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Out of the empirical box: A mixed-methods study of tool innovation among Congolese BaYaka forager and Bondongo fisher–farmer children

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ABSTRACT

Tool innovation has played a crucial role in human adaptation. Yet, this capacity seems to arise late in development. Before 8 years of age, many children struggle to solve the hook task, a common measure of tool innovation that requires modification of a straight pipe cleaner into a hook to extract a prize. Whether these findings are generalizable beyond postindustrialized Western children remains unclear. In many small-scale subsistence societies, children engage in daily tool use and modification, experiences that theoretically could enhance innovative capabilities. Although two previous studies found no differences in innovative ability between children from Western and small-scale subsistence societies, these did not account for the latter's inexperience with pipe cleaners. Thus, the current study investigated how familiarity with pipe cleaners affected hook task success in 132 Congolese BaYaka foragers (57 girls) and 59 Bondongo fisher–farmers (23 girls) aged 4–12 years. We contextualized these findings within children's interview responses and naturalistic observations of how pipe cleaners were incorporated into daily activities. Counter to our expectation, prior exposure did not improve children's performance during the hook task. Bondongo children innovated significantly more hooks than BaYaka children, possibly because they participate in hook-and-line fishing. Observations and interviews showed that children

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imagined and innovated novel uses for pipe cleaners outside the experimental context, including headbands, bracelets, and suspenders. We relate our findings to ongoing debates regarding systematic versus unsystematic tool innovation, the importance of prior experience for the ontogeny of tool innovation, and the external validity of experimental paradigms.

Introduction

Tool innovation—defined as the conceptualization and fabrication of a novel tool to solve a problem (Cutting, Apperly, Chappell, & Beck, 2014; Neldner et al., 2019)—is at the core of our species' ability to adapt and thrive in diverse environments. Childhood is thought to uniquely support innovation because children spend much of their time in exploratory learning and hypothesis testing (Carruthers, 2002; Gopnik, 2020; Lew-Levy, Milks, Lavi, Pope, & Friesem, 2020). However, empirical findings suggest that children aged 3–7 years struggle to innovate novel tools (Carr, Kendal, & Flynn, 2016; Rawlings & Legare, 2021). Given its adaptive importance, it is puzzling that tool innovation seems to arise late in development.

Of the few experimental paradigms measuring tool innovation capabilities, the hook task has become a benchmark (Beck, Williams, Cutting, Apperly, & Chappell, 2016). During the hook task, participants are asked to retrieve a prize (e.g., a sticker, a piece of candy) from a small basket at the bottom of a clear tube. To succeed, children must modify a straight pipe cleaner into a hook, insert the hook into the tube, and lift the basket to retrieve the prize (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011; original task from Weir, Chappell, & Kacelnik, 2002). Fewer than 10% of British children aged 4 or 5 years spontaneously solve the hook task (Beck et al., 2011; Cutting, Apperly, & Beck, 2011; Cutting et al., 2014). Children younger than 8 years also struggle to innovate in other experimental paradigms such as the floating peanut task (Hanus, Mendes, Tennie, & Call, 2011; Nielsen, 2013) and the add–subtract–reshape task (Cutting, 2013; Neldner et al., 2019).

In contrast to unsystematic—or exploratory—innovation, the hook task is a systematic—or problem-oriented—innovation task (Legare & Nielsen, 2015). Children may struggle with systematic innovations because these are ill-structured problems. Ill-structured problems lack information about the transformations needed to get from a starting state to an end goal (Cutting et al., 2011; Shallice & Burgess, 1991; White, Burgess, & Hill, 2009). During the hook task, children must (a) understand that pipe cleaners bend, (b) identify the hook as a viable solution, and (c) shape the hook and retrieve the prize. Through scaffolding or priming, children more readily solve ill-structured problems. For example, Cutting et al. (2014) found that the combination of pipe cleaner bending practice and seeing a ready-made pipe cleaner hook (but not manipulation by itself) bolstered 5- and 6-year-old children's success on the hook task. Context may also influence children's ability to solve ill-structured problems. Sheridan, Konopasky, Kirkwood, and Defeyter (2016) found that when tested in a museum setting, 50% of American 4- and 5-year-olds solved the hook task. The authors argued that the exploratory learning environment promoted by the museum may positively affect children's innovative capabilities.

Variation in the degree to which children learn through exploration in different sociocultural contexts may further shape their innovative capabilities. In many small-scale subsistence societies, children's learning is primarily self-initiated and children engage in tool use and modification during work and play (Lancy, 2016, 2017). These experiences may help children generate creative solutions to novel problems at an early age. However, two studies have found that young San forager and Indigenous Australian children living in small rural communities show low rates of innovation during the hook task, similar to those found in postindustrialized settings (Neldner, Mushin, & Nielsen, 2017; Nielsen, Tomaselli, Mushin, & Whiten, 2014). Although it is possible that tool innovation capabilities arise late in development across human societies, artifacts of experimental paradigms themselves may also be at play.

Experimental paradigms do not always yield externally valid results when used across cultural contexts (Broesch et al., 2020; Hruschka, Munira, Jesmin, Hackman, & Tiokhin, 2018; Kline, Shamsudheen, & Broesch, 2018; Rogoff, Dahl, & Callanan, 2018). This may be especially problematic with regard to the hook task because whereas postindustrialized children are usually familiarized with pipe cleaners in daycare and preschool, many children in small-scale subsistence societies with comparatively low market integration are not. Familiarity, context, and experience with tool innovation interact with each other, so any advantage children from small-scale subsistence societies glean from making their own toys and tools could be masked during tasks where precursor materials and experimental testing are unfamiliar (Neldner et al., 2017, 2019; Nielsen et al., 2014).

In the current study, we investigated how prior exposure to pipe cleaners affected hook task performance in two small-scale subsistence societies: Congolese BaYaka foragers and Bondongo fisher–farmers. To assess whether familiarity with pipe cleaners improved children's performance during the hook task, we compared children from two villages. In Village 1, pipe cleaners remained novel. In Village 2, children were given pipe cleaners twice during the 2 weeks prior to testing to use however they pleased. Following Beck et al. (2011) and Cutting et al. (2014), half the children in both villages received pipe cleaner bending practice immediately prior to testing. Given the novelty of the testing environment for many of our participants, we also sought to understand how children innovated in everyday settings. To do so, we conducted structured observations in Village 2 to uncover how pipe cleaners were modified and incorporated into daily activities. We also asked children to list the ways in which they thought pipe cleaners might be useful in an object-uses task (modified from Beck et al., 2016; Defeyter & German, 2003). Because tool use and modification are a central part of their developmental niche, we expected BaYaka and Bondongo children to innovate at an earlier age than has been reported in previous studies conducted in postindustrialized societies (Beck et al., 2011; Cutting et al., 2014; Gonul, Takmaz, Hohenberger, & Corballis, 2018).

Ethnographic background

BaYaka rely on hunting, gathering, fishing, and horticultural gardening for subsistence, and they are relatively age and sex egalitarian (Boyette, Lew-Levy, Sarma, Miegakanda, & Gettler, 2020). Bondongo subsist on hunting, fishing, and gardening, and they maintain status and age hierarchy (Boyette, Lew-Levy, & Gettler, 2018). BaYaka and Bondongo have access to a limited number of market goods, including fishhooks, machetes, and (less frequently) shotguns. BaYaka children and adolescents spend about 30% of their time in play, and more than 60% of this play is with objects and/or in pretense (Lew-Levy, Boyette, Crittenden, Hewlett, & Lamb, 2020). Whereas data on Bondongo children's time allocation is not currently available, Boyette (2016) reported similar values for neighboring Central African Ngandu farmers. BaYaka and Bondongo children often play with self-constructed toys such as dolls made from the stems of banana plants and toy cars made from discarded plastic (e.g., flip flops) and local plants (Fig. 1). From a young age, BaYaka and Bondongo children play with tools such as knives and machetes (Lew-Levy et al., 2019). By middle childhood, children in both communities are proficient users of tools during household and subsistence tasks.

Although schools are available in the surveyed communities, BaYaka and Bondongo have less exposure to formal education than the other small-scale subsistence societies in which the development of children's innovative capabilities has been explored (Neldner et al., 2017; Nielsen et al., 2014). There are two schools in each village: a public elementary school and a preparatory (pre) school for BaYaka children (Bombjaková, 2018). However, due to the remoteness of the villages and lack of resources, schools are infrequently in session and lessons are usually delivered for 1–2 h a day. Children's school participation is sporadic owing to their important role in family subsistence work, especially during the 3- to 4-month fishing season when many Bondongo and BaYaka families move to remote camps.

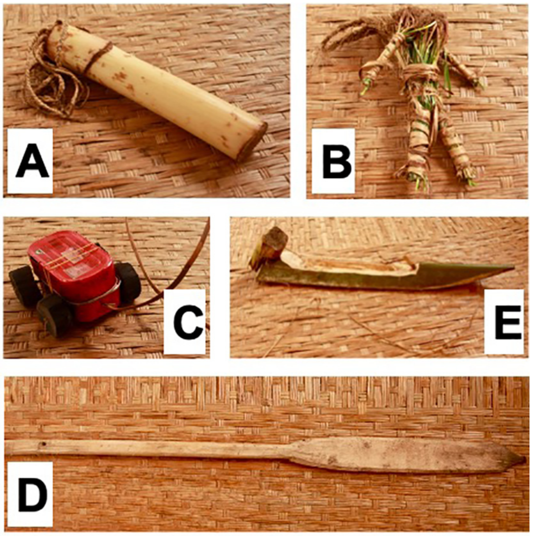

Fig. 1. BaYaka and Bondongo children's self-constructed toys, including dolls made from the stems of banana plants and grass (A, B), toy cars made from discarded sardine tins (also often from pieces of old flip flops) (C), toy boats made from bamboo (D), and toy paddles carved from wood (E).

Method

Participants

Data were collected in two remote villages in the Likouala region of the Republic of Congo in July and August 2019. Both BaYaka and Bondongo inhabit each village. We planned to collect data with BaYaka only; however, because of their expressed interest, Bondongo children in Village 2 were invited to participate in the study. Community and parental consent, as well as child assent, was obtained prior to all testing (see online supplementary material for details). Because age is not commonly documented for BaYaka, we used age estimates (in years) based on birth order (see Diekmann et al., 2017, for details) when available and used consensus estimates with guidance from local research assistants otherwise. Bondongo age in years is typically known. A total of 132 BaYaka children with estimated ages from 4 to 12 years participated in the study (Village 1: n = 62, M_{age} = 8.26 years, SD = 2.30, 39% female; Village 2: n = 70, M_{age} = 7.97 years, SD = 2.53, 47% female). A total of 59 Bondongo children aged 4–12 years participated in the study (M_{age} = 8.02 years, SD = 2.73, 39% female). There was no significant difference between the ages of BaYaka children from Village 1 and those from Village 2 (t = 0.65, SE = 0.44, p = .52) or between the ages of BaYaka and Bondongo children from Village 2 (t = 0.10, SE = 0.45, p = .92).

The study was approved by the research ethics office of Simon Fraser University.

Materials and procedures

Pipe cleaner distribution

Two weeks prior to testing, all children within our target age range from Village 2 were given two pipe cleaners each. This procedure was repeated a week later. In total, 288 pipe cleaners were distributed to 105 BaYaka children and 272 pipe cleaners were distributed to 86 Bondongo children. Upon request, an additional ~ 100 pipe cleaners were given to children from outside of our target age range in both societies in Village 2. No pipe cleaners were distributed to children in Village 1. To understand how children innovated with pipe cleaners in their everyday lives, the second author conducted daily observational sampling walks of Village 2 starting the day after each distribution. Walks were conducted either in the morning (n = 2) or during the afternoon (n = 6), initially alternating; however, on several occasions morning walks were delayed until the afternoon due to village meetings or rain. Walks alternated between two routes, either clockwise or counterclockwise around the village, making sure to pass every household. Upon observing a pipe cleaner, its usage was recorded along with details regarding the size and the sex and age makeup of the group using it. The pipe cleaner's state and location were also recorded if it was unattended. Observations were made without drawing attention to the pipe cleaners to avoid inadvertently encouraging specific uses.

Hook task

Testing setting and materials. In each of the two villages, testing occurred in a quiet room within the research house. A thick string and pipe cleaner (both 30 cm) were placed on either side of a vertical clear tube (20 cm height, 5 cm diameter) mounted on a base (23 × 8 × 1 cm); the pipe cleaner side was counterbalanced (see Fig. S1 in supplementary material). The experiment was administered with BaYaka in Village 1 by the first author, with BaYaka in Village 2 by the second author, and with Bondongo in Village 2 by a Bondongo research assistant. All consent and experiment scripts were translated and back-translated into Yaka for BaYaka participants and into Lingala for Bondongo participants prior to implementation. Testing was video-recorded, and written notes were kept in case of camera failure.

Procedure. While holding a locally familiar hard candy, the experimenter said, "Do you see this candy?" The candy was then placed into a small wicker basket that was dropped into the tube. "If you can get it out using these things [the experimenter gestured at the string and pipe cleaner] it will be yours." Participants were pseudorandomly assigned to either the *bending demo* condition or the *control* condition, such that age and sex were balanced across groups. In the bending demo condition, the experimenter picked up the object on the left (counterbalanced—pipe cleaner or string) and wrapped it around a pencil, saying, "You can bend this like this. Now you try." Children were encouraged to wrap the object around the pencil, and this was repeated for the other object. In the control condition, children proceeded directly to the experiment after the candy and basket were placed into the tube. Participants were allowed 3 min to extract the candy. We opted to extend the usual 1- to 2-min testing window so as to not limit innovations that might occur after several minutes (see Voigt, Pauen, & Bechtel-Kuehne, 2019). If children were reluctant to touch the tools, the experimenter issued an encouraging prompt (e.g., "Do you want to try?") at 15 s intervals (see supplementary material for protocol deviations). If participants did not pick up the tools or interact with the tube for 45 s, the experiment was stopped. Thus, trials ended after participants (a) successfully retrieved the candy, (b) tried to retrieve the candy for 3 min, (c) exhibited signs of discomfort, or (d) did not interact with the tube or objects for 45 s or if (e) the experimenter committed a major procedural deviation (see supplementary material for description). Children who did not retrieve the candy by the end of testing were given the same type of candy from the bag. To minimize crosstalk, we aimed to test friend/sibling groups in sequence, and once children were tested, we tried to separate them from those who were waiting to participate; however, this was not always possible.

Coding. A trained research assistant, blind to the hypotheses, coded all trials from video except in one case of video malfunction for which trial notes were used instead. Variables of interest were (1) *first object inserted:* the first object that entered the tube, either pipe cleaner, string, or body part (hand or mouth); (2) *success:* a binary indicator of whether or not the child extracted the candy from the tube during the 3-min testing window; and (3) *method:* the way in which the candy was extracted. Possible methods were (a) *pipe cleaner hook,* where the participant modifies a pipe cleaner by bending it into a hook; (b) *pipe cleaner or string wedge,* where the participant wedges the end of a straight pipe cleaner or the string into the spokes of the basket; and (c) *hand,* where the participant reaches into the tube to retrieve the basket with one's fingers (usually only children under 5 years of age). The second author recoded 25% of the videos. Intercoder reliability was high for all categories (first object inserted: kappa = .87; success: kappa = .90; method: kappa = .92).

Table 1
Numbers of participants in the hook task and method used to solve the hook task.

		Unsolved or no tool used	String or pipe cleaner wedge	Pipe cleaner hook	Total
BaYaka: Village 1	Control	27	2	0	29
No pipe cleaner exposure	Bending	29	1	2	32
	Total	56	3	2	61
BaYaka: Village 2	Control	37	3	0	40
Two weeks' pipe cleaner exposure	Bending	25	1	1	27
	Total	62	4	1	67
Bondongo: Village 2	Control	20	3	4	27
Two weeks' pipe cleaner exposure	Bending	23	3	4	30
	Total	43	6	8	57

Participant exclusion. We excluded trials in which (a) the experimenter stopped the trial within the first 30 s to avoid participant frustration (n = 3 BaYaka), (b) the camera malfunctioned and notes were unavailable (ns = 1 BaYaka and 1 Bondongo), or (c) the experimenter provided a major hint during the trial (n = 1 Bondongo). After exclusions, our final sample size consisted of 185 children (Table 1).

Analyses. To examine the effect of pipe cleaner exposure on children's success in the hook task, we fit a series of binary logistic regression models to the data from BaYaka children only. Model 1 investigated children's first tool choice. Children were considered correct (1) if the first tool they inserted into the tube was the pipe cleaner alone or with the string, and they were considered incorrect (0) if they inserted either the string or a body part (e.g., hand, mouth) or did not insert any object into the tube within the testing window. Model 2 examined whether exposure to pipe cleaners affected children's propensity to manufacture and successfully use the hook. Children were considered successful (1) if they bent the pipe cleaner into a hook and successfully extracted the candy, and they were considered unsuccessful (0) otherwise. In both models, we controlled for age (continuous in years) and sex (0: female; 1: male). We also included predictor variables for condition (0: control; 1: bending demo), village (Village 1: no pipe cleaner exposure; Village 2: 2 weeks' exposure), and their interaction.

To examine cross-cultural variation in children's rates of innovation, we fit additional binary logistic regression models to the data from Village 2 only. The dependent variable in Model 3 was first tool choice. The dependent variable in Model 4 was the successful manufacture and use of the hook. In both models, we controlled for age and sex and included predictors for condition, society (0: BaYaka; 1: Bondongo), and their interaction.

All models were fit using the *arm* package (Gelman & Su, 2018) and the *MuMIn* package (Bartoń, 2020) in R (R Core Team, 2013).

Object-uses task

Procedure. To understand how exposure to pipe cleaners might affect children's ideas about their functionality, we conducted a modified object-uses task immediately after the hook task and irrespective of whether children completed the hook task (Beck et al., 2016; Defeyter & German, 2003). During this task, the experimenter held up the pipe cleaner and asked children, "If I gave this to you, what could you do with it?" After each response, the experimenter prompted, "What else?" If children did not respond, the experimenter prompted further by asking, "If I gave this to you and you took it home, what could you do with it?" and then "What could this help you with?" This process was repeated for the string.

Coding. Children's responses to the object-uses questions were translated from video, with guidance from two field assistants. After translation, all responses (304 in total) were independently grouped into four inferred categories by the first and second authors (kappa = .87), with disagreements being resolved by consensus: (1) *Hide:* hiding or storing the item for future use; (2) *General Play:* incorporating the item into an unspecified play activity or end result; (3) *Specific Play:* incorporating the item into

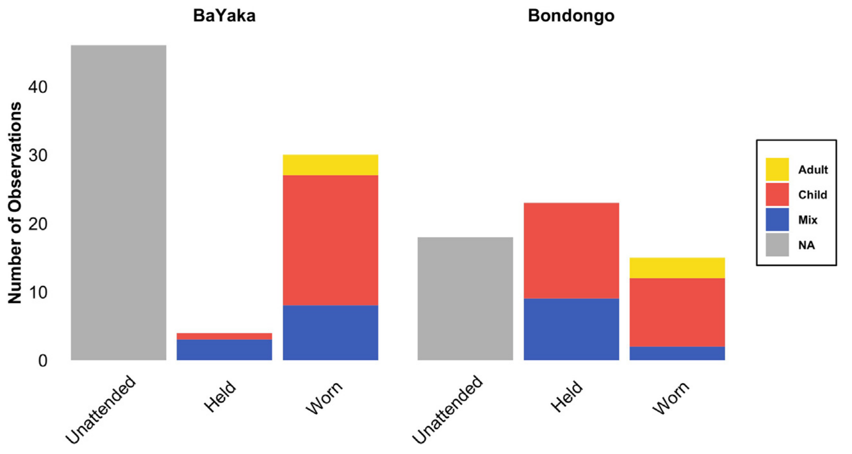

Fig. 2. Pipe cleaner sightings recorded during observational sampling walks in Village 2. NA, not applicable.

a specific play action or end result; or (4) *Specific Use:* incorporating the item into a specific functional action or end result (see Table S1 in the supplementary material for all responses and their inferred categories). The total number of response categories was summed for each participant (range = 0–4).

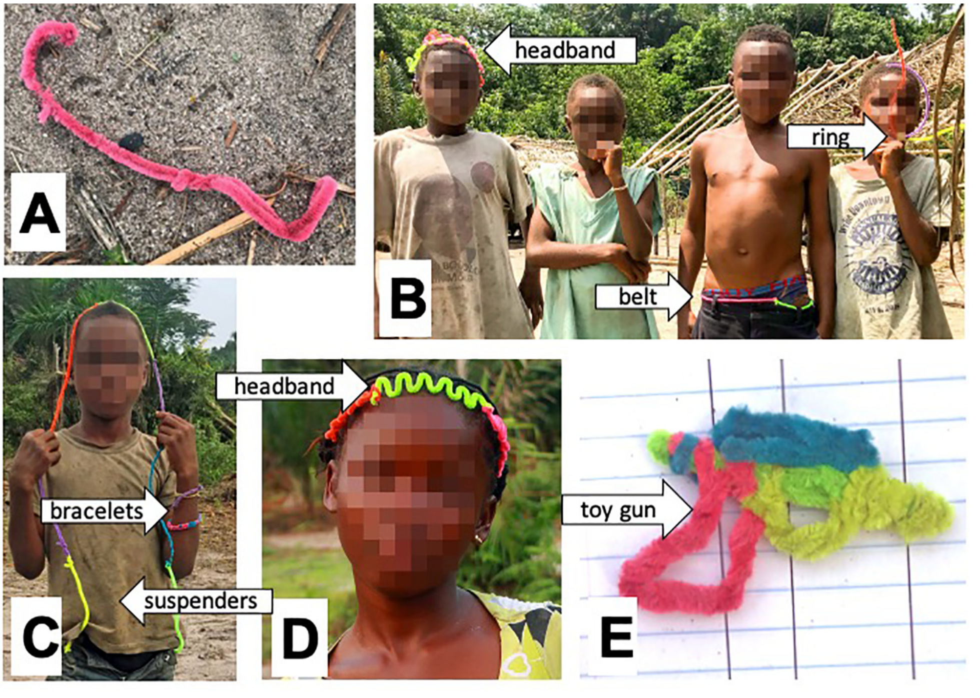

Fig. 3. Village 2 observations of pipe cleaner uses in children's free play. (A) Unattended pipe cleaners were often found in modified states. (B, C) BaYaka children observed with pipe cleaners modified into a crown, belt, ring, bracelets, and nonfunctional suspenders. (D, E) Bondongo children observed with pipe cleaners modified into a crown and toy gun.

Results

Pipe cleaner distribution

In Village 2, the second author recorded 136 pipe cleaner sightings—80 in BaYaka and 56 in Bondongo areas or possession—during the eight observational sampling walks (Fig. 2). For BaYaka, pipe cleaners were most commonly found unattended (57.5%). All but 5 of 80 pipe cleaners were observed to be in modified states, with substantial bends or twists (Fig. 3A). Active engagement with pipe cleaners, including holding or wearing them as headbands, armbands, bracelets, necklaces, and hair decorations, was most often observed in groups of children (25.0%) or mixed groups of adults and children (13.8%) and only rarely in adult-only groups (3.8%). Outside of scheduled observations, we also observed BaYaka children wearing pipe cleaners as rings, crowns, belts, and suspenders (Fig. 3B).

For Bondongo, pipe cleaners were most commonly sighted while being held or worn by children (42.9%) (Fig. 3D). They were also observed in mixed groups of children and adults (19.6%), in adult-only groups (5.4%), and unattended (32.1%). One Bondongo child was observed playing with a toy gun made from four pipe cleaners (Fig. 3E). No pipe cleaners were found in unmodified states within Bondongo areas of the village.

Hook task

Of the 128 BaYaka experiment participants, 3 of them—all in the bending practice condition—solved the hook task by bending a pipe cleaner into a hook to retrieve the candy (Table 1). Furthermore, 7 participants successfully retrieved the candy from the tube by wedging the pipe cleaner or the string between the spokes of the basket. However, this was not considered tool innovation because no modification took place. The effects of condition, village, and their interaction were not significant predictors for children's first tool inserted or for their ability to manufacture and successfully use a hook in Model 1 and Model 2, respectively. In Model 1 only, older participants (B = 0.32, SE = 0.11, p = .005, relative risk (RR) = 1.38) were more likely than younger participants to insert the pipe cleaner into the tube first. A comparison of Akaike's information criterion corrected for small sample sizes (AICc; Burnham & Anderson, 2002) further suggests that the inclusion of condition, village, and their interaction did not improve model fit above and beyond the effect of age and sex in both Models 1 and 2. In sum, pipe cleaner exposure and bending demonstration did not improve BaYaka children's performance on the hook task. For full model results, see Table S2 in the supplementary material.

In Village 2, 8 of 57 Bondongo children who participated in the experiment bent the pipe cleaner into a hook to retrieve the candy. In addition, 6 Bondongo participants successfully retrieved the candy from the tube without innovating by wedging the pipe cleaner or the string between the spokes of the basket (Table 1). In Model 3, condition, society, and their interaction did not significantly predict first tool inserted for BaYaka children (67 participants) and Bondongo children (57 participants) from Village 2. However, age was a significant and positive predictor of inserting the pipe cleaner into the tube first (B = 0.34, SE = 0.11, p = .001, RR = 1.41). AICc comparisons suggest that age and sex alone had stronger power for predicting children's first tool choice than Model 3. In other words, there is little evidence for cross-cultural variation in children's first tool choice. In Model 4, Bondongo children were significantly more likely to manufacture and successfully use the hook than BaYaka children from Village 2 (B = 2.21, SE = 1.04, p = .033, RR = 9.04). Furthermore, a comparison of AICc values suggests that the inclusion of condition, society, and their interaction improved the predictive power of the model above and beyond age and sex alone. For full model results, see Table S3 in the supplementary material.

Because of excessive participant shyness, likely due to the unfamiliar testing environment (see Broesch, Callaghan, Henrich, Murphy, & Rochat, 2011, and supplementary material for discussion), many children (37 BaYaka and 8 Bondongo) did not interact with either the objects or the tube during the testing window. To ensure that the inclusion of these children did not obscure otherwise significant results, we refit Models 1–4 without these participants. Model results remained consistent (see Table S4 in supplementary material).

Object-uses task

Only 9 BaYaka participants (7%), 4 from Village 1 (no pipe cleaner exposure) and 5 from Village 2 (two weeks' exposure), listed one or more uses for the pipe cleaner or string (see Fig. 4 and Table S1). BaYaka children gave 13 and 12 responses for uses of the pipe cleaner and string, respectively. In Village 1, notable responses from BaYaka children included using the pipe cleaner to "fix shoes" and to "look for honey" and using the string to "fetch nuts" and "clean the garden." In Village 2, notable responses from BaYaka children included using the string to "make a slingshot." Of the 3 BaYaka children who modified the pipe cleaner into a hook during the hook task, 2 provided object uses for the pipe cleaner.

A total of 43 Bondongo participants (75.4%) provided 76 and 57 responses for uses of the pipe cleaner and string, respectively. Notable responses for Bondongo children included using the pipe cleaner to "rock the baby so he doesn't cry" and "make a house" and using the string to "attach it to my pants like a belt so they don't fall" and "make a motorcycle out of sandals." All 8 Bondongo children who modified the pipe cleaner into a hook during the hook task provided object uses for the pipe cleaner. For Bondongo and BaYaka children who both participated in the hook task and responded to the object-uses questions (46 participants), there was no correlation between hook use and the total number of uses categories (0–4) generated for the pipe cleaner (r = .05, p = .76) or string (r = −.14, p = .35). A full list of elicited object uses and their categories can be found in Table S1 in the supplementary material. Because children's responses were short, we were unable to assess the feasibility of the elicited object uses.

Discussion

This study investigated how exposure to pipe cleaners affected hook task performance in Congolese BaYaka forager and Bondongo fisher–farmer 4- to 12-year-olds. Because children in these communities frequently participate in tool use and modification, we expected them to innovate at an early age. Moving beyond the hook task, we also conducted naturalistic observations and elicited object uses

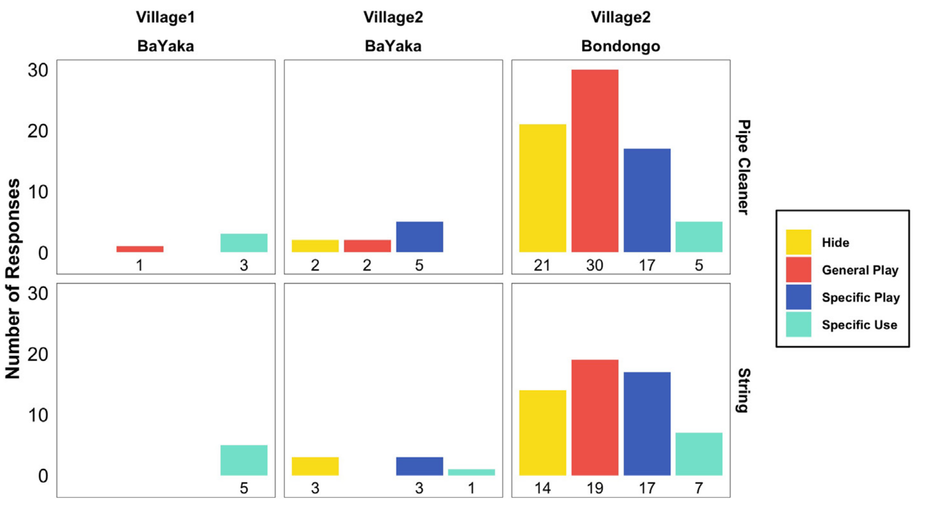

Fig. 4. Responses to the object-uses questions by category. In total, 4 BaYaka from Village 1 (6% of total sample), 5 BaYaka from Village 2 (7% of total sample), and 43 Bondongo from Village 2 (75% of total sample) provided object-use responses. The limited responses of BaYaka participants were likely due to participant shyness. Categories were as follows: (1) *Hide:* hiding or storing the item for future use; (2) *General Play:* incorporating the item into an unspecified play activity or end result; (3) *Specific Play:* incorporating the item into a specific play action or end result; and (4) *Specific Use:* incorporating the item into a specific functional action or end result.

from participants to understand how children innovate with novel materials in daily life. In what follows, we situate our findings within the broader developmental and cross-cultural literature on tool innovation. Specifically, we discuss the implications of our findings for ongoing debates regarding the importance of prior experience on the ontogeny of tool innovation, systematic versus unsystematic tool innovation, and the external validity of experimental paradigms.

Counter to our expectation, and in line with other studies conducted in postindustrialized settings and in small-scale subsistence societies (see Carr et al., 2016, and Rawlings & Legare, 2021 for reviews), we found that young BaYaka and Bondongo children's rates of tool innovation during the hook task were low. Like Cutting et al. (2014), we found that pipe cleaner bending practice did not improve performance. Furthermore, BaYaka children in Village 2, who were provisioned with pipe cleaners for 2 weeks prior to testing, were no more likely to innovate during the hook task than BaYaka children in Village 1, for whom pipe cleaners remained novel. Due to participant shyness, we were not able to investigate whether pipe cleaner experience increased the number of pipe cleaner uses BaYaka children thought of during the object-uses questions. However, like Beck et al. (2016), we found no correlation between children's object uses and hook task performance (but see Gonul, Hohenberger, Corballis, & Henderson, 2019).

Although overall success on the hook task was low, Bondongo fisher–farmer children were significantly more likely than BaYaka children to bend the pipe cleaner into a hook. This finding was unanticipated. Bondongo children's enhanced hook use may be consistent with their increased exposure to fishing hooks from very young ages compared with BaYaka children who are more familiar with forest fishing using dams. These findings highlight the fact that tool innovation is not a capacity that is either present or absent but rather an emergent ability to integrate relevant information (i.e., remember, recognize, synthesize, and generalize relevant experience; see Deák, 2014). Future research should investigate how variation in prior relevant experiences during everyday activities improves children's performance during innovation tasks.

Previous studies of hook task performance in small-scale subsistence societies were conducted with children under 6 years of age (Neldner et al., 2017; Nielsen et al., 2014). By including a wider age range of children spanning early and middle childhood, the current study offers a developmental perspective on children's tool innovation in two small-scale societies. We found that older children were significantly more likely than younger children to select pipe cleaners as their first tool of choice, suggesting that the cognitive skills associated with material selection improve with age. Beck et al. (2011) found that more than 60% of U.K. children aged 8–11 years manufactured a hook during the hook task (see Fig. S2 in supplementary material). Although older BaYaka and Bondongo children were slightly more likely to innovate a hook than younger ones (see Tables S2 and S3 in supplementary material), this association was not significant. With more time to familiarize themselves with the experimental apparatus and to try different strategies, it is possible that children generally, and older children specifically, may have been more successful at the hook task (Voigt et al., 2019). That age did not strongly predict hook task performance may also be due to BaYaka and Bondongo children's limited exposure to formal education. Many of the cognitive skills (e.g., executive functioning) and social skills (e.g., one-to-one interactions with adults) needed to successfully complete the hook task are accrued as children work their way through school (Davis, Stieglitz, Kaplan, & Gurven, 2020; Rawlings & Legare, 2021). To avoid confounding the effect of exposure to education with age on children's tool innovation capabilities, future investigations in small-scale subsistence societies should develop new experimental paradigms that more closely reflect typical social interactions and available materials of the participating communities.

In contrast to the limited systematic tool innovation within the experimental task, our naturalistic observations suggest that BaYaka and Bondongo children are successful at applying unsystematic innovations to meet their aesthetic and practical needs. Specifically, BaYaka and Bondongo children in Village 2 modified and combined pipe cleaners into headbands, bracelets, anklets, necklaces, hair accessories, belts, rings, and suspenders during free play (see Fig. 1). That children seemed to primarily innovate decorative items may reflect the colorful pipe cleaners we chose for our study. Moreover, we observed two novel headband styles (twists and zig-zag) emerge from a short play session of 10- and 12-year-old Bondongo girls, suggesting that adult input was not necessary. Our findings provide anecdotal support for the idea that peer play serves as a natural think tank that might encourage the discovery of novel objects and tools (Carr et al., 2016; Gonul et al., 2019; Lew-Levy, Milks, et al., 2020; McGuigan et al., 2017). These findings are important because both systematic and unsystematic innovations (e.g., accidents, recombination) can result in novel adaptive technologies (Mesoudi, 2021). To date, however, psychologists have largely neglected the cognitive development of unsystematic innovative capabilities. Future studies should consider how social contexts, especially within more naturalistic settings such as group play, facilitate the development of both systematic and unsystematic tool innovations.

One important limitation of the current study was the high rates of participant shyness (see supplementary material for further discussion). Like many experimental paradigms, the hook task was developed in a postindustrialized context where children are often exposed to one-to-one and face-to-face pedagogical interactions with adults both inside and outside of school (Rogoff, Matusov, & White, 1998). In contrast, although children in the current study have access to schools, attendance is sporadic and often secondary to participation in subsistence activities. Furthermore, as in other small-scale subsistence societies (see discussions in Lancy, 2010; Rogoff et al., 1998), BaYaka and Bondongo learning contexts outside of school are primarily participatory; children learn alongside adults and other children while engaging in meaningful community activities. Variation in how concepts are interpreted, ways of answering questions, and norms surrounding researcher–participant relationships are always important considerations when conducting experiments across cultures (Hruschka et al., 2018). These issues are exacerbated when working with children. Although we attempted to account for familiarity with the testing materials, the unfamiliar test setting, and specifically one-to-one and face-to-face interactions with the experimenters, may have nonetheless contributed to participant shyness and negatively affected hook task performance. The circumstances for the current study likely apply to many other cross-cultural experiments conducted in societies with limited access to schooling.

In conclusion, we expected that children from small-scale subsistence societies would have more success on the hook task than children from postindustrialized societies so long as they were familiar with the testing materials (i.e., pipe cleaners). However, contrary to our expectation, we found no evidence that previous exposure to pipe cleaners improved BaYaka and Bondongo children's hook task performance. Our data are consistent with theories claiming that systematic tool innovation is generally difficult for children. However, by employing a mixed-methods approach, we contextualized our experimental findings within more naturalistic observations and interviews. As a result, we were able to show that BaYaka and Bondongo children were perfectly capable of imagining and manufacturing meaningful and useful novel objects using pipe cleaners. We suggest that future studies with children in both small-scale subsistence and postindustrialized societies employ naturalistic observations alongside experimental paradigms to fully understand the ontogeny of both systematic and unsystematic tool innovation and how it may be affected by children's sociocultural environment.

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Author contributions

S.L-L. and S.M.P. designed the study, collected and analyzed the data, and wrote the manuscript. D.H., M.A.K., and T.B. provided critical feedback on the study design and manuscript. All authors approved the final version of the manuscript for submission.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2021.105223.

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