11th child in the chain (Child K), although able to operate the Pan-pipes using lift in her response period, was unwilling to do so in the presence of the next child (Child L). Therefore, the child who modeled to Child K (Child J) was asked back into the room and acted as the model for Child L.

Statistical analyses described below were conducted on the method used by the children to operate the Pan-pipes during their response periods. Child K, although unwilling to demonstrate the Pan-pipes, was able to operate them during her response period and so is included within these analyses.

In the no-information control, only 3 of the 16 children discovered how to operate the Pan-pipes and only 1 used the lift method. Significantly more children used the lift method in the diffusion chain (20/20) than in the no-information control (Fisher’s exact test, \( p < .001 \)).

It could be considered that because Child K was unwilling to demonstrate to Child L, the chain terminated at that point. This complete transmission chain still comprised 10 children (with 9 child–child transmissions), all of whom used lift. Significantly more children in this diffusion chain (9/9) used lift than the control children (1/16, Fisher’s exact test, \( p < .001 \)).

Discussion

The marked contrast between children’s universal adoption of the lift technique in the diffusion chain and failure (with 1 exception) to discover it in the control condition in Experiment 1 demonstrates unequivocally that children may copy tool use from their peers with such reliable fidelity that the same technique is transmitted among as many as 20 children, creating a “laboratory microculture.”

Recent studies have shown transmission of a behavior along diffusion chains in both children and adults (Flynn, 2008; Horner et al., 2006; Mesoudi & Whiten, 2004), but none has demonstrated transmission among more than 10 individuals, as the current study does, and only two such studies have
focused on tool use (Flynn, 2008; Flynn & Whiten, 2008a). The only exceptions to robust transmission in the current experiment, the unwillingness of Child K to perform while another child watched and of Child Q to respond during her first response period, could plausibly have occurred because these 2 young children were a little nervous in the relatively novel and unnatural testing context.

Together, the current experiment and the diffusion chain studies of Flynn and Whiten (2008a) and Flynn (2008) on the transmission of tool use among young children demonstrate that cultural fidelity can be maintained across substantial numbers of transmission events in young children. In a second experiment, we explored potential underlying social learning mechanisms through the use of a ghost procedure.

Experiment 2: Dissecting observational learning using ghost conditions

Method

Participants

A total of 92 children (39 girls and 53 boys) with an age range of 3 years 2 months to 4 years 10 months (mean age = 3 years 11 months) were recruited from nursery schools in Fife, Scotland, and County Durham, England. A preliminary analysis of variance (ANOVA) showed no significant difference in age across the experimental groups, $F(5, 86) = 1.55, p > .05$. Nor were differences found between the ages of children in the experimental groups and the no-information control, $F(6, 101) = 1.28, p > .05$.

Materials

The same Pan-pipes apparatus and rewards as those described for Experiment 1 were used.

Procedure

Children were assigned to either a control group or one of six experimental conditions: demonstration lift, demonstration poke, ghost-with-tool lift, ghost-with-tool poke, ghost lift, or ghost poke. These groups were matched for age and gender. All testing took place in a room at the children's nurseries.

In the demonstration lift condition, a child was invited to sit in front of the Pan-pipes and was told, “I am going to have a go, and then you can have a go.” Then the experimenter inserted one end of the stick tool through a hole at the front of the clear box (Fig. 1D) and proceeded to use the lift method (Fig. 1A). After the reward emerged, it was shown to the child but not given to him or her. Once the experimenter had demonstrated the lift method 15 times, the stick tool was put on the table in front of the Pan-pipes and the experimenter rebaited the task with the reward in full view of the child. The experimenter then said, “Now you can have a go. You can touch anything on the table.” The demonstration poke condition used the same procedure as the demonstration lift condition except that the poke method was used instead of the lift method.

All instructions were designed to be as neutral as possible so as not to inform or ask the child to copy the model's actions. This was done because we wished to elicit children's spontaneous responses and make direct comparisons with the responses of chimpanzees, who of course were not provided with informative verbal cues (Hopper et al., 2007). Potential ostensive cues (e.g., the experimenter looking at the tool or smiling when the child made a “correct” response) were also minimized. This ensured that the experimental conditions were as similar as possible to those used previously with chimpanzees. It has been found that providing such ostensive cues can significantly affect the ability of children to learn about a particular task (Nielsen, 2006; Topál, Gergely, Miklósi, Erdőhegyi, & Csibra, 2008), a factor we did not wish to introduce.

Before the children in the ghost conditions entered the testing room, a length of fine fishing line (0.3 mm in diameter) was tied to the T-bar at the top of the apparatus. This thin was chosen to minimize any visual impact, and no child in any of the ghost test conditions commented on it. Once the child entered the room, he or she was asked to sit on a chair in front of the Pan-pipes. Then the experimenter stood behind the Pan-pipes and discretely moved the apparatus depending on whether the child was in the ghost lift condition (T-bar lifted) or ghost poke condition (block pulled backward).
Each time the reward fell from the Pan-pipes, the experimenter showed the child the reward but did not let him or her keep it. Throughout the display, the stick tool rested on the table in front of the Pan-pipes in full view of the child. Once this movement had been completed 15 times, the child’s attention was distracted with another task and the fishing line was quickly removed out of sight of the child. The experimenter then asked the child to turn back to face the Pan-pipes and baited it in full view of the child, who was then told, “Now you can have a go. You can touch anything on the table.”

Two ghost-with-tool conditions followed the same procedure as described for the ghost lift and ghost poke operations except that the tool was incorporated into the demonstration. For the ghost-with-tool lift display, the tool was attached to the T-bar with magnets and was raised and lowered with the T-bar for each ghost-with-tool display of lift. Similarly, for the ghost-with-tool poke display, one end of the tool was attached to the front face of the blockage with magnets. As the experimenter pulled the blockage back using fishing line, the tool moved backward with it as if “pushing” the blockage. After the 15 “demonstrations,” the experimenter removed the fishing line from the Pan-pipes out of sight of the child and also uncoupled the tool from either the T-bar or blockage, depending on the condition.

After each of these displays, the child was given an access period during which he or she could interact freely with the Pan-pipes and stick tool. This lasted for 5 min or until the child had completed 15 successful operations (regardless of the method used). An interaction was deemed to be successful when the child used the stick tool to retrieve a reward from the Pan-pipes. The child was allowed to keep all of the stickers he or she obtained. If after 1 min the child had not touched the Pan-pipes or stick tool, he or she was prompted, “You can do anything you want. You cannot break it.” If after 5 min the child had not retrieved a reward from the Pan-pipes, he or she was classed as “unable to solve the task.” All test sessions were video-recorded and coded as described for Experiment 1.

The responses of children in each of these six experimental conditions were also compared with those of the 16 children tested in the no-information control reported in Experiment 1.

Results

Level of success

Of the 92 children tested in the six experimental conditions, 45 (49%) were able to successfully operate the Pan-pipes and retrieve a reward using the lift, poke, or push-slide method, significantly more than the 3 children who were successful in the no-information control (3/16 or 19%, Fisher’s exact test, \( p = .03 \)).

Whether children used lift or poke, significantly more were successful in the demonstration lift (13/15) and the demonstration poke (11/16) groups compared with those in the no-information control (3/16) (Fisher’s exact test, \( p < .01 \) for both) (Fig. 2). Overall, a significantly greater proportion of children were successful in the demonstration conditions combined (24/31) compared with those in the control condition (\( p < .001 \)).
The success of children in the ghost conditions was intermediate between those in the live demonstration conditions and the no-information control. However, the number of children who were successful in the ghost (8/15) and ghost-with-tool (4/15) lift conditions was not significantly greater than 3 of 16 children in the no-information control (Fisher’s exact test, \( p > .05 \) for both). Nor was there a significant difference in the number of successful children in either the ghost-with-tool (5/16) or ghost (4/15) poke condition compared with the control (\( p > .05 \) for both). Overall, the 34% of children in the ghost condition who were successful represents a figure considerably closer to that for the no-information control (19%) than to that in the live demonstration conditions (77%).

This situation is reflected in the finding that, overall, children in the full demonstration conditions were significantly more successful (24/31) than children who saw either a ghost-with-tool display (9/31, Fisher’s exact test, \( p < .001 \)) or a ghost display (12/31, \( p = .004 \)). There was no significant difference in the level of success of the children who saw a ghost-with-tool or basic ghost display (\( p > .05 \)).

**Level of matching: First responses**

Children’s first responses were coded according to the categories in Table 1. These initial exploratory interactions with the task were not always successful. Of the 13 children who were eventually successful in the demonstration lift condition, 9 used lift as their first response, whereas 6 of the 11 children who were eventually successful in the demonstration poke condition displayed poke during their first response. However, all of the first responses of the children who were unsuccessful in their first attempt were approximations of the demonstrated method (insert tool lift [ITL] for lift and insert tool poke [ITP] for poke) (Table 1), indicative of social learning. Combining unsuccessful approximations and successes, all children in each of the demonstration conditions attempted only the method they had witnessed, a highly significant difference (Fisher’s exact test, \( p < .001 \)).

**Table 1**

<table>
<thead>
<tr>
<th>Child</th>
<th>Lift demo 1st</th>
<th>Lift demo Suc</th>
<th>Poke demo 1st</th>
<th>Poke demo Suc</th>
<th>Ghost tool lift 1st</th>
<th>Ghost tool lift Suc</th>
<th>Ghost tool poke 1st</th>
<th>Ghost tool poke Suc</th>
<th>Basic ghost lift 1st</th>
<th>Basic ghost lift Suc</th>
<th>Basic ghost poke 1st</th>
<th>Basic ghost poke Suc</th>
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Note. 1st, first interactions; Suc, first successful responses. The conditions are as follows: lift demonstration (lift demo), poke demonstration (poke demo), basic ghost lift, basic ghost poke, ghost-with-tool lift (ghost tool lift), and ghost-with-tool poke (ghost tool poke). Children responded successfully with lift (L), poke (P), or push–slide (PS) actions as defined in the Method section of Experiment 1 (see also Fig. 1). In certain cases, children’s first interaction with the Pan-pipes was unsuccessful (they used the tool to manipulate the apparatus but were unable to retrieve the reward); these actions were “insert tool lift” (ITL), where children attempted lift but failed to raise the blockage high enough to release the reward, “insert tool poke” (ITP), where children inserted the tool into the lower pipe from where the reward would emerge and one child did not use the tool but instead tried to reach up the reward chute with a hand (IHR). The gray shading represents those children who made no contact with either the tool or Pan-pipes.
Only 2 children were successful with their first response in the ghost-with-tool conditions (2 performing poke in the poke group). However, several children attempted lift (ITL) or poke (ITP) (Table 1). The proportions of ITL versus ITP(+P) were significantly higher in the lift group (8:0) than in the poke group (0:9), with the latter including the 2 successful poke actions (Fisher’s exact test, \( p < .001 \)). Thus, there was evidence of (emulative) learning here despite these children’s ultimate lack of success.

Responses in the basic ghost conditions were very different, with no ITL in the lift group and no ITP in the poke group, and inspection of Table 1 indicates that insufficient signs of matching were shown for statistical testing.

**Level of matching: All responses**

Each successful child used only one method to extract the reward from the Pan-pipes (whether it be lift, poke, or push-slide). Therefore, the first successful responses shown in Table 1 are representative of all the responses made for the child. For analysis, children were classed as either “lifters,” “pokers,” or “push-sliders.”

Considering all of their responses, significantly more children used lift in the demonstration lift group (13/15) than in the no-information control (1/16) (Fisher’s exact test, \( p < .001 \)) (Fig. 2). Similarly, significantly more children used poke in the demonstration poke group (11/16) than in the no-information control (2/16) (Fisher’s exact test, \( p = .003 \)).

Of those children in the ghost-with-tool conditions who were successful (4/15 for lift and 5/16 for poke), all used the same method as that shown in the display. The proportion of successful lift versus poke, therefore, was significantly higher in the lift group (4:0) than in the poke group (0:5) (Fisher’s exact test, \( p < .03 \)).

By contrast, in the basic ghost conditions, more successful children in the lift group used poke (5) than lift (3). Given that of the only 4 successful children in the basic poke group, 2 used poke and 2 used push-slide, no significant matching in these basic ghost conditions occurred (\( p > .05 \) for contrasts in lift, poke, or poke plus poke-slide).

**Discussion**

Of the 31 children who witnessed a full demonstration by an adult, 24 successfully operated the Pan-pipes. As many as 28 attempted the task, and all did so in a manner that matched the form of demonstration they had seen. Of those who were successful, 13 of 13 matched the lift method they had seen and 11 of 11 matched the poke method they had seen. This high degree of fidelity to the method witnessed is consistent with the results of Experiment 1 in which the same technique was transmitted among consecutive dyads of a total of 20 children.

The ghost condition results contrasted with this, with children in these conditions achieving significantly less success. Their success levels would not be sufficient to support the transmission of a diffusion chain of the kind recorded in Experiment 1. This indicates that the learning mechanisms underlying this chain involved more than emulation of the object movements involved (OMR [Custance et al., 1999]), which was the information to which the ghost conditions were restricted. We conclude that for young children, watching a model’s actions that can be imitated typically plays a crucial role in cultural transmission among peers for tool use of the kind we studied.

As would be predicted, the contrast between the demonstration and ghost conditions was greatest for the basic ghost condition, which provided the most minimal information. Not only was there a relative lack of success in this group compared with the demonstration condition, but there also was no statistically significant measure of matching to what had been witnessed. Indeed, 8 of 11 children who attempted the task after seeing the ghost lift display put the tool into the delivery chute and 7 of 10 did this after watching the ghost poke display, just as did 7 of 10 children in the no-information control who worked on the Pan-pipes (Table 1). There were signs that at least some children did learn in the basic ghost condition insofar as all 3 children who successfully used lift were in the lift group. (In the ghost poke group, of the 4 successful children, 2 used poke and 2 used push-slide, but this appears to be comparable to the 5/8 successful children in the ghost lift group and 2/3 children in the control group who also succeeded in using poke.) Nevertheless, overall it is very clear that the limited extent of information provided in the basic ghost condition for emulation falls far short of that necessary to
sustain the diffusion chains of Experiment 1. The social learning processes involved in these chains must have involved more than emulation in relation to the blockage movements alone.

As one might predict, the ghost-with-tool condition yielded an intermediate picture. Overall, the children were significantly less successful than those in the demonstration groups and, indeed, were not significantly more successful than children in the basic ghost or control conditions. However, in their initial attempts at the task, they revealed a significant tendency to match what they had seen. They tried to make the tool do what it had done in the ghost display. The result was that just under a third of these children succeeded, and all of those who succeeded employed the method displayed in the ghost display they had witnessed, just as children in the demonstration conditions were highly faithful to the method they had seen. Of the children in the ghost-with-tool condition who failed, 5 merely pushed the tool into the delivery chute, as did so many children in the basic ghost and control conditions, so that children’s performance in this condition was highly variable (Table 1).

Overall, the results of the ghost-with-tool condition show that emulation based on this level of information (the maximum a ghost condition could display) would be insufficient to sustain a transmission chain with the repeated fidelity we observed in Experiment 1. However, it is notable that nearly a third of children at this age learn enough from watching the movements of the tool and blockage. It is likely, therefore, that this level of information would be sufficient to seed and sustain a cultural chain of transmission of tool use for such a subset of children, as exemplified in the lift versus poke actions of the tool in the Pan-pipes task.

One might question whether it is really appropriate to call this emulation. What is being copied could be described as the actions of the tool; when achieved in normal life by an agent wielding the tool, these actions are in effect an extension of the bodily action. A counter argument to this is that the movements of the tool presented a fuller display of object movements, perhaps better facilitating OMR. These alternative interpretations underline the ambiguous status of recreating the movements or actions of a tool in relation to the emulation/imitation distinction (Whiten et al., 2004).

Our results are in some ways consistent with the existing ghost condition literature, but they also differ importantly in other ways and extend our understanding of the nature of social learning in young children particularly for tool-use tasks. Each of the five previous ghost experiments, reviewed in the Introduction, provided some evidence of children learning from and matching a ghost display, consistent with a capacity for emulation (Hopper et al., 2008; Huang & Charman, 2005; Subiaul et al., 2007; Tennie et al., 2006; Thompson & Russell, 2004). Our results differ most markedly in the case of the basic ghost conditions, where at best there were (nonstatistically significant) hints that a few children learned more than those in a no-information control. In the ghost-with-tool condition, children showed more evidence of social learning, but it remained the case that fewer than a third were successful, significantly fewer than in the live demonstration conditions. Thus, unlike the previous studies, in our own experiments children showed virtually no evidence for emulation in the basic ghost condition and showed variable evidence for it in the ghost-with-tool condition despite the fact that, to an initiated adult eye, the latter condition carries extensive information about how to successfully gain rewards from the Pan-pipes.

Why the difference? We suggest that the most likely explanation lies in the complexity of the cognitive challenge to children inherent in the task presented to them. All of the previous studies employed very simple manipulations: sliding a mat (Thompson & Russell, 2004), manipulating simple objects together (Huang & Charman, 2005), pushing or pulling a swing door (Tennie et al., 2006), tapping a series of images in the correct order (Subiaul et al., 2007), and sliding a small door to the left or right (Hopper et al., 2008). By contrast, in our basic ghost condition, children saw only how the obstacle could move to release the reward, so they themselves needed to generate a tool-based manipulation that could achieve this, a task that required a certain sophistication in understanding how the Pan-pipes might work and how the tool could be used productively. Perhaps an adult could manage this, but it appeared to be too difficult for young children of the age range tested. The ghost-with-tool condition provided much more information—either that the tool could be inserted into the upper pipe and push the blockage back or that it could be hooked under the T-bar of the blockage and lifted up to release the reward. However, in these displays, the tool was already in place to achieve these effects; thus, the displays lacked the demonstrations of how a human agent could manipulate the tool into the configurations and actions necessary for success. As noted above, the information in the ghost-with-
tool display was sufficient for a subset of children but not for most of them, who were not able to supply these missing elements themselves to succeed.

The current results and the above interpretation are consistent with the hypothesis of Hopper and colleagues (2008; see also Whiten et al., 2009) that individuals may be able to rely on emulation for learning about procedures that are sufficiently simple that their current cognitive capacities can supply the missing elements needed for successful action, but where the task complexity exceeds this threshold it will be necessary to view an agent completing the task such that imitation of what this model actually does can come into play. This is consistent with the stronger claim of Bauer and Kleinkech (2002): “Age alone does not determine whether children will evidence emulation. Rather, children can emulate novel causal sequences well before the age of 4, just so long as the task demands are manageable. In short, it appears that the learning strategy a young child is capable of using varies as a function of task demands, not age” (p. 19). Therefore, the interplay between age and task complexity on children’s observational learning offers an exciting avenue for future research.

The hypothesis that a role for emulation is contingent on task complexity relative to cognitive competence is supported by parallel results with chimpanzees that showed no evidence of emulation in either of the Pan-pipes ghost conditions described in the current article (Hopper et al., 2007) yet did provide evidence of emulation, even if relatively fleetingly, when the task required merely pushing a small door to the left or right to gain a reward (Hopper et al., 2008). Comparison of these chimpanzee studies with the current child study suggests both commonalities and differences. Chimpanzee responses were similar to child responses in two main respects: first, for the chimpanzees, witnessing a conspecific model perform poke or lift actions on the Pan-pipes produced more evidence of successful and matching responses than did either kind of ghost display (Hopper et al., 2007; Whiten et al., 2005); and second, chimpanzees showed more evidence of emulation in a ghost experiment requiring only a simply motoric response than in one requiring the more complex Pan-pipes task (Hopper et al., 2007, 2008).

Differences between chimpanzee and child responses can be found in the level of success. Whereas some children in all of the ghost conditions showed some success and, in the case of the ghost-with-tool condition, matching to what had been witnessed, chimpanzees failed to successfully tackle the Pan-pipes after watching either kind of ghost condition but did so with significant fidelity after watching conspecifics operate the task.

Conclusions

Young children are able to acquire a technique to retrieve a reward from a tool-use task with high fidelity after observing either an adult or a fellow child. Our first experiment attempted to mirror the transmission of information down generations and among peers (Boyd & Richerson, 1996; Guglielmino et al., 1995; Mesoudi, Whiten, & Laland, 2006; for a review, see Kashima, 2000). The children tested in Experiment 1 maintained the use of the lift method along a chain of 20 children. Not only were these children able to operate the task, but they also showed 100% fidelity to the method they had witnessed. The same was true for those tested in adult–child dyads in Experiment 2.

In contrast to those children who observed a human model (whether a child [Experiment 1] or an adult [Experiment 2]), those who were tested in the ghost display conditions (Experiment 2) were significantly less successful than those who had observed an adult model even when the tool was included in the ghost display. In addition, there was no significant difference in the number of children who were able to operate the task in the ghost conditions compared with those in the no-information control, consistent with the belief that children are primarily imitators (Call, Carpenter, & Tomasello, 2005; Nielsen, 2006; Williamson & Markman, 2006).

This is not, however, a clear story. Although the children were not as successful in the ghost-with-tool condition as those who saw an adult model, all of those who were successful used the same method as that shown in the ghost-with-tool display. This is emulative learning. The children in this condition who did not succeed may have needed the additional information about actions available to their more successful peers in the full demonstration condition or lacked motivation elicited by watching a live model at work. Further experiments will be needed to tease apart such potential explanations, which would not only provide a greater understanding on the role of motivation but
also allow cross-species comparisons following on from other developmental studies (see, e.g., Carpenter, Call, & Tomasello, 2002) and comparative studies (Hopper et al., 2008).

The results of these two experiments confirm that children may copy faithfully both from their peers and from unfamiliar adults. The children copied a conspecific in a dyadic interaction, and this fidelity of matching was maintained along a series of transmission events, providing support for extending previous diffusion studies (Flynn, 2008; Horner et al., 2006). This is particularly impressive because there were three potential ways the children could retrieve the reward from the Pan-pipes and yet all children tested used the method demonstrated. In addition, for the Pan-pipes, provision of a ghost display was typically inferior to live demonstrations for the children to operate the apparatus. Even the inclusion of a tool did not improve their overall success, although it did increase the likelihood that a subset of children would use the method demonstrated. We urge that further research be conducted to investigate the interplay among social learning mechanisms, task complexity, and motivation.

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