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Early Plant Learning in Fiji

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Abstract

Recent work with infants suggests that plant foraging throughout evolutionary history has shaped the design of the human mind. Infants in Germany and the US avoid touching plants and engage in more social looking toward adults before touching them. This combination of behavioral avoidance and social looking strategies enables safe and rapid social learning about plant properties within the first two years of life. Here, we explore how growing up in a context that requires frequent interaction with plants shapes children's responses with the participation of communities in rural Fiji. We conducted two interviews with adults and a behavioral study with children. The adult interviews map the plant learning landscape in these communities and provide context for the child study. The child study used a time-to-touch paradigm to examine whether 6- to 48-month-olds ($N = 33$) in participating communities exhibit avoidance behaviors and social looking patterns that are similar to, or different from, those of German and American infants. Our adult interview results confirmed that knowledge about daily and medicinal uses of plants is widely known throughout the communities, and children are given many opportunities to informally learn about plants. The results of the child behavioral study suggest that young Fijian children, like German and American infants, are reluctant to reach for novel artificial plants and are fastest to interact with familiar household items and shells. In contrast to German and American infants, Fijian children also quickly reached for familiar real plants and did not engage in differential social looking before touching them. These results suggest that cultural contexts flexibly shape the development of plant-relevant cognitive design.

Keywords: Cognitive development, Cognitive evolution, Culture and cognition, Social learning, Behavioral avoidance, Infancy

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Plants present a surprisingly complex evolutionary problem. On the one hand, they are an indispensable component of human life. In some Indigenous societies and over the course of human evolution, plants must be gathered from (or grown in) the local environment to be used as food and raw materials for building artifacts (e.g., Hardy and Kubiak-Martens 2016). At the same time, plants have countless defense mechanisms that can be quite dangerous to us—including toxins and sharp morphological features such as thorns and stinging hairs—developed over millions of generations of evolutionary arms races with their animal consumers (e.g., Chen 2008; Fürstenberg-Hägg et al. 2013; Mithöfer and Boland 2012; Palo and Robbins 1991). Therefore, humans, like other animals, must evolve strategies for balancing plants' costs and benefits.

Behavioral strategies for avoiding contact with plants are an effective way to reduce exposure to dangerous toxins, thorns, and spines (Wertz and Wynn 2014b; Włodarczyk et al. 2018).[1] Although an initial avoidance of all plants may be the safest bet, especially early in life, it is certainly not tenable in the long term and must eventually be overridden. How this plays out is complicated. Dangerous plant defenses might be present only in certain parts of the organism (e.g., plants with toxic leaves may bear edible fruits), or only during certain phases of the growing cycle (e.g., young plant leaves might be perfectly safe, but older plant leaves at the end of the season can build up enough toxic compounds to be deadly). More complicated still, the same plants can have different effects depending on an individual's physical condition. For example, some plants are medicine for particular ailments but poison if the ailment is absent (e.g., extracts from species of foxglove [genus: *Digitalis*] are a traditional treatment for heart failure but can kill you if your heart is strong: Hood et al. 2004; Withering 1785). All of this presents a complicated learning environment for any novice plant-hunting human.

In response to plants' complex defense mechanisms, humans too have evolved an array of sophisticated processing techniques that can transform inedible and dangerous plants into medicine and food. Skipping any of these seemingly unnecessary steps may spell a long and painful death by slow poisoning. A famous example is the nardoo (*Marsilea dummondii*) poisoning that contributed to the deaths of Robert O'Hara Burke and William John Wills on their ill-fated Victorian Exploring Expedition (the Burke and Wills Expedition) when they became lost in the Australian outback in 1861. Though Burke, Wills, and their one surviving companion, John King, were able to eat sufficient volume of nardoo for survival, they developed beriberi: a disease produced by thiamine deficiency caused by the high levels of thiaminase in the nardoo. Burke, Wills, and King learned about nardoo from the local aboriginal group, the Yandruwandra, who ate nardoo without issue. The Yandruwandra could benefit from nardoo as a food source because they practiced a series of processing steps that leach and deactivate the thiaminase. These steps had to be learned—not by trial and error (as Burke and Wills illustrate), but by the combination of careful attention to plants and careful attention to more knowledgeable community members to master the technique of unlocking the plant's nutrition (Henrich 2015).

[1] Behavioral avoidance is of course not the only strategy humans possess for mitigating plant dangers. Instead, behavioral avoidance operates alongside a variety of other mechanisms, including enzymatic detoxification pathways, conditioned taste aversions, and food neophobia (see Włodarczyk et al. 2018 for a more detailed discussion).

The complexities of identifying beneficial and dangerous plants (or plant parts), coupled with the widespread use of complex processing techniques, led to the proposal that humans rely on social learning to acquire information about plants (e.g., Wertz and Wynn 2014a; Wertz 2019). Through social learning, humans can build extensive banks of cultural knowledge that are tailored to the specific plants in the local ecology, the dietary needs of the local population, and the types of cultural artifacts that are required to live in a particular place. Such extensive knowledge about plants, including their uses and effects, has been well documented across human societies (e.g., Begossi et al. 2002; Placek et al. 2017; Scalise Sugiyama et al. 2020). In short, social learning provides the basis for overturning avoidance behaviors for particular plants (or plant parts). Of course, social learning and behavioral avoidance mechanisms alone are not sufficient for safely navigating interactions with plants. The cognitive systems involved must also contain procedures for distinguishing different types of plants from one another and generalizing one instance of learning to new entities and contexts, among others. The entire network of cognitive mechanisms that enable the safe acquisition of knowledge about plants has been dubbed Plant Learning and Avoidance of Natural Toxins (PLANT; Wertz 2019).

Recent research has begun to provide evidence for the PLANT system. Modeling work confirms the central role of social learning and the importance of correctly distinguishing between plant types (Oña et al. 2019), and a growing body of empirical evidence shows that infants rely on a combination of behavioral avoidance and social learning strategies for plants. Infants from 8 to 18 months of age minimize physical contact with plants by delaying their initial reach (Elsner and Wertz 2019; Wertz and Wynn 2014b; Włodarczyk et al. 2018, 2020) and touching plants less often than other types of entities (Włodarczyk et al. 2018, 2020). Infants' avoidance behaviors are similar for benign-looking plants and plants with sharp-looking thorns, suggesting that infants initially treat all plants as potentially dangerous (Włodarczyk et al. 2018). Critically, this behavioral avoidance strategy appears to be tightly linked with social learning procedures. Infants look more toward adults before touching plants (Elsner and Wertz 2019) and engage in selective social learning about plant properties. Infants as young as 6 months of age socially learn about plant edibility (Wertz and Wynn 2014a) and selectively decrease their reluctance to touch plants (Włodarczyk et al. 2020) based on observing adults' actions. Finally, there is evidence that 18-month-olds generalize learned edibility information only to similar-looking plants (Wertz and Wynn 2019) and use more stringent generalization rules for plants than for artifacts (Gerdemann and Wertz 2021).

The existing research is consistent with the proposed PLANT system, but much remains to be discovered about these cognitive mechanisms. One outstanding question is how the PLANT system develops in different cultural contexts. According to one hypothesis, the PLANT system builds a knowledge bank tailored to the specific environment in which an individual lives and uses local cultural knowledge gleaned from others to do so. Therefore, there is good reason to expect developmental flexibility in response to differing environmental and cultural experiences over the course of the lifespan. However, it is not yet clear which aspects of experience have an impact on the development and operation of the PLANT system. Here we investigate the effect of two broad categories of experiences on plant avoidance behaviors in early childhood: (1) exposure to plants in daily life and (2) the presence of adults who are knowledgeable about plants. The existing empirical work on this topic has primarily been conducted with infants in urban and suburban areas of Germany and the US, where contact with plants is limited and adults tend to know very little about the local plant life. In the present study, we explore the plant learning environment for young children in traditional communities on Kadavu Island, Fiji, and examine their behavior toward plants. In these communities, children grow up in an environment where living closely with plants is a prominent feature of daily life and adults have detailed plant knowledge to impart. Therefore, by comparing the responses of Fijian children to the previously documented behavior of German and American infants, we can explore the effect of increased exposure to plants in daily life and close contact with adults who have more extensive knowledge about plants.

Kadavu, Fiji

Kadavu, Fiji, is the southernmost island in the Fijian archipelago (Fig. 1). McNamara has been working with the participating communities in Kadavu since 2017; Kadavu became a focal site for this research because of the communities' focus on horticultural cultivation of *yaqona* (kava) and adherence to traditional land rights as the primary focus of economic and social life. Village populations range from approximately 300 to 150 Indigenous iTaukei Fijian community members. Rural Fijian life is typically organized around traditional hierarchical kinship and political organizational structures that focus on extensive cooperation among extended families for land ownership, resource management, and day-to-day food production (Becker 1995; Gervais and Fessler 2017; McNamara and Henrich 2017b; Toren and Pauwels 2015). As a more traditional society, much of daily life is driven by normative behavior and expectations based on kinship, rather than individual preference. This contributes to a setting in which behaviors are considered more salient than internal states such as intentions (McNamara et al. 2019) and where children in particular are especially sensitive to learning based on social status and hierarchy (Toren 1990).

At the time of data collection, Kadavu was Fiji's most prominent area for cultivation of yaqona, making it something of a gold-rush for cultivating the mildly narcotic plant that plays a central role in nearly every important social gathering—both casual and more formal and ritual in nature (Aporosa 2019a, 2019b; Katz 1999; McNamara and Henrich 2017a; Shaver 2015; Tomlinson 2004). Most families have garden plots near the village household compound and more extensive plantations further afield on traditionally held family land. This connection to plants and the land is an essential part of traditional iTaukei identity (Baba et al. 2013; Kaplan 2005; Ryle 2010). As a result of its ancestral land ties and the contemporary value of growing yaqona, Kadavu has been (at least at the time of data collection) one of the islands in Fiji with the least tourist development. Many communities remain relatively separated because of the lack of infrastructure and direct governmental intervention in village daily affairs. Many residents have lived in the city of Suva but return to the village for various periods of time because the cost of living is lower, the support of family is greater, and the general lifestyle—though more focused on manual labor—is more laid back than life in the city. This context can provide further insight into how a community with deep traditional knowledge of the local ecology might transmit this knowledge outside of formal learning environments.

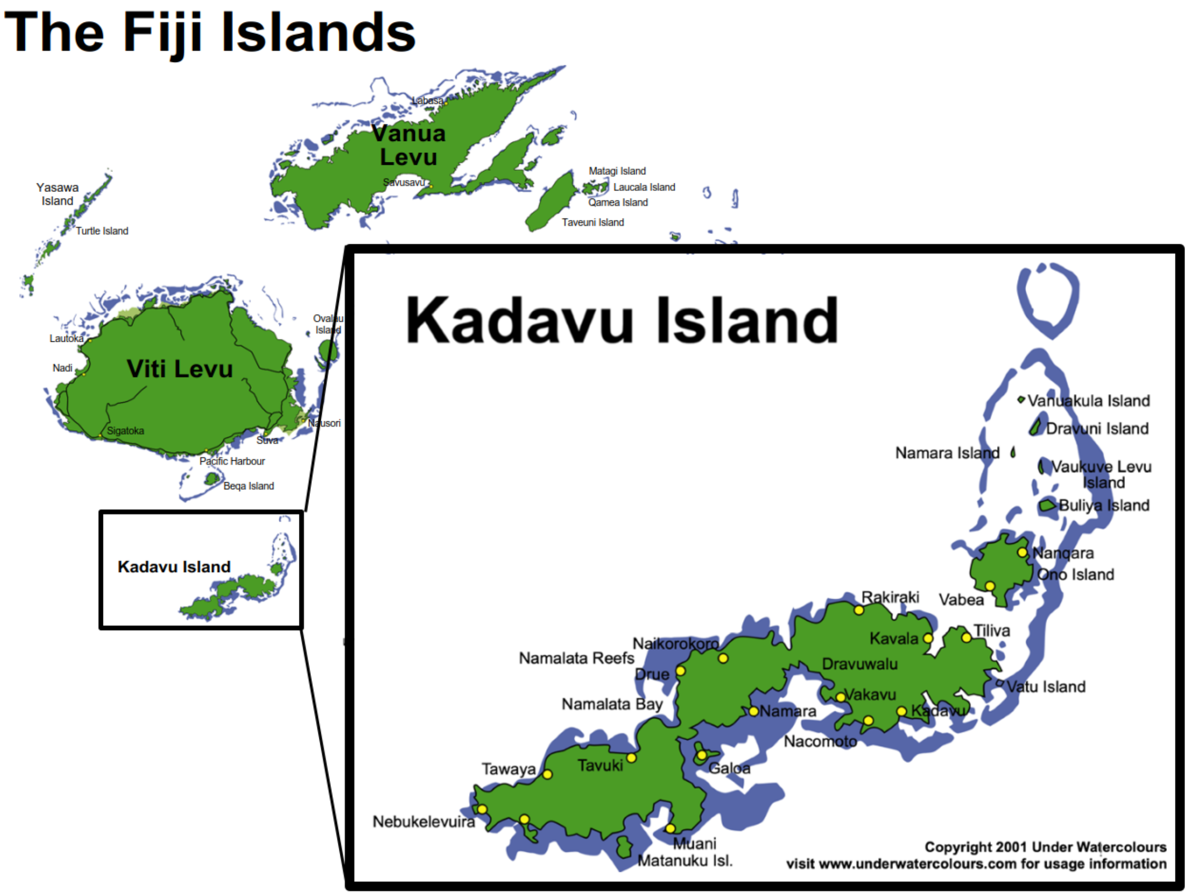

Fig. 1 Map of Kadavu Island, Fiji. Participating communities live in the Tavuki region on the southwestern edge of the island

Hypotheses and Predictions

We examine how the plant learning landscape affects children's interactions with plants in these traditional learning settings in two studies. We begin with an exploratory section to examine cultural consensus models of adult plant knowledge and cultural models of when and how children should be learning about or restricted from plants. These models will provide the necessary context to interpret any possible deviations we may find among the Fijian children's behavior toward plants compared with previous research in Germany and the US.

We follow our plant learning context-mapping interviews with an experimental study to examine how Fijian children interact with plants. This study used a version of the time-to-touch paradigm (e.g., Elsner and Wertz 2019; Wertz and Wynn 2014b) in which plants and a series of control objects are presented to infants while their reaching and social looking behavior is measured. In the current study, children were presented with familiar real plants and unfamiliar artificial plants; the control objects were novel artifacts that matched shape and color features of the plants, familiar artifacts, and naturally occurring entities other than plants (i.e., shells). Our goal with this study was to establish whether Fijian children would behave similarly to or different from German and American children. Because it is not yet known how different cultural contexts affect the PLANT system, we based our specific predictions on the patterns of behavior found in those previous studies.

If young children in our participating Indigenous iTaukei Fijian communities exhibit a similar behavioral avoidance strategy for plants as infants in Germany and the US, they will minimize contact with plants (both real and artificial) compared with the control objects. We made the following pre-registered hypotheses for how children in Fiji might respond:[2]

> *Hypothesis 1: Children will be reluctant to touch plants.* If children exhibit a behavioral avoidance strategy for plants, then we predict children will take longer (measured in milliseconds) to touch plants compared with other objects. This reluctance to touch will be especially pronounced for unfamiliar plants.
>
> *Hypothesis 2: If children refuse to touch our stimulus objects, these objects will more often be plants.* As a further measure of the possible behavioral avoidance strategy for plants, we further predict that, when children refuse to touch the stimuli, they will more often refuse to touch the plants than the other kinds of objects.
>
> *Hypothesis 3: Children will exhibit more social referencing behaviors when presented with plants.* We secondarily predict that, if Fijian children's behavioral avoidance strategy for plants is coordinated with social learning mechanisms, then young children will exhibit more social looking to adults (measured in milliseconds and number of looks) in the time before touching plants than in the time before touching the other kinds of objects.

Cultural Models of Plant Knowledge: Adult Interviews 1 and 2

We assess the plant learning environment through two adult interviews. The first seeks to establish the cultural knowledge setting in which children are being raised in the domains of gardening, farming, wild edible plants, and traditional medicinal plant knowledge. The second was conducted along with the child study and assesses more direct exposures and training in plant uses children receive in their typical daily experience.

Sampling in participating communities focused on recruiting as many participants as possible within the timeframe of McNamara's field season in participating communities. For the adult plant knowledge pre-interview, this included at least one representative as a head of household for each house in participating villages. For the child study, this included all children within the target age range plus an adult caregiver for each child. For households with multiple children in the target age range, one adult caregiver was interviewed for all of the participating children. Most caregivers were mothers, but some fathers and grandparents were also interviewed. Choice of adult caregiver was dictated by caregiver availability at the time of child participation. This is also indicative of typical caregiving in Fijian communities, where extended family are more often present for various alloparenting support (Silk 1980). This sampling procedure was selected to maximize data collection in a limited time window while minimizing disruption to village life in participating communities. This helps preserve positive rapport with communities to facilitate long-term collaboration between McNamara's ongoing research and participating communities. All interviews were conducted by McNamara

[2] See OSF pre-registration here: https://osf.io/ydbcj

with a research assistant from the community (the same assistant as for the child study discussed below). Interviews were conducted in Standard Fijian, with the participants being given the option to respond in English or Fijian as they pleased.

We analyze the data from these interviews using cultural consensus modelling. The focal interview questions were conducted as open-ended prompts to free-list as many items as possible within the target domain. This free-listing interview technique was developed in cognitive anthropology; it uses the order and frequency of an item across participants' lists to assess how coherent or consistent the domain is and how prevalent particular items are across the domain (Bernard 2011; Romney et al. 1986). For example, if one were to assess the group consensus concept of what fruits are, we might ask a group of people to list all of the fruits they can think of. The first person lists apple, banana, pear; the second, peach, banana, strawberry; the third, banana, apple, strawberry—and so on. From these lists, we can determine how consistent the group's concept of fruit is by how many items are similar across lists. To the extent that everyone lists the same items and in relatively similar order, the domain is highly consistent—or shows high consensus. We can further assess salience of particular items in this domain by examining how often items show up early in the list—items listed earlier are assumed to be more easily brought to mind and therefore highly indicative of or highly salient within the domain.

We analyze adult interview data using the AnthroTools package (Purzycki and Jamieson-Lane 2016) for R (R Development Core Team 2008). The cognitive salience of listed items is calculated as a mean salience score, reported as Smith's S (Smith 2016; Smith and Borgatti 1997; Smith et al. 1995). Individual item salience is calculated by taking into consideration both the total number of items an individual listed and the order of the items. In our fruit example above, person 1's salience score for banana would be lower than person 3's because person 3 listed it first and person 1 listed it second. Smith's S is the mean value of an item's salience across the entire sample. As items are listed more often and at earlier positions in participants' lists, the item's S value increases. Therefore, prominent items in the cultural domain have high S values.

Interview 1: Plant Uses and Knowledge

For our first interview, we survey the local common knowledge of plants. Because it is a primarily horticultural society, daily interaction with plants that are grown or gathered from the local area are common. However, many of the people living in participating villages have also spent substantial amounts of time working for wages and living in urban centers such as the capital city, Suva. As such, these communities have a transitional status between market integration and reliance on local resource cultivation via traditional methods and practices.

Adult plant knowledge interviews were conducted June 12–30, 2017. Participants were selected according to availability during researcher visits to villages. Forty-three participants (31 men, 13 women; 20–85 yrs., mean age = 51.11) were recruited for this study. Participation was completely voluntary. Participants were invited to participate in the study if they were over the age of 18 and if they resided in the participating villages.

This interview asked about local farming techniques, age of learning and starting one's first farm, plants grown in farms, wild edible plants, and traditional Fijian medicinal plants. Interview questions are open ended and rely heavily upon free listing—participants are encouraged to list as many plants as they can remember in their gardens or farming plantations, wild edibles, and traditional plant medicines plus their uses. Information about age at first farming and starting farms plus who teaches people to farm will also provide background how plant knowledge is transmitted. (See ESM S1 for the interview questions.)

We focus our analysis on questions about what plants are grown in the gardens (plots near house compounds) and farms (*teitei* plantations farther from villages, with larger plots), as well as knowledge of local wild edibles and traditional medicinal plants. For more insight into the cultural transmission profile of gardening/farming knowledge, we also assess answers to how old participants were when they first started growing plants and from whom they learned these skills.

Item salience for the top 10 items listed for plants grown in gardens or on plantations/ farms (Plants Cultivated), wild edible plants, traditional medicinal plants, and who respondents learned to farm from are shown in Table 1. We find that the domain of cultivated plants has the highest consistency, with wild edibles coming in second. The primary cultivated plants are starchy staples *dalo/suli* (taro), *tavioka* (cassava), *uvi* (yams), and the region's main cash crop, *yaqona* (kava). The domain of traditional medicine has far less consensus and showed difference in expertise; some respondents listed as many as 18 items while others did not list any. Most respondents reported learning to farm from their fathers ($n = 22$) and elders ($n = 8$) or grandfathers ($n = 4$), indicating a vertical cultural transmission path through the male line. We also find the modal age respondents reported starting to learn farming is 10 years old, with some ranging as young as 6 and others into adulthood (twenties into fifties) for those who started farming after moving to Kadavu, after having grown up and lived in the city.

Interview 2: Parent Expectations of Child Interactions with Plants

Our second adult interview was conducted along with the child behavioral study. This interview bridges the information gathered in Interview 1 to further examine the early childhood plant learning environment. The questions assessed how plants are presented to young children by their caregivers and through exposure to plant uses and interactions in daily life.

A sample of 26 adult caregivers completed plant learning on April 12–26, 2018. These adults were recruited to complete this follow-up interview immediately after their child participated in the behavioral study protocol discussed below.

Our focal questions for this analysis follow an open-ended free-listing paradigm similar to that in Interview 1. We ask caregivers which plants are deemed safe or dangerous for children, plus non-plant dangers and other restrictions or learning provisions caregivers indicate for young children. We also ask about the kinds of chores children learn to do around the village (many of which involve plants), how children are taught these chores, and who teaches them (see ESM S1 for questionnaire details).[3] These answers help to inform a map of the community cultural model of how

[3] Adult caregiver interviews also include Likert-scale frequency data on events such as restrictions on access to plants and other objects, frequency of exposure to plants, and frequency of direct instruction about plants and other common objects. This frequency data is analyzed along with the results of the child behavioral study below. The full interview dataset can be found on the project OSF page (https://osf.io/6zsng/?view_only=f7040c52cebb4d279fa6adb3a941b8c6).

Table 1 Cultural consensus modelling of cognitive salience for the top 10 items in interview 1 questions about plants grown in gardens and on plantations/farms (Plants Cultivated), Wild Edible plants, Traditional Medicinal plants, and from whom respondents learned farming. Mean salience (*M*) is the average salience of the item for each individual respondent; Smith's *S* is the salience of the item across the sample

	Plants Cultivated				Wild Edibles				Traditional Medicine				Learned to Farm from			
Rank	Items	Salience (*M*)	Smith's *S*	*n*	Items	Salience (*M*)	Smith's *S*	*n*	Items	Salience (*M*)	Smith's *S*	*n*	Items	Salience (*M*)	Smith's *S*	*n*
1	dalo/suli/taro	0.78	0.76	39	uvi	0.90	0.59	25	vativati	0.55	0.19	13	father	1	0.60	18
2	yaqona	0.86	0.71	33	tivoli	0.58	0.23	15	totodro	0.69	0.17	9	elders	1	0.23	7
3	tavioka/cassava	0.78	0.68	35	koleka	0.68	0.20	11	drauniguava	0.70	0.15	8	grandfather	1	0.07	2
4	uvi/yam	0.68	0.37	22	uto	0.64	0.17	10	wabosucu	0.71	0.13	7	grandfather and father	1	0.03	1
5	bale	0.44	0.33	30	kawai	0.58	0.14	9	wabutako	0.77	0.12	6	auntie/grandfather	1	0.03	1
6	kumala/sweet potato	0.73	0.20	11	ota	0.45	0.13	11	vivedu	0.72	0.12	6	father and elders	1	0.03	1
7	jaina/banana	0.39	0.18	18	tavioka	0.76	0.10	5	uci	0.58	0.11	7				
8	vudi/plantain	0.49	0.16	13	via	0.41	0.10	9	vacea	0.82	0.11	5				
9	baigani/eggplant	0.43	0.16	15	vewa	0.58	0.09	6	dabi	0.67	0.11	6				
10	cabbage/caveti	0.37	0.16	17	popo	0.64	0.08	5	sago	0.60	0.08	5				

children are expected to interact with plants: what they should be given access to or restricted from, what they should learn early in life, and some indication of how variable these domains of knowledge are in the community.

Item salience values for the top 10 items listed for Interview 2 focal questions are shown in Table 2. We focus on questions about items that children are restricted from touching, with more specific questions about what plants and objects they are restricted from. We find restricted items are sharp objects, hot objects, and plants with thorns, poison, or other sharp parts (*dalo* taro and *baigani* eggplant have small irritating hairs; chilis can burn; lemon trees have thorns; flowers listed include several species that are poisonous). Our questions about the cultural transmission of plant knowledge include questions about what interactions children have with plants, the children's chores or jobs around the village, and the age at which they begin doing these chores. Most young children are left to their own devices to play around compounds, and the average age they begin to learn these jobs is 3.71 years. When asked if the chores children learn are gendered, 58% reported that there are girls' chores (domestic, indoor activities) and boys' chores (outdoor, physical labor activities), though 46% say they teach girls and boys to do both kinds of work. Girls' labor that primarily involves plants focuses around weaving traditional mats—cultivating, curing, and weaving the *voivoi* (genus: *Pandanus*) leaves. This practice has traditionally been exclusively women's work. Boys, on the other hand, typically are expected to learn farming from their fathers (corroborating Interview 1), though both girls and boys are more and more exposed to farming since yaqona cultivation is such an important source of income in the area.

Finally, we look to further questions about what specific tasks children are explicitly taught about plants, how they are taught to do these things, and who teaches them. The majority of the explicit teaching about plants has to do with cultivation, though some are also learning traditional medicine. The predominant way of teaching is though instruction and allowing children to learn by observation. This transmission is predominantly vertical, with parents and grandparents doing the majority of the teaching. However, some oblique transmission is also reported from other relatives, other neighbors, and even other children.

Discussion: Adult Plant Use and Experience Interviews

Across two interviews, we find evidence of a fairly consistent cultural consensus on which plants are of prominent importance for cultivation, a wide variety of knowledge about wild edible and medicinal plants, and the relative timing of when young people learn farming from their fathers. We further find that young children are exposed to plants in a more modified capacity from as young as ~3–4 years of age. Up until then, children are restricted from touching dangerous objects, including sharp or hot household items as well as poisonous and sharp/pointy/ stinging plants. Children are not expected to contribute meaningfully to household plant production before around middle childhood at approximately 10 years old, but young children are already learning the basics of the care and keeping of plants as they watch their elder siblings and family members go about their daily business.

Table 2 Cultural consensus modelling of cognitive salience for the top 10 items in interview 2 questions about how children are permitted or restricted from interacting with plants and other objects; what interactions and chores children do that involve plants; and how children learn these activities plus who children are learning from. Mean salience (M) is the average salience of the item for each individual respondent; Smith's S is the salience of the item across the sample

Rank	Items	Salience (M)	Smith's S	n	Items	Salience (M)	Smith's S	n	Items	Salience (M)	Smith's S	n
	Warned about				Plants Not Allowed to Touch				Objects Not Allowed to Touch			
1	knife	0.79	0.26	8	lemon tree/moli	0.81	0.19	5	knife	0.91	0.60	17
2	matches	0.65	0.19	7	chili/rokete/boro	0.75	0.18	5	matches/masese	0.66	0.23	9
3	fire	0.69	0.17	6	flowers/senikau	0.88	0.17	4	gas stove	1	0.08	2
4	stove	0.70	0.09	3	mauli/popo plant	0.59	0.11	4	hot pots	0.81	0.06	2
5	stones	1	0.04	1	dalo	0.86	0.08	2	sharp things	0.75	0.06	2
6	stay close to house	1	0.04	1	rosi	0.83	0.08	2	spade/fork	0.59	0.05	2
7	sharp things (knife)	1	0.04	1	baigani/eggplant	0.70	0.07	2	fork	0.58	0.04	2
8	climb trees	1	0.04	1	yagona	0.60	0.06	2	house materials roofing	1	0.04	1
9	sharp things	0.50	0.04	2	jaina/banana	0.52	0.05	2	muddy water	1	0.04	1
10	climbing	1	0.04	1	cactus	1	0.05	1	stove	0.50	0.04	2
	How Children Interact with Plants				Children's Chores				Gendered Chores			
1	weaving	0.76	0.13	4	rake	0.74	0.25	8	girls learn more about jobs in the house	0.42	0.15	9
2	weeding	0.78	0.10	3	clean	0.92	0.23	6	boys learn more about jobs outside	0.34	0.13	10
3	don't know	1	0.09	2	pick up rubbish	0.69	0.14	5	both learn both girl's and boy's jobs	0.83	0.07	2
4	pull out the plants	0.67	0.09	3	sweep	0.83	0.10	3	boys go to the farm	0.46	0.05	3
5	just touching	1	0.04	1	pick up leaves	0.83	0.07	2	girls do washing	0.53	0.04	2
6	build small houses with plants	1	0.04	1	clean beds	0.73	0.06	2	girls do cooking	0.49	0.04	2
7	when in the village or garden	1	0.04	1	grass trimming	0.67	0.06	2	girls wash dishes	0.46	0.04	2

Table 2 (continued)

Rank	Items	Salience (*M*)	Smith's *S*	*n*	Items	Salience (*M*)	Smith's *S*	*n*	Items	Salience (*M*)	Smith's *S*	*n*
8	play	1	0.04	1	wash dishes	0.51	0.04	2	boys do hard physical jobs	0.40	0.03	2
9	pick the fruit	1	0.04	1	weed the household	1	0.04	1	boys do grass cutting	0.80	0.03	1
10	eat them	1	0.04	1	collect empty bobo packets	1	0.04	1	boys empty the bin	0.80	0.03	1
	What Are Children Taught about Plants				How Do You Teach Children Chores				From Whom Do Children Learn about Plants			
1	gardening	0.75	0.13	4	instructions	0.77	0.59	19	parents	0.90	0.43	12
2	farming	0.63	0.10	3	watch/observation	0.62	0.30	12	others	0.94	0.30	8
3	how to plant	0.95	0.09	2	watch and learn	1	0.16	4	parents only	1	0.20	5
4	medicine	0.70	0.09	3	demonstration	0.42	0.07	4	grandfather	0.60	0.14	6
5	weeding	0.54	0.04	1	show them what to do	1	0.04	1	grandmother	0.61	0.12	5
6	Grandparents might teach things	1	0.04	1	show what to do	1	0.04	1	grandparents	0.70	0.11	4
7	teach about how to take care of the garden	1	0.04	1	letting her follow what I'm doing	1	0.04	1	relatives	0.47	0.09	5
8	yaqona	1	0.04	1	give advice	1	0.04	1	auntie	0.41	0.08	5
9	sometimes	1	0.04	1	let watch	1	0.04	1	uncle	0.47	0.08	4
10	protect the plants that give food	1	0.04	1	show them how to do it	1	0.04	1	neighbor	0.55	0.04	2

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Child Behavioral Study

We examine how the Plant Learning and Avoidance of Natural Toxins (PLANT) system may be activated and expressed in the plant-learning context of our participating Indigenous iTaukei Fijian communities using a modified version of the time-to-touch protocol previously used with German and American infants (e.g., Elsner and Wertz 2019; Wertz and Wynn 2014a). In this study, we presented a series of stimuli to young children and measured their reaching and looking behavior. The stimuli were plants (both real and artificial), novel artifacts that matched shape and color features of the plants, familiar artifacts, and other naturally occurring entities (shells). The goal of this study is to assess whether Fijian infants and young children exhibit similar behavioral avoidance and social referencing strategies as German and American infants. If Fijian children show different patterns of behavior, then the results of the adult Interviews 1 and 2 may suggest aspects of environments and culture that could lead to a different developmental trajectory.

Thirty-three children aged 6 months to 3.9 years (mean age $= 26.39$ months) participated in this study on April 12–26, 2018. This age range was targeted for similarity to previous studies (typically conducted with 8- to 18-month-olds; Elsner and Wertz 2019; Wertz and Wynn 2014b; Włodarczyk et al. 2018, 2020) and to obtain the maximum possible sample size in the participating communities. Although this sample includes children older than in the previous studies, according to McNamara's existing ethnographic experience with these communities, children younger than 4 years of age are infrequently given explicit tasks to do with plants and other household chores. Thus, this age range is ideal to test how children may be spontaneously interacting with plants and other household items before social roles are applied to further shape their learning.

The sample size was relatively small in this study because of the population size in participating villages (which range from around 150 to 250 individuals across all ages) and constraints of time available to researchers in the various locations; nevertheless, the child sample size exceeded the minimum goal of $N = 30$. The final sample size constitutes the full population of children 3 years and younger in three villages.

We used a within-subject repeated measures design. Each participating child was presented with all 10 stimuli. Because of the large number of stimuli, full counterbalancing was not possible; our counterbalancing ensured that each stimulus object was presented roughly the same number of times in each position (items 1–10) across the sample.[4] The stimuli were divided into five categories, with two individual items per category: familiar real plants, unfamiliar artificial plants, novel manmade artifacts, familiar manmade artifacts, familiar shells (see below for further detail). These categories were the same as those used in previous studies (Elsner and Wertz 2019; Wertz and Wynn 2014b; Włodarczyk et al. 2018, 2020) and allowed us to interrogate several possible alternative explanations for children's behavior in the study. For example, if Fijian children avoid plants as we predicted, they should have longer touch latencies for plants (real and artificial) than for all other stimulus types. Alternatively, if Fijian children instead avoid unfamiliar entities, they should have longer latencies for

[4] See the project OSF page for the full study documentation (https://osf.io/6zsng/?view_only=f7040c52cebb4d279fa6adb3a941b8c6).

the artificial plants and novel artifacts than for the other stimulus types. And, if Fijian children are particularly avoidant of unfamiliar plants, then they should exhibit the longest touch latencies for the artificial plants.

Once each stimulus item was placed in front the child, they were allowed up to approximately 15 s to touch an item in its area of interest (AOI; see below). Items were removed after a touch or after 15 s had lapsed. This maximum trial length was selected to minimize participant fatigue.

Children were sampled from their home villages according to the time that researchers were present in the participating villages and according to parent/child availability. Children were sampled from houses by moving from house to house, starting from the house of the village headman.

We presented children with 10 stimulus items: two real plants, two realistic-looking artificial plants, two novel manmade artifacts, two familiar manmade artifacts, and two non-plant naturally occurring objects (Fig. 2). The real plants were cuttings from a mango tree and a coconut palm tree that were collected from the villages and placed in a plastic pot with dirt. Both real plants were familiar to children from the local surroundings of the villages and harmless to humans (see ESM S5.2.). The two artificial plants were selected for their similarity to real plants but were unfamiliar to the children in this study. One plant was made with large fabric leaves similar to the palm fronds common around villages; the other was made from smaller plastic leaves that do not resemble any local plants.

The novel artifacts were constructed to control for low-level features of the plant stimuli. The blue artifact was constructed with leaves of the fabric artificial plant that had been painted black and arranged in a ring around the top of two cylinders covered with blue and yellow waterproof tape. The green artifact shared the plants' color and was constructed out of beaded pipe-cleaners glued to a plastic base to mimic the tendril-like structures and movement of the plants.

Fig. 2 Object stimuli for the behavioral study. Each child was presented with all 10 objects in counterbalanced order

The familiar artifacts and natural objects (shells) both serve as controls for more general responses toward familiar vs. novel objects. That is, children may respond differently to objects they see frequently (plants, familiar artifacts, and shells) than objects they have never seen before (the novel artifacts). Including the shells in the stimulus set also allowed us to see whether children would perhaps respond differently to naturally occurring entities (plants, shells) than manmade objects (novel and familiar artifacts). The familiar and natural objects were also chosen to be somewhat blander in appearance in contrast to the bright colors of the novel artifacts. Our familiar objects, an aluminum cooking pot and a serving spoon, are both highly familiar household objects that every child interacts with extensively on a daily basis. The shells were nautilus and conch shells collected on beaches at the edge of participating villages.

Procedure

Data on child touch and social referencing behaviors toward the target objects were collected by McNamara and a local Indigenous iTaukei experimenter who lives in the participating communities. McNamara handed the items for the touch procedure to the local research assistant following the order listed in a counterbalancing sheet. The local research assistant interacted directly with the child participants. McNamara also monitored the time elapsed from item placement to touch (or the maximum time of 15 s if no touch was observed). McNamara was aware of the research hypotheses but the local research assistant was not. McNamara did not directly observe touching behaviors but instead monitored time elapsed and set up video capture equipment before and after the procedure.

The procedure occurred within the participants' houses; all persons were seated on the floor in the middle of the room. The previous studies with German and American children were conducted with the participants and experimenter seated at a table. Indigenous Fijian households are often sparsely decorated and have minimal furniture, so the choice to conduct the study while seated on the floor maintains consistency with children's daily lives. Children participated with their caregivers in the room. Caregivers sat on the floor with the child either in their lap or seated just in front of their legs. Some children opted to move from their caregivers and sit further away; we allowed this choice based upon each child's assent to participate.

Stimulus items were kept out of view inside a cardboard box until their relevant trial. McNamara sat behind and off to the side of the child to hold the stimulus items not being presented out of view and pass the next item to the research assistant. The research assistant sat in front and off to the side in view of the child, positioned such that he could place the items in front of the child within reaching distance (within approximately 6–12 in. depending on child size) and pass items back and forth to McNamara. Item trials began when the research assistant's hand left the item as it was placed on the floor in front of the child. Caregivers were asked not to give instruction to the children but to allow them to explore the items at their own pace. No explicit instructions were given to the child during trials.

Video Coding

Child Behavior During the experimental sessions, children's touching and looking behaviors were recorded with two field video cameras (iPod Touch, 6th Gen) and coded with video coding software (Datavyu: Datavyu Team 2014). The cameras captured the sessions from two angles (frontal, and to one side of the child and stimulus object).

Video Coding Procedure After returning to the lab, video data were coded by a research assistant blind to the study hypotheses using a standardized coding system that was adapted to fit the specifics of the Fiji field setting. Each trial began once the object was placed on the floor in front of the child and the experimenter's hand was removed. The trial period continued for up to 15 s from the point the experimenter's hands left the object. Trials ended either when the child touched an object in its AOI or after 15 s elapsed without a touch to the object's AOI. Object AOIs were the same as in previous studies (e.g., Elsner and Wertz 2019; Wertz and Wynn 2014b) and targeted the leafy parts of the plants and the corresponding top parts of the other stimulus objects. Specifically, the AOIs were the leaves and stems of the real and artificial plants, the black fringe part of the blue novel artifact, the green tendril part of the green artifact, and the lid and rim of the pot; because they did not have a well-defined top part, the AOIs for the spoon and the shells were the entire object. The initial phase when the stimulus objects appeared and were accessible to children's reach prior to the start of the trial was on average 998.3 ms ($SD =$ 548.55) across conditions. Our behaviors of interest—touch latency and social looking—were each coded separately.

Touch Latency Touch latencies were calculated from the beginning of the 15 s interval until infants touched the object with either their hand or their foot.[5] Any time that any part of the infant's hand or foot (coded separately) came in contact with the stimulus object's AOI was coded as a touch; if no touch was observed, children were given the maximum 15 s trial length as in previous studies (Elsner and Wertz 2019; Wertz and Wynn 2014b).

Social Referencing Social referencing is a two-phase process that includes first looking to another individual to observe their behavior and then regulating one's own behavior based on what they observe (Schmitow and Stenberg 2013). As in the previous investigation of social referencing behavior, we focus only on the first part of this process—looking to another individual—because the adult experimenter in our study did not react when presenting the stimuli (Elsner and Wertz 2019). Accordingly, social looks were coded as any time the child looked toward adult faces (either experimenter or caregiver) immediately following a look at the stimulus object. Social looking was coded from the point when the stimulus object first became visible to the child until the child first touched the object's AOI or 15 s had lapsed, whichever came first. Most social looking events were directed toward the experimenter, corroborating patterns found in other societies (Elsner and Wertz 2019).

[5] Foot touch was added to the site-specific protocol. In rural Fijian households, people go around in bare feet most of the time and spend much of their time sitting and working on the floor, as it is considered rude to sit up on a chair unless one is of chiefly rank. Therefore, exploring their world with the feet and the hands is more typical for Fijian children than may be the case in settings with common use of elevated surfaces such as chairs and tables or with footwear.

Reliability Codes from the primary research assistant coder were first cross-checked against rough codes from McNamara recorded during initial data processing; of these, 8.79% of the trials (29 of 330) showed a disagreement between the rough coding and final coding as to whether or not a touch event happened. The trials that showed disagreement were reevaluated by McNamara to resolve the disagreement.[6] A second independent coder then coded a randomly selected 24% of the videos coded by the primary coder. The agreement between these two coders ranged from 99% to 72% (trial phase onset = 96%, offset = 86%; first touch onset = 96%, offset = 99%; social looking onset = 80%, offset = 72%).

Results

Our confirmatory analyses testing Hypotheses 1–3 focused on how long it takes children to touch the stimulus objects (touch latency), whether or not they actually touch the objects (categorical touch coding), and whether children exhibit social referencing behaviors by looking at adults before touching the stimulus objects (social looking). For all of our analyses, we use hierarchical regression clustering the 10 object trials within each participating child. These regressions are implemented in R using the lme4 framework (Bates et al. 2015; Kuznetsova et al. 2014; R Development Core Team 2008; Tremblay and Ransijn 2015).

Hypothesis 1: Children will be reluctant to touch plants We test this hypothesis by predicting touch latency by stimulus object using hierarchical linear regression on the untransformed latency scores.[7] We initially predicted that Fijian children will behave like German and American infants and exhibit the longest latencies to touch plants (real and artificial).

A first look at the descriptives of touch latency in this study shows that a plurality (46%) of object trials went to the maximum 15,000 ms, while 8 trials showed an object touch event in less than 1 ms.

As shown in Table 3,[8] the object with the longest least-squares mean touch latency is the plastic artificial plant, with an average of around 10.5 s before first touch. On the other hand, the shortest touch latency observations were in the spoon and the real plant 2 (mango tree) trials.

[6] The majority of these rough vs. primary research assistant coding disagreements were caused by awkward camera angles ($N = 10$) or the child touching the pot rather than the plant ($N = 16$). For the "touches pot" trials, 14 were on artificial plant trials. This may indicate an extra layer of aversion to touching the artificial plants directly.

[7] Other studies using similar data have used log-transformed latency data to deal with nonnormality of residuals. These transforms do not substantially improve nonnormality in our data, so we retain the nontransformed data here.

[8] Touch latency data in this study showed nonnormal residuals. Although this is a less serious problem in hierarchical linear regression than in OLS, comparisons to transformed variables were also conducted. None of the transformed variables completely eliminated nonnormality of the residuals, and all corroborate the overall pattern of findings in the raw metric. For ease of interpretation, we report the raw metric here. See ESM S2 for models comparing the raw milliseconds metric with log-transformed, square-root-transformed, and robust heirarchical linear modelling results.

As shown in Figs. 3 and 4, Tukey's all-pair comparisons tests indicate that children were significantly faster to touch both the spoon (−3464.36, .95CI [−6834.33, −94.40], $p = 0.04$) and plant 2 (−3620.85, .95CI [−6990.81, −250.88], $p = 0.02$) than the plastic artificial plant (for full Tukey's all-pair comparisons table, see ESM Table S1). Thus, we find that our initial predictions for Hypothesis 1 are only partially supported.

Hypothesis 2: If children refuse to touch our stimulus objects, these objects will more often be plants Though we have a more precise picture of touch latency in our analyses for Hypothesis 1, some of the instances of observed touches were at the maximum duration of the trial. To further clarify which of the stimulus objects were most likely to have no observed touch at all, we aim to predict a binary touch/no touch code (coded as a touch with either the hand or foot) using binomial logistic multilevel regression. We initially predicted that no-touch trials would occur most often for plants (real and artificial).

Overall, this touch vs. no-touch analysis corroborates the touch latency analyses for Hypothesis 1. As shown in Table 4, the object with lowest probability of an observed touch trial is the plastic artificial plant. Conversely, the spoon and real plant 2 (mango tree) showed the highest probabilities of an observed touch during their object trials. Note that only the plastic artificial plant showed a probability of touch that was significantly different from 50%.

As shown in Figs. 5 and 6, Tukey's all-pair comparisons tests indicate that children were significantly more likely to touch both the spoon (0.97, .95CI [0.70, 1.00], $p < 0.01$) and plant 2 (0.93, .95CI [0.54, 0.99], $p = 0.03$) than the plastic artificial plant (for full Tukey's all-pair comparisons table, see ESM Table S4). Thus, we find that our initial predictions for Hypothesis 2 are only partially supported.

As a further exploratory analysis, we examine how demographic variables of sex, age in months, or village location impact on whether children touch or do not touch items. We find that only age is a significant predictor; for each additional month of age, children are 9% less likely to touch an item (0.48, .95CI [0.46, 0.50], $p = 0.046$).

Hypothesis 3: Children will exhibit more social referencing behaviors when presented with plants. We use linear multilevel regression (Table 5)[9] to examine the duration of social looking across object trials. We initially predicted that children will look more often at adults—either the experimenter or the caregiver—before touching the stimulus objects during plant trials (both real and artificial plants).

A first look at the descriptives of social look duration in this study shows that social looking was relatively rare: 30% of the object trials showed less than 1 ms of social looking, with a further 20% showing less than 1000 ms. When this behavior did occur, we find that children on average looked to adults longest in the cooking pot trials (on average 466.73 ms longer duration than real plant 1, though this is not a significant difference: $p = 0.15$). As shown in Figs. 7 and 8, Tukey's all-pair comparisons tests indicate that children looked to adults significantly longer in the cooking pot trials than for the green novel artifact (1203.39, .95CI [174.70, 2232.09], $p = 0.01$), shell 2 (1230.18, .95CI [201.49, 2258.88], $p = 0.01$), and plastic artificial plant (1129.21,

[9] Time duration data in this study showed nonnormal residuals (see the previous note for implications). See ESM S3.

Table 3 Least Squares Means of touch latency in milliseconds across items. Children were on average slowest to touch the plastic plant and fastest to touch plant 2 (mango tree) and the spoon

	Dependent Variable: Touch Latency	
	Estimate	[.95CI]
Plant 1: Coconut Palm	8159.09***	[5939.32, 10,378.87]
Plant 2: Mango Tree	6814.48***	[4594.71, 9034.26]
Artificial Plant: Fabric	9358.76***	[7138.98, 11,578.53]
Artificial Plant: Plastic	10,435.33***	[8215.56, 12,655.11]
Novel Artifact: Blue	9182.06***	[6962.29, 11,401.84]
Novel Artifact: Green	8966.42***	[6746.65, 11,186.20]
Familiar Artifact: Pot	9032.30***	[6812.53, 11,252.08]
Familiar Artifact: Spoon	6970.97***	[4751.19, 9190.74]
Shell 1: Conch	9268.97***	[7049.19, 11,488.74]
Shell 2: Nautilus	8067.58***	[5847.80, 10,287.35]
Observations $n(N)$	330(33)	
	Random Effects	
	Variance (SD)	
Intercept	23,594,418 (4857)	
Residual	18,734,345 (4328)	
	Model Fit Metrics	
Log Likelihood	−3192.64	
Akaike Inf. Crit.	6409.27	
Bayesian Inf. Crit.	6454.86	

†$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

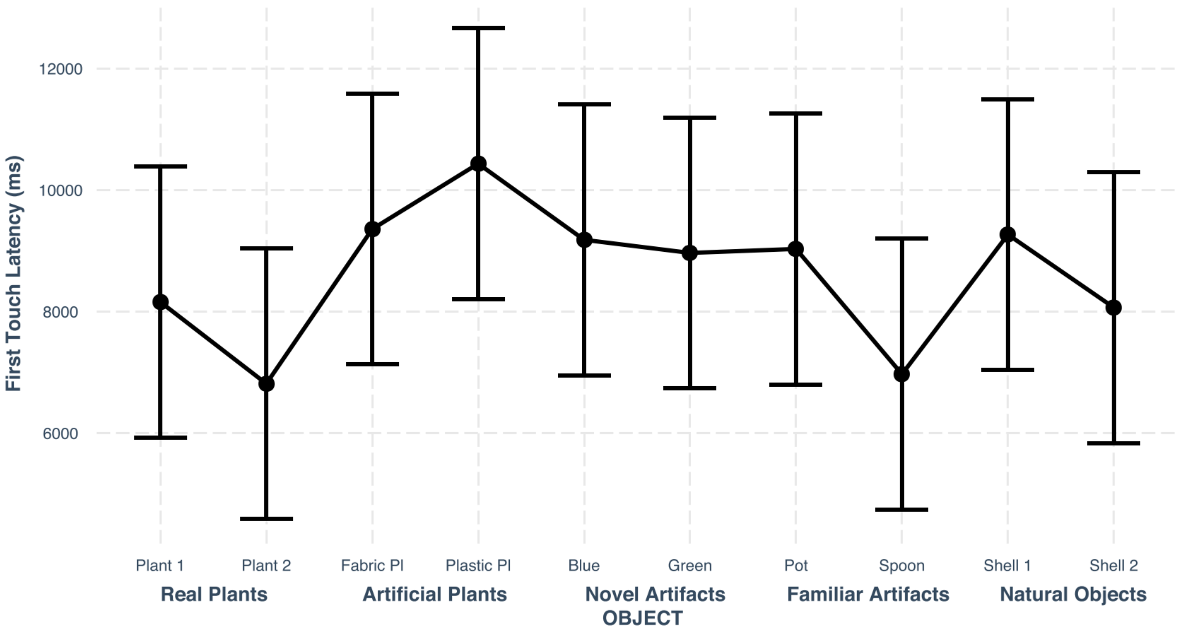

Fig. 3 Least squares means touch latency across objects. Error bars show .95 CI

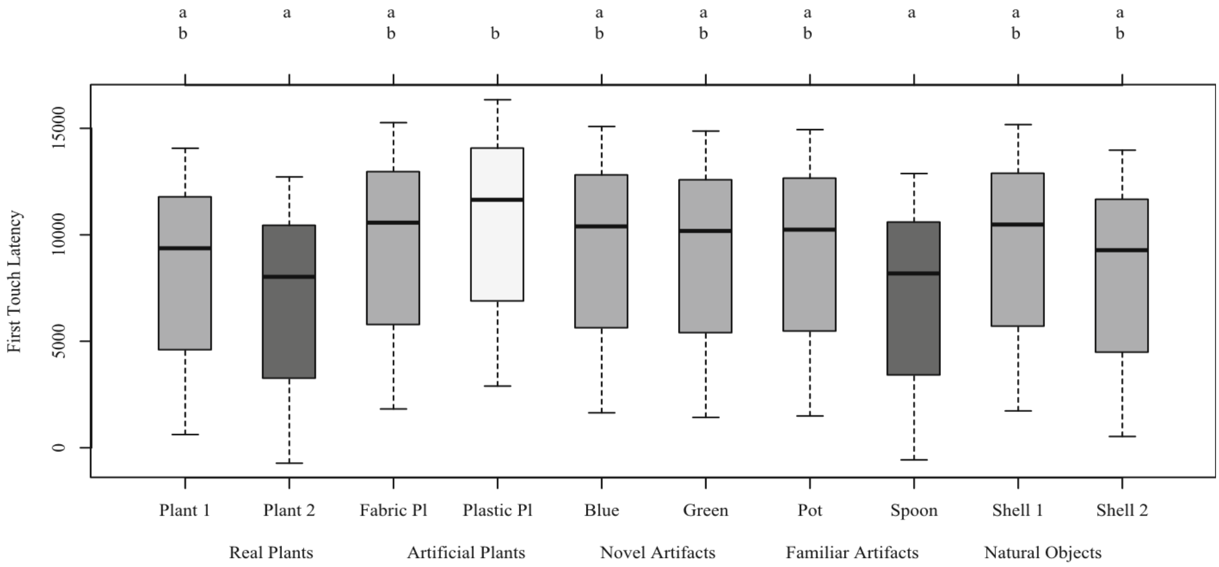

Fig. 4 Box plots of object touch using Tukey's all-pair comparisons. The significant differences were in longer touch latencies for the plastic plant vs. both plant 2 (mango) and the spoon. Error bars show .95CI

.95CI [100.52, 2157.91], $p = 0.02$; for full Tukey's all-pair comparisons table, see ESM Table S5). Thus, we find that our initial predictions for Hypothesis 3 are not supported.

Exploratory Analysis for Hypothesis 3: Frequency of Social Looking For a final exploratory look at infants' social referencing behaviors prior to touching the stimulus objects, we use Poisson regression to predict counted number of social looks during object trials. An initial assessment of how often social looks occurred during object trials confirms that social looking was relatively rare (mean = 1.25, median = 1, range = 0–8). A plurality of trials had no social referencing looks ($N = 149$, 45% of all trials), 18% had 1 social look, 13% had 4 social looks, and just 0.6% had the maximum of 8 observed social referencing looks.

Table 6 shows our Poisson hierarchical regressions predicting numbers of social looks by stimulus object. We focus our written analysis on our model examining frequency of social looks in object trials depending on child's age (Age × Object in Table 6). We add this interaction with age to these models as a more exploratory measure to avoid overfitting the models in our main hypotheses and to address specific questions about potential age effects in social looking. The most frequent social looks were observed in the cooking pot trials, corroborating our duration of social looking analysis discussed above. We therefore retain the cooking pot trials as our reference condition in our written analysis. Children around the sample average age of 26.39 months performed an average of 1.27 looks in the cooking pot trials ($IRR = 1.27$, .95CI [0.71, 2.26], $p = 0.41$). Although we do not find any significant effects of age in these trials, children 1 SD lower than the average age (approximately 14.40 months) performed an average of 1.52 social looks in the trials and children 1 SD above the average age (approximately 38.39 months) performed an average of 1.07 social looks.

We do, however, find that the green novel artifact trials and the plant 1 (coconut palm) trials were significantly impacted by age (effect of age for cooking pot vs. green artifact: $IRR = 1.05$, .95CI [1.01, 1.10], $p = 0.02$; effect of age for cooking pot vs. plant

Table 4 Probabilities of touch vs. no touch of objects with model comparisons across models with controls for demographics

	No Touch (0) vs. Touch (1)			
	Base Model *Probability* [.95CI]	Age *Probability* [.95CI]	Sex *Probability* [.95CI]	Location *Probability* [.95CI]
Plant 1: Coconut Palm	0.73	0.96*	0.67	0.72
	[0.40, 0.92]	[0.64, 1.00]	[0.20, 0.94]	[0.35, 0.92]
Plant 2: Mango Tree	0.56	0.56	0.56	0.57
	[0.24, 0.84]	[0.24, 0.84]	[0.24, 0.84]	[0.24, 0.84]
Artificial Plant: Fabric	0.27	0.27	0.27	0.27
	[0.08, 0.60]	[0.08, 0.60]	[0.08, 0.60]	[0.08, 0.60]
Artificial Plant: Plastic	0.09**	0.09**	0.09**	0.09**
	[0.02, 0.30]	[0.02, 0.30]	[0.02, 0.30]	[0.02, 0.30]
Novel Artificial: Blue	0.32	0.32	0.32	0.32
	[0.10, 0.66]	[0.10, 0.66]	[0.10, 0.66]	[0.10, 0.66]
Novel Artificial: Green	0.22†	0.22†	0.22†	0.22†
	[0.06, 0.54]	[0.06, 0.54]	[0.06, 0.54]	[0.06, 0.54]
Familiar Artificial: Pot	0.44	0.44	0.44	0.44
	[0.16, 0.76]	[0.16, 0.76]	[0.16, 0.76]	[0.16, 0.76]
Familiar Artificial: Spoon	0.75	0.75	0.75	0.75
	[0.41, 0.93]	[0.41, 0.93]	[0.41, 0.93]	[0.41, 0.93]
Shell 1: Conch	0.22†	0.22†	0.22†	0.22†
	[0.06, 0.54]	[0.06, 0.54]	[0.06, 0.54]	[0.06, 0.54]
Shell 2: Nautilus	0.50	0.50	0.50	0.51
	[0.20, 0.80]	[0.20, 0.80]	[0.20, 0.80]	[0.20, 0.81]
Age in Months		0.48*		
		[0.46, 0.50]		
Sex (Female=0)			0.61	
			[0.15, 0.93]	
Location (Vil. 2 v. Vil. 1)				0.49
				[0.08, 0.91]
Location (Vil. 3 v. Vil. 1)				0.65
				[0.02, 0.99]
Observations *n*(*N*)	330 (30)	330 (30)	330 (30)	330 (30)
	Random Effects (in logits)			
	Variance (SD)	Variance (SD)	Variance (SD)	Variance (SD)
Intercept	7.40 (2.72)	7.38 (2.72)	7.34 (2.71)	7.42 (2.72)
	Model Fit Metrics			
Log Likelihood	−154.75	−152.64	−154.68	−154.72
Akaike Inf. Crit.	331.51	329.28	333.36	335.43
Bayesian Inf. Crit.	373.30	374.87	378.95	384.82

†$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

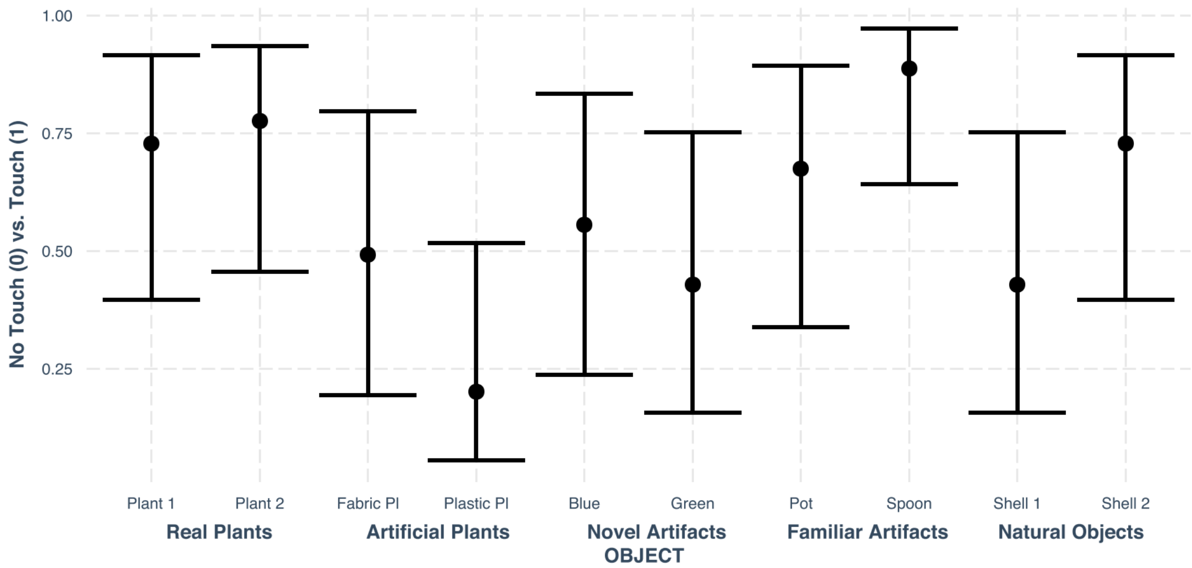

Fig. 5 Probability of touch across objects. Error bars show .95 CI

1: $IRR = 1.05$, .95CI [1.01, 1.09], $p = 0.01$), with older children looking more to adults prior to touching these objects than younger children. In the green novel artifact trials, this translates to the youngest children performing an average of approximately 0.45 social looks, children at the sample average age performing approximately 0.67 social looks, and the oldest children performing an average of approximately 1.05 social looks. For plant 1, the youngest children performed an average of approximately 0.83 social looks, children at the sample average age performed approximately 1.21 social looks, and the oldest children performed an average of approximately 1.77 social looks.

Though older children trend toward more social looking in the plant 1 trials than in the cooking pot trials, the difference is not significant (cooking pot vs. plant 1 for children +1 SD above mean age: $IRR =$ 1.66, .95CI [0.92, 2.99], $p = 0.09$). However, older children do perform significantly more social looks in the fabric artificial plant trials (cooking pot vs. fabric plant for children +1 SD above mean age: $IRR =$ 1.79, .95CI [1.00, 3.19], $p = 0.049$; an average of approximately 1.91 social looks for the older children).

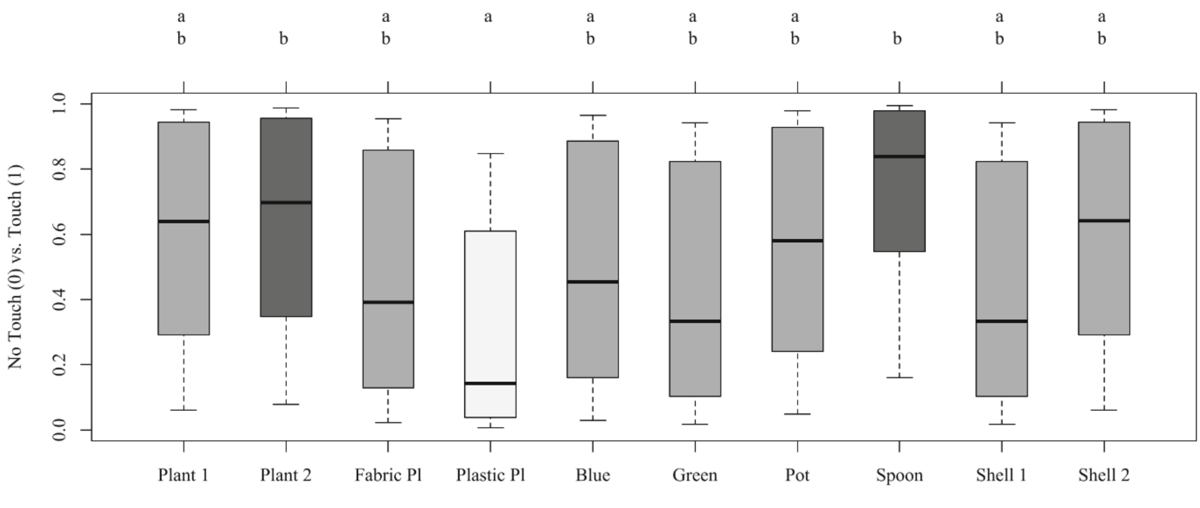

Fig. 6 Box plots of probability of object touch using Tukey's all-pair comparisons. Significant difference in fewer instances of item touch for the plastic plant vs. both plant 2 (mango) and the spoon. Error bars show .95CI

Table 5 Least Squares Means of social look duration in milliseconds across items. Longest social looking was for the cooking pot trials

	Mean Social Look Duration (ms)	
	Estimate	[.95CI]
Plant 1: Coconut Palm	1842.18***	[1295.88, 2388.48]
Plant 2: Mango Tree	−532.67	[−1169.93, 104.59]
Artificial Plant: Fabric	−224.61	[−861.87, 412.65]
Artificial Plant: Plastic	−662.48*	[−1299.74, −25.22]
Novel Artificial: Blue	−483.21	[−1120.47, 154.05]
Novel Artificial: Green	−736.67*	[−1373.93, −99.41]
Familiar Artificial: Pot	466.73	[−170.53, 1103.99]
Familiar Artificial: Spoon	−126.73	[−763.99, 510.53]
Shell 1: Conch	−316.30	[−953.56, 320.96]
Shell 2: Nautilus	−763.45*	[−1400.71, −126.19]
Observations *n*(*N*)	330 (33)	
	Random Effects	
	Variance (SD)	
Intercept	819,450 (905.2)	
Residual	1,744,299 (1320.7)	
	Model Fit Estimates	
Log Likelihood	−2798.88	
Akaike Inf. Crit.	5621.77	
Bayesian Inf. Crit.	5667.35	

†$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Correlations between touch latency, social looking, and caregiver interviews For our final exploratory analysis, we look at correlations among touch latency, social looking duration, and our caregiver interview questions about how often children are exposed to

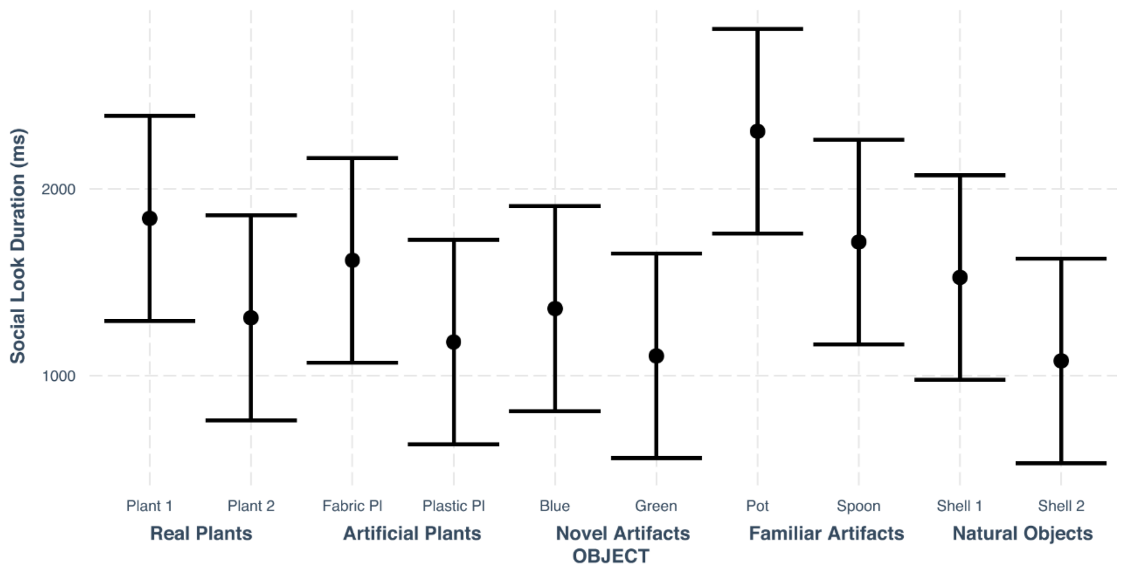

Fig. 7 Least squares means social look duration (ms) across objects. Error bars show .95CI

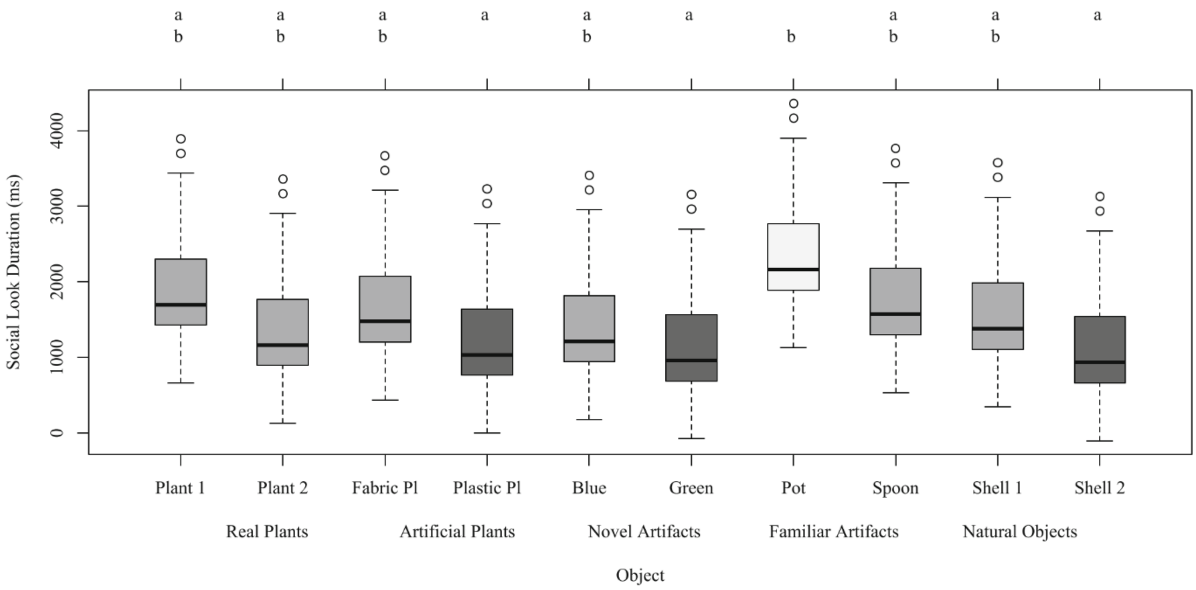

Fig. 8 Box plots of social looking duration using Tukey's all-pair comparisons. Significant difference in longer social looking duration for cooking pot compared with the green novel artifact, shell 2 (nautilus), and plastic plant. Error bars show .95CI

plants and the other items in our stimulus set. These caregiver interview items span a range of topics and are covered in three main categories of questions: (1) How often are children exposed to plants or other things like our stimuli? (2) How do children behave in their typical environments? and (3) Have children seen items like our stimuli before? We list the correlations between these items and touch latency and social look duration in Table 6. See the ESM for full correlation tables and the items in the questionnaire (S5.3).

First, this analysis revealed that children who exhibited more social looking were also significantly slower to touch the stimulus items ($r_{328} = 0.20$, $p = 0.0003$; though this significant correlation did not hold for the trials of only the real and artificial plants) (Table 7).

For our questions asking how often children are exposed to plants and other objects, we find that going outside more often and interacting with plants at the farm more often are associated with longer touch latencies ($r_{328} = 0.32$, $p < 0.0001$ and $r_{318} = 0.18$, $p = 0.001$, respectively), whereas seeing caregivers taking care of plants and interacting with plants in general decreases touch latency ($r_{308} = -0.36$, $p < 0.0001$ and $r_{318} = -0.13$, $p = 0.02$, respectively). We also find that spending more time at the farm, outside, and being told not to touch plants increases overall social looking duration ($r_{328} = 0.15$, $p = 0.006$; $r_{318} = 0.12$, $p = 0.02$; and $r_{318} = 0.13$, $p = 0.02$, respectively). All of the touch latency correlations remain present when looking only at children's behavior in the real and artificial plant trials except for the frequency of touching plants at the farm. For social looking, only the frequency of visits to the farm remained a significant correlate in the real and artificial plant trials.

Our analyses showed that children's typical behaviors are associated with longer touch latencies, but not their social looking behavior. Specifically, children who are reported as more shy or fearful and slower to approach things (as one would expect) are also slower to touch our stimulus items ($r_{328} = -0.20$, $p = 0.0002$ and $r_{318} = -0.12$, $p = 0.03$, respectively).

We similarly find that familiarity with our stimulus items was associated with decreased touch latency for all items except plant 1 ($r_{328} = 014$, $p = 0.01$) and had a mixed effect on social looking.

Table 6 Model Comparisons for Poisson regressions predicting social look frequency by object with demographics. IRR = Incidence Rate Ratio, calculated as the exponentiated coefficient for the fixed effects.

	Touch Latency (Total)	Social Look (Total)	Touch Latency (Plants Only)	Social Look (Plants Only)
Touch latency				
Social Look	0.20***		0.14	
Likert 1–5 (1=never; 5=every day)				
How often go to farm	−0.06	0.15**	0.01	0.18*
How often go outside	0.32***	0.12*	0.32***	0.11
How often interact w plants	−0.13*	0.04	−0.18*	0.01
How often name plants	−0.06	0.05	−0.16	0.10
How often child sees care for plants	−0.36***	0.05	−0.32***	0.09
Eat fruit from plant	−0.07	0.00	−0.05	0.05
Touch plants at farm	0.18**	−0.02	0.14	0.02
Touch plants in bush	−0.04	0.00	−0.09	0.01
How often stop from touching plants	0.07	0.13*	0.06	0.13
How often stop from touching things	0.05	0.00	−0.05	−0.09
Likert 1–5 (1=a bit; 5=a lot)				
How active	−0.07	0.04	−0.03	0.03
How shy/ fearful	−0.20***	0.07	−0.08	0.06
Attentive to objects	−0.03	0.10	−0.01	0.08
Notices small changes	−0.08	−0.07	−0.13	−0.12
How fast to approach things	−0.12*	−0.01	−0.11	−0.07
Has child seen xx before? Y/N Yes=1				
Plant 1	0.14*	−0.06	−0.13	0.12
Plant 2	−0.11	0.14*	0.17	−0.06
Fake Fabric	−0.12*	−0.01	−0.19*	0.10
Fake Plastic	−0.14*	0.12*	−0.16	−0.07
Blue Artifact	−0.21***	−0.01	−0.12	0.00
Green Artifact	−0.09	0.07	−0.11	0.08
Pot	−0.17**	0.04	−0.17	0.08
Spoon	−0.17**	0.04	−0.17	0.08
Shell 1	−0.13*	−0.03	−0.07	−0.06
Shell 2	−0.07	0.11*	0.01	0.10

†$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table 6 (continued)

	Social Look Frequency				
	Base Model *IRR* [*.95CI*]	Age *IRR* [*.95CI*]	Sex *IRR* [*.95CI*]	Location *IRR* [*.95CI*]	Age × Object *IRR* [*.95CI*]
					[0.94, 1.01]
Age × Green vs. Plant 1					1.00
					[0.96, 1.05]
Age × Pot vs. Plant 1					0.95*
					[0.92, 0.99]
Age × Spoon vs. Plant 1					0.97
					[0.93, 1.01]
Age × Shell 1 vs. Plant 1					0.96*
					[0.93, 1.00]
Age × Shell 2 vs. Plant 1					0.97
					[0.93, 1.01]
Observations *n*(*N*)	330 (33)	330 (33)	330 (33)	330 (33)	330 (33)
Random Effects	Variance (SD)	Variance (SD)	Variance (SD)	Variance (SD)	Variance (SD)
Intercept	0.58 (0.76)	0.54 (0.73)	0.52 (0.72)	0.51 (0.71)	0.51 (0.72)
Model Fit Estimates					
Log Likelihood	−478.71	−478.61	−478.34	−478.08	−471.83
Akaike Inf. Crit.	979.42	981.22	982.67	986.17	991.66
Bayesian Inf. Crit.	1021.21	1026.81	1032.06	1043.16	1082.84

†$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

From these correlations, we see some evidence that the children's environment has an impact on their behavior. The more exposure children have to parents working with plants and interacting with plants in the household area, the faster they are to interact with plants. At the same time, more exposure to the outside world and more rules about not touching plants are associated with more looking to adults for information about the stimulus items in our study.

Discussion

Our child behavioral study revealed that children in our participating Indigenous iTaukei Fijian communities were slowest and least likely to touch the plastic artificial plant, consistent with our first and second hypotheses. However, they did not avoid all types of plants, unlike in Germany and the US (Elsner and Wertz 2019; Wertz and Wynn 2014b; Włodarczyk et al. 2018, 2020). In fact, Fijian children were faster to touch the real mango plant—a plant that is both highly familiar and often known as a source of food—than any of the other stimuli. Fijian children were also quick to touch

Table 7 Correlations among touch latency, social look duration, and caregiver interview items for all items and for plants (real and artificial) only

	Touch Latency (Total)	Social Look (Total)	Touch Latency (Plants Only)	Social Look (Plants Only)
Touch latency				
Social Look	0.20***		0.14	
Likert 1–5 (1=never; 5=every day)				
How often go to farm	−0.06	0.15**	0.01	0.18*
How often go outside	0.32***	0.12*	0.32***	0.11
How often interact w plants	−0.13*	0.04	−0.18*	0.01
How often name plants	−0.06	0.05	−0.16	0.10
How often child sees care for plants	−0.36***	0.05	−0.32***	0.09
Eat fruit from plant	−0.07	0.00	−0.05	0.05
Touch plants at farm	0.18**	−0.02	0.14	0.02
Touch plants in bush	−0.04	0.00	−0.09	0.01
How often stop from touching plants	0.07	0.13*	0.06	0.13
How often stop from touching things	0.05	0.00	−0.05	−0.09
Likert 1–5 (1=a bit; 5=a lot)				
How active	−0.07	0.04	−0.03	0.03
How shy/ fearful	−0.20***	0.07	−0.08	0.06
Attentive to objects	−0.03	0.10	−0.01	0.08
Notices small changes	−0.08	−0.07	−0.13	−0.12
How fast to approach things	−0.12*	−0.01	−0.11	−0.07
Has child seen xx before? Y/N Yes=1				
Plant 1	0.14*	−0.06	−0.13	0.12
Plant 2	−0.11	0.14*	0.17	−0.06
Fake Fabric	−0.12*	−0.01	−0.19*	0.10
Fake Plastic	−0.14*	0.12*	−0.16	−0.07
Blue Artifact	−0.21***	−0.01	−0.12	0.00
Green Artifact	−0.09	0.07	−0.11	0.08
Pot	−0.17**	0.04	−0.17	0.08
Spoon	−0.17**	0.04	−0.17	0.08
Shell 1	−0.13*	−0.03	−0.07	−0.06
Shell 2	−0.07	0.11*	0.01	0.10

†$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

the spoon, as were German and American infants. Thus, we find that Fijian children's behavior toward plants is more nuanced than that of German and American infants.

Interestingly, we do not find the touch latency pattern corroborated in the social looking data, as was the case for German infants (Elsner and Wertz 2019). Instead, Fijian children's social looks to adults prior to touching the stimulus items were most common for the familiar cooking pot. Based on the results of Adult Interview 2, this may be because the pot is the item that children would most often be directly warned against touching. Thus, our child participants may have been looking more to check if it was alright to touch the pot. Our results indicate that age had an effect on children’s willingness to touch the stimulus items, with children becoming less likely to touch the stimulus objects as they get older. This finding may have been driven by the two-year-olds in the sample, who often were observed to avoid touching any and all of the items presented.

Finally, we found correlations between children’s touch latency, social looking, and the adult caregiver interviews following the experiment (Adult Interview 2). We find some evidence that exposure to adults caring for plants and children’s general exposure to plants are associated with shorter touch latencies for plants. However, children who spend more time outside tend to have longer touch latencies. Children who go to the family farm more often also exhibit longer social looking times for plants. Of course, the correlational results must be interpreted with caution, but taken together, they support the notion that different experiences with plants—in this case, exposure to plants cultivated in farms and in the outdoor area around family compounds—modulate children’s behavior toward plants.

General Discussion

Our examination of the Plant Learning and Avoidance of Natural Toxins (PLANT) system in a community sample of Indigenous iTaukei Fijians who regularly have intensive contact with plants reveals partial support for our initial hypotheses and some intriguing avenues for further research. First, we find that the adults in this community have considerable knowledge about plants. The cultural knowledge structure around how plants should be cultivated and when children should begin learning how to do so is relatively consistent. Most adults in the community have some knowledge of wild edibles and traditional medicines, though this knowledge shows lower degrees of consensus. Children in these communities are exposed to plants from a very young age as they watch their family members engage in daily tasks, but they are not expected to contribute in a meaningful way to household plant production until they are around 10 years of age. From around 3–4 years of age, children start doing chores that expose them to plants in a modified capacity, most frequently through weaving and weeding. Prior to that time, parents warn their children against touching poisonous, sharp, and stinging plants. Children primarily learn about plants from their family members, especially their parents, although there is some learning from neighbors and other children too. In sum, the interview results confirm that children growing up in this community have substantial exposure to plants and live with adults who are knowledgeable about the local plant life.

The child behavioral study showed that Indigenous iTaukei Fijian infants and young children behave in a more nuanced way toward plants than German and American children. Infants in the Germany and the US generally avoided touching all plants in our stimulus set (e.g., Elsner and Wertz 2019; Wertz and Wynn 2014b), whereas children in this community showed a clear reluctance only to interact with the plastic artificial plant. In fact, Fijian children were fastest and most likely to touch one of the real plants (the mango plant) and the spoon. Additionally, unlike German infants

(Elsner and Wertz 2019), children in this community did not show increased social looking for plants. Instead, children looked most to adults in the trials with the cooking pot. This makes sense in light of our interview findings that hot household objects such as pots are common items children are explicitly told not to touch. Ethnographically, Indigenous iTaukei households often have very little furniture and few elevated surfaces because it is considered rude to elevate oneself in the presence of others of higher authority. Therefore, most activity occurs on the floor—in prime reaching distance of infants. Children have to be warned all the more about not touching the hot stoves and pots because they are not on elevated countertop surfaces. Although this did not appear to make children less willing to reach for the pot, they were more likely to check with an adult prior to doing so. It is worth noting that the interviews also showed that children are warned against touching some plants, but those prohibitions seemed not to influence children's behavior toward the plants in this study. This may be because the plants used in the behavioral study were different from the ones children were prevented from touching. In contrast, the pot was chosen to be similar to those children would see in their own homes.

Our results show that Fijian children behave differently toward plants in our study than German and American children. The way they behave, in conjunction with the interview data, provides some clues as to what may be driving their behavior. The familiar mango plant and the unfamiliar plastic plant come in at opposite ends of the spectrum, suggesting that familiarity with a plant may lessen children's reluctance to touch it. This is consistent with the hypothesized operation of the PLANT system whereby the initial avoidance response to an unknown plant can be overturned by social information that a plant is safe to touch (Wertz 2019). It is also consistent with recent findings that watching an adult touch plants reduces German infants' avoidance of them (Włodarczyk et al. 2020).

In our study, children's responses to the mango plant and the plastic plant were more pronounced than their responses to the coconut plant and the fabric plant. This may also be due to the relative familiarity of these plants: mango trees are typically grown inside villages, while coconuts often are not. The mango trees similarly are more explicitly cultivated and are said to have been planted by the ancestors, whereas coconuts often take root where they land near the edges of beaches or next to their mother plants. Coconut trees are also more dangerous than mango trees because of the threat of being fatally hit by a falling coconut, which is why coconuts are often not grown to maturity within villages. Therefore, the young children participating in our study are more likely to directly interact with a mango tree than a coconut tree. Similarly, the fabric plant looked similar to the palm trees in the local environment, whereas the plastic plant looked very dissimilar from the plants Fijian children typically encounter, which may have led to the more pronounced avoidance behaviors. Importantly, familiarity alone should not be sufficient to override an initial avoidance of an unfamiliar plant. This is because a very dangerous plant may be regularly encountered, but never become safe for a child to touch. Instead, "familiarity" is likely a proxy for past experiences of parents or other individuals signaling that a plant is safe, although this remains to be tested. Though this is only an initial step, these findings may provide important evidence that the PLANT system produces more specific patterns of approach and avoidance early in life in a cultural context that produces intensive regular exposure to plants in children's daily lives.

At a broad level, it seems likely that intensive exposure to plants and/or adults who are knowledgeable about the local plant life influences the development of the PLANT system such that children in the first years of life exhibit different reactions to familiar and unfamiliar plants. Our correlational analysis supports this view, although the results must be interpreted with caution. Children in our study who more often interact with plants and see their caregivers taking care of plants were faster to reach for our stimulus items. In contrast, children who more often went outside and spent time at the farm were more reluctant to touch and spent more time social looking. Children who were more often prohibited from touching plants also looked longer at the adults before touching. These findings parallel previous results suggesting that American and German infants who see their parents caring for plants take longer to touch plants (Wertz and Wynn 2014b) and engage in more social looking (Elsner and Wertz 2019). It is interesting that the relevant experience related to Fijian children's increased caution is being outside and at the farm, whereas for the German and American infants observing parents with plants fills that role. Additionally, German infants who more often experience their parents stopping them from touching plants show more avoidance behaviors toward thorny plants, but not benign-looking ones (Włodarczyk et al. 2018), but unlike the Fijian children, their social looking behavior was not related to this factor (Elsner and Wertz 2019). Finally, German infants whose parents report knowing more about plants took longer to touch novel, benign-looking plants (Włodarczyk et al. 2020).

These findings point to more specific aspects of experience that may be relevant to the development and operation of the PLANT system across cultures, but they are far from determinative. As correlational results with small sample sizes, the findings must be taken with a considerable grain of salt. Yet, along with the main finding that Fijian infants and young children respond differently to plants than German and American children do, the correlational results underscore the likely importance of ontogenetic exposure to plants and adults with plant knowledge for the PLANT system. What is needed going forward is a series of studies across many cultures that systematically differ along these dimensions, along with experiments to tease apart which social and cultural inputs are most relevant for learning about plants (e.g., Wertz and Wynn 2014a, 2019; Włodarczyk et al. 2020).

One dimension that would be especially interesting to explore is the effect of living in environments with different amounts of plant life and/or different amounts of dangerous plants. While at first glance, a factor such as the proportion of plants (or dangerous plants) may not seem to have much to do with "culture" per se, there is good reason to suspect that the presence of different kinds of plants in the environment would be part of the cultural context of plant learning. This is because a particularly high (or low) density of (dangerous) plants may systematically modulate (1) the kind of information that caregivers would impart to young children and (2) default assumptions about the likelihood of injury from plants and, as a consequence, the amount of caution children would witness adults exhibiting in their everyday encounters with plants. Both of these factors would likely influence children's own responses to novel plants.

Our social looking results also point to some intriguing cross-cultural differences in how social referencing might be expressed in different contexts. Previous studies in small-scale and more traditional learning contexts suggest that the cognitive strategies for social learning are distinct from the more structured, formal learning environments in more industrialized and urbanized settings (Callaghan et al. 2011; Lancy and Grove 2010; Lancy et al. 2010). More formal, industrialized, and/or urban learning environments tend to focus on abstract reasoning and on direct, explicit instruction. On the other hand, children in informal learning settings tend to learn as they need to by being more deliberate about directing their own attention than upon how their caregiving instructors modify the targets of their attention (Callaghan et al. 2011; Kline 2015). As a result, children in these more informal and traditional settings tend to be better able to modulate their own attention, and more likely to direct their attention to the object in use rather than the explicit instruction of the person offering the learning opportunity (Clegg and Legare 2016). This has led to some suggestion that teaching does not occur in these traditional environments. However, as corroborated by our own Interview 2 results, this does not appear to be the case; elders provide various opportunities for learning by modifying aspects of the task or the environment to facilitate learning in ways that are more suited to the less abstract and more holistic processing behind these traditional tasks (Hewlett 2011, 2016; Kline 2017; Lancy and Grove 2010).

Finally, the children who participated in our study belonged to a broad age range from 6 months to 3 years of age, and we found some interesting age effects in our study. Children were in general less likely to reach for the stimulus items with increasing age, which contrasts with previous findings of no age effects for touch latency in the 8- to 18month-old age range in German and American infants (Elsner and Wertz 2019; Wertz and Wynn 2014b; Włodarczyk et al. 2018). We also found that Fijian children looked more often to adults as they got older, which is similar to the pattern found with German infants (Elsner and Wertz 2019). While our study incorporated as many children within our age range as were available in the participating communities, it is difficult to draw firm conclusions from the small sample in the current study. It is possible, for example, that the touch latency age effect in the current sample is the result of the broader age range we tested, or it could reflect a cultural difference in how cautiously young children engage with their environment. Future studies will be necessary to investigate these kinds of developmental effects in detail.

Another challenge with this work is that, since this protocol is primarily designed with a different cultural world in mind, the added unfamiliarity of the task may have impacted the results above and beyond any underlying cognitive capacities that may guide child behavior (Berry 1989; Peña 2007; Triandis and Marin 1983). The research assistant for this work was also a member of this community, a practice that is in line with best practices principles of working with Indigenous communities (Bartlett et al. 2012; Mila-Schaaf 2006). However, because this research assistant was known to these children, this too is a change from the German and American samples that may have influenced outcomes in our study. Further research development will benefit greatly from bringing more protocols designed specifically with these other cultural worlds in mind, better still if done so by researchers from the communities themselves (Kline et al. 2018; McNamara and Naepi 2018; Rad et al. 2018).

Conclusion

We find limited but intriguing evidence for cross-cultural expression of the Plant Learning and Avoidance of Natural Toxins (PLANT) system in our community sample of Indigenous iTaukei Fijians. This may provide initial evidence that this system forms a functional cross-cultural universal (Norenzayan and Heine 2005)—a cognitive mechanism that is present in diverse contexts but evoked differently depending on the cultural context it is expressed within (see also Barrett 2015; Tooby and Cosmides 1992). With our combination of social learning, ethnographic grounding, and experimental protocols from cognitive science, this research is also an important step in unifying the theories of evolved psychological mechanisms and the cultural evolutionary dynamics that modulate them to particular environments over time (Heyes 2019; McNamara et al. 2019). This study is only the first step in a long line of research that can broad our understanding of early cognitive development beyond Western Educated Industrialized Rich and Democratic societies (WEIRD: Henrich et al. 2010; Nielsen et al. 2017). As this research area progresses, we expect to find ever more ways that diverse contexts amplify and fine-tune the evolved cognitive toolkits that humanity shares.

Supplementary Information Supplementary material to this article is available. For more information see http://hdl.handle.net/21.11116/0000-0007-5486-3.

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