RESPONSE TO NATURALISTIC THREATS IN INFANCY

Fachbereich Erziehungswissenschaft und Psychologie

Arbeitsbereich Vergleichende Entwicklungspsychologie

der Freien Universität Berlin

Dissertationsschrift zur Erlangung des akademischen Grades

Doktorin der Philosophie (Dr. phil.)

M.A.
Aleksandra Włodarczyk

Berlin 2018

Erstgutachter: Prof. Dr. Ulman Lindenberger

Erstgutachterin: Dr. Annie E. Wertz

Zweitgutachterin: Prof. Dr. Katja Liebal

Datum der Disputation: 28.02.2019.

Acknowledgements

I would like to express my deep gratitude to my advisor Dr. Annie E. Wertz for her continuous support and guidance during the process of working on my dissertation; for her patience, motivation and great knowledge. I am also very grateful to the members of the Max Planck Research Group Naturalistic Social Cognition for their encouragement and help. I would especially like to thank Prof. Dr. Ulman Lindenberger, the chair of the Max Planck Research School on the Life Course (LIFE), as well as the faculty and the coordinators of the LIFE Program for their great support and unique research environment which shaped my professional and personal development. Many thanks to my friends and family for their love and encouragement. Lastly, I would like to thank to my dear husband for his faithful support and care.

Publication Notes

Publication 1

Włodarczyk, A., Elsner, C., Schmitterer, A., & Wertz, A.E. (2018). Every rose has its thorn: Infants' responses to pointed shapes in naturalistic contexts. *Evolution & Human Behavior.* https://doi.org/10.1016/j.evolhumbehav.2018.06.001

Publication 2

A manuscript based on Chapter 2 is currently under review at Cognitive Development.

Włodarczyk, A., Rioux, C., & Wertz, A.E. (under review). Social information reduces infant's avoidance of plants. *Cognitive Development.*

Table of Contents

General Abstract

Negotiating environmental threats has been a key component of humans' everyday life over evolutionary time. Evolutionary psychologists argue that millions of years of threat encounters have likely left their mark on the human mind (Barrett, 2005, 2015; Cosmides & Tooby, 1997). Consistent with this proposal, human infants differentially attend to and learn about ancestrally-recurrent threats such as dangerous animals and angry faces (Barrett & Broesch, 2012; LoBue, 2013). Little is known, however, about infants' reactions to ancestrally recurrent dangers in broader naturalistic contexts. Although they may seem harmless, plants manufacture a variety of different defenses that can be dangerous to humans. Accordingly, infants are reluctant to touch benign-looking plants; a behavioral strategy that protects them from potential plant dangers (Wertz & Wynn, 2014a).

This dissertation investigates several novel aspects of this behavioral avoidance strategy toward plant threats including infants' responses to visible plant threats (i.e., thorns). The findings presented in Chapter 1 show that 8- to 18-month-old infants exhibit both an initial reluctance to touch and minimized subsequent physical contact with plants compared to other object types. Interestingly, infants treat all plants as potentially dangerous, whether or not the plants look benign or are covered in sharp-looking thorns. Chapter 2 demonstrates that infants continue to exhibit this behavioral avoidance strategy toward plants even when additional social cues are present. Surprisingly, however, infants do not respond differently to the plants or other stimulus objects in negative and positive social information conditions. Instead, they seem to react to the fact that the experimenter touched the objects. The eye-tracking study presented in Chapter 3 did not find evidence that the presence of pointy-shaped elements influence 8- to 10-month-old infants' visual attention toward plants, novel artifacts, and familiar artifacts.

Taken together, the findings of this thesis suggest that understanding the complexity of infants' responses to threat in the natural world requires taking into account both the type of entity that infants are responding to (plants vs. non-plants) and the different aspects of social information provided by others (touch vs. emotional expression).

General introduction

I. Why is studying threat interesting and important?

Managing threat has been an ever-present problem in humans' daily life since the emergence of the genus *Homo* about 1.9 million years ago (Barrett, 2005, 2015; Wood & Collard, 1999). Individuals effectively managed three broad types of threat throughout human history: the physical environment (e.g., natural disasters), other species (e.g., parasites), and conspecifics (e.g., aggressors; Buss, 2005). Those who did so successfully enjoyed a survival advantage compared to those whose responses to threat were inadequate. Thus, the problems related to managing different types of threats were a key component of human evolution.

Among the multitude of theoretical approaches in modern psychology, scientists taking evolutionary perspective on human behavior are notable for their attention to problems of survival and threat management (Buss, 2005). Problems like threat mitigation that directly impact survival are particularly important from this perspective because surviving to reproductive age facilitates the fundamental driver of the evolutionary process: the differential reproduction of successful design features (Cosmides & Tooby, 1997; 2000; Darwin, 1871; Hamilton,1964; Williams, 1966). Thus, successfully negotiating threat is a prerequisite for individuals to maintain their capacity to reproduce.

Successfully negotiating threat has likely left its mark on the human mind. Evolutionary psychologists propose that cognitive systems producing human behavior have evolved to solve recurrent problems whose solutions covaried with reproductive outcomes during human evolution (Cosmides & Tooby, 1997; Geary, 2005). As Barrett (2015) notes, is important to bear in mind that the comforts and protections of our modern lives did not accompany humans for most of their evolutionary history (Barrett, 2015). Humans spent over 99% of their history living in hunter-gatherer societies (Cosmides & Tooby, 1997). Some of the main challenges of our ancestors' daily lives were evading attacking predators, avoiding toxins while gathering plant food, and finding mates while simultaneously avoiding aggressive and unreliable conspecifics. Consequently, millions of years of such threat encounters have likely shaped all levels of human cognitive architecture from perception to decision-making and motor control (Barrett, 2005). Threat sensitivity has enabled quick assessment of potential sources of harm in the environment and decision about adequate defensive behavior.

In line with this proposal, there is considerable empirical evidence showing that evolutionarily threatening stimuli are privileged in human cognition and behavior. Numerous studies using prototypical evolutionarily threatening stimuli—dangerous animals such as snakes and spiders and angry facial expressions—showed that human responses to threat-relevant stimuli systematically differ from the reactions to neutral stimuli (Öhman, 2009). Both adults and preschool children differentially allocate attention to and learn about evolutionarily threatening stimuli (for review see LoBue & Rakison, 2013). For example, studies using various visual attention paradigms (e.g., standard visual search, dot probe, flanker task, and inattentional blindness paradigms) show that adults detect evolutionary threats like snakes and spiders more quickly than a variety of perceptually similar yet benign stimuli, such as frogs or caterpillars (Flykt, 2005; Hayakawa, Kawai, & Masataka, 2011; Lipp & Derakshan, 2005; Lipp, Derakshan, Waters, & Logies, 2004; LoBue, 2010a; LoBue & DeLoache, 2008, 2011; Masataka & Shibasaki, 2012; New & German, 2015; Öhman, Flykt, & Esteves, 2001).

These findings are extended by results based on eye-tracking technology (LoBue, 2014), indicating that both an advantage in perception (i.e., faster fixations to threats vs. nonthreats) and an advantage in behavioral responding (i.e., faster behavioral responding to threats once a target is first fixated) underlie quick orientation toward threat in detection tasks. Additionally, humans quickly detect the presence of threatening stimuli in a social context, namely threatening facial expressions (i.e., the “Face in the crowd hypothesis,” Hansen & Hansen, 1988). People detect threatening (i.e., angry or fearful) faces more quickly than happy, neutral, or even sad faces (Calvo, Avero, & Lundqvist, 2006; Eastwood, Smilek, & Merikle, 2001; Öhman, Lundqvist, & Esteves, 2001).

Similar results were found in studies with younger participants. For example, 9- to 13-year-old children detected snakes and spiders more quickly than a variety of other animals in a standard visual detection paradigm (Waters & Lipp, 2008). Studies using a modified visual search procedure indicated that children as young as three years of age detected images of snakes and spiders more quickly than flowers and perceptually similar animals (LoBue & DeLoache, 2008; LoBue, 2010a). Toddlers also detected angry facial expressions more quickly than happy or neutral faces, replicating previous findings with adults. Importantly, and similar to results with adults, comparisons within *negative* facial expressions (i.e., angry, fearful, sad) revealed that, overall, young children detected the threat-relevant faces the most quickly (LoBue, 2009).

Besides quick orienting toward threatening stimuli, other components of human attention are also sensitive to threat. There is evidence that participants exhibit difficulty disengaging from threatening stimuli when they are presented as distracters. For example, individuals are slower to detect happy faces when angry faces are presented as distracters in a standard visual search task (Horstmann, Scharlau, & Ansorge, 2006) and they are slower to detect images of cats or rabbits when snakes and spiders are the distracters (Forbes, Purkis, & Lipp, 2011; Lip & Waters, 2007). Convergent evidence comes from studies using the flanker task, where participants are slower to detect the target image when the distracter images are threatening faces (Fenske & Eastwood, 2003). Together, these results strongly support the claim that humans preferentially allocate attention to evolutionary threatening stimuli.

The previous findings were extended by New, Cosmides, and Tooby, (2007) who revealed similar attentional effects for the broader ancestrally important category of animals, as opposed to different broad categories of inanimate entities (New, Cosmides, and Tooby, 2007). New and colleagues argue that human attentional systems are equipped with category-specific selection criteria to monitor animals (including humans) in the environment. The authors tested this notion in a change-detection paradigm where participants were presented with a series of brief exposures of pairs of complex natural scenes that were shown rapidly changing between versions: one with the scene alone and then the scene plus an added object that was either animate (human, animal) or inanimate (plants or different artifacts including moving ones such as vehicles). The participants were asked to respond as quickly as they could whenever they detected a change from one picture to the next. The results showed that individuals were faster and more accurate in detecting changes in the scenes with animals compared to changes in scenes with inanimate objects, even when those inanimate objects were much larger than an animal, such as buildings. This sensitivity of the visual system to the broad category of animals is consistent with Barrett's (2005, 2015) postulate about humans possessing an array of complex visual system adaptations to predators and prey. Since animals, but not inanimate objects, are likely to move in the real world, humans evolved visual detection mechanisms that track and update the locations of animals, but not inanimate objects.

Obviously, cognitive systems for dealing with threat are not only sensitive to evolutionarily relevant dangers, but can also flexibly respond to novel threats in modern human environments. For example, it was shown that adults also preferentially allocate attention to modern threatening artifacts, such as knives and syringes (Blanchette, 2006; Brosch &Sharma,

2005; LoBue, 2010b). Whereas, young children preferentially attend to syringes (stimuli with which they had negative experience), while showing no evidence of differentially attending to knives (stimuli with which they had little or no negative experience; LoBue, 2010b). Based on these results, LoBue (2010b) suggests that previous experience is one of the important factors influencing attentional sensitivity to threat and that heightened attention may facilitate learning about threatening stimuli (cf. Öhman & Mineka, 2001).

LoBue's proposal is consistent with the idea underlying approach to learning about threat taken by evolutionary psychologists. Similar to the category-specific attention system reviewed above, researchers have proposed specialized learning processes for many evolutionary important categories of information, including threat (Barrett, Peterson, & Frankenhuis, 2016; Tooby & Cosmides, 1992; Wertz & Wynn, 2014b; Wertz & Moya, 2019). For instance, young children in two populations—urban children from Los Angeles and children from an indigenous Amazonian society in Ecuador—were shown to exhibit prepared learning about danger in the context of animals (Barrett & Broesch, 2012). Using an experimental learning task, the authors showed that information about whether an animal was dangerous was learned in a single trial without feedback, immediately entered long-term memory, and was recalled with only minor attenuation a week later. In contrast, information about the animals' names and diets was immediately forgotten.

Interestingly, ancestral threats appear exceptionally often among clinical fears and phobias and some researchers relate this clinical data to the propensity to readily learn long-lasting and overly strong fear of these stimuli (Coelho & Purkis, 2009; Nesse, 1994; Öhman & Mineka, 2001; Seligman, 1971). Some researchers have proposed that this kind of fear acquisition is the result of domain-specific mechanisms dedicated for evolutionary threats (Boyer & Bergstrom, 2011). Accordingly, there is evidence showing enhanced fear conditioning to evolutionary threatening stimuli compared to neutral stimuli and its nonconscious processing (Öhman, 2009).

These results seem to imply that human cognition is riddled with biases or erroneous systems that make us overresponsive when confronted with particular kinds of stimuli (here threat-relevant) in the environment. Indeed, these systems lead us to mistakes in one direction. As Johnson and colleagues pointed out, we mistake sticks with snakes, but rarely snakes with sticks (2013). Does it mean our evolved cognition is actually irrational? Several researchers suggest that what may seem like irrational biases are in fact adaptive responses to the structure of the environment (e.g., Gigerenzer & Selten, 2002). The "biases" humans have for dealing with threat make sense when viewed from the perspective of error management (e.g., Haselton & Buss, 2000; Haselton & Nettle, 2006; Johnson, Blumstein, Fowler, & Haselton, 2013). From this perspective, dealing with danger entails judgments made under uncertainty with asymmetrical costs and benefits. That is, the costs of two possible errors made when deciding whether to employ defensive behavior are not equal: a false positive (i.e., reacting defensively when in fact there is no danger) and a false negative (i.e., not reacting defensively when in fact danger occurs). False negatives are often much more costly compared to false positives. Therefore, despite increasing overall error rates, the seemingly-biased cognitive system in fact minimizes overall costs, by differentially minimizing the errors that are more costly (Haselton & Buss, 2000; Haselton & Nettle, 2006; Johnson, Blumstein, Fowler, & Haselton, 2013). In line with this error management logic, Nesse (2001; 2005) has compared the human mind, like other biological systems, to a smoke detector: It is a tool created to protect from harm, whose false alarms are expected and accepted in defense against harms with great costs. Thus, seemingly-biased decisions that result in overresponse to threat are actually adaptive (Gigerenzer & Selten, 2002; Haselton, et al, 2009).

Taken together, the findings reviewed above present considerable evidence that the human mind is remarkably well designed for the important problem of dealing with environmental threat. Importantly, despite being seemlingly-biased, many levels of cognitive architecture cooperate together to make human beings well attuned to respond to danger flexibly and adequately. The evolved attentional sensitivity to ancestral threats is accompanied by mechanisms that readily gain knowledge about both evolutionarily relevant and modern, environment-specific threat, and retain that information for considerable amounts of time, thus enabling relevant responses to threat in the future.

It is surprising, however, that despite the importance of effective threat management, few researchers have studied the broader naturalistic context of this problem. Most studies concerning danger perception and learning have focused on the same group of stimuli, namely dangerous animals and facial expressions. Whereas, little attention has been paid so far to inanimate elements of the environment that are threatening and potentially fatal to humans.

II. Why investigate responses to threat in infants?

Even though the studies described above provide convincing evidence supporting evolutionary claims about humans' preparedness for coping with threat, they are limited because they only tested older participants. Both adults and toddlers have likely already had some kind of experiences with both evolutionarily relevant and modern threats and therefore possibly bring along negative associations about threatening stimuli when entering the lab. The aim of this thesis is shedding some light on the response to threat early in ontogeny when previous experiences with threat are minimal. Therefore, here, responses to threat will be investigated in young infants. Research with infants can be particularly interesting because infancy is a period of particular vulnerability and lack of knowledge entailing a huge dependence on caregivers and the information provided by adults (Boyer & Bergstrom, 2011; Hahn-Holbrook et al., 2011). It raises interesting questions of whether infants already possess any mechanisms to help navigate threatening features of their environment, and to what extent they use information about threat provided by adults.

Recently, researchers have begun to study behavioral responses to threatening stimuli in infancy and found that mechanisms for dealing with threat appear surprisingly early in ontogeny (for review see LoBue, Rakison, & DeLoache, 2010). Similar to findings with adults and preschool children, these results suggest that threatening stimuli are privileged on multiple levels of cognitive processing. For instance, before the end of the first year of life, infants orient attention more quickly toward threatening stimuli (snakes and angry faces) than non-threatening stimuli (flowers and happy faces; LoBue & DeLoache, 2010) and also look longer at schematic images of spiders than at scrambled versions of these animals suggesting that infants may possess some kind of perceptual template for how these stimuli should be arranged (Rakison & Derringer, 2008). Additionally, infants at this age preferentially associate threat-relevant animals (snakes) with a fearful vocal sound (DeLoache & LoBue, 2009) and show special processing of angry and fearful faces (e.g., Leppänen et al. 2007).

Interestingly, the developmental schedule of the emergence of typical children's fears seems to coincide with the age that dangerous encounters have repeatedly taken place during human evolution (Boyer & Bergstrom, 2011). For example, fear of strangers appears when infants start to move about on their own by means of crawling (around 8 months of age). That is the time when infants are likely to encounter conspecifics outside of the immediate protection of their own caregivers. As the occurrence of infanticide has been shown in most primates (Hrdy, 1977) and additionally the risk of physical threat and homicide from step-fathers has been much greater than from the male relatives (Daly & Wilson, 1988; 1998), the fear of strangers is directed at unrelated and generally non-kin males.

Consistent with the preferential attention of adults toward the broad category of animals reviewed previously and human adaptations to predator and prey described by Barrett (2005; 2015), there is evidence suggesting that newborns are already particularly sensitive to animals. When presented with pairs of point-light displays depicting biological motion (a moving hen) and the other non-biological (random) movement, newborns looked significantly longer at the biological than the random motion (Simon, Regolin, & Bulf, 2008). Further, results with older infants in the first year of life, showed convergent evidence for the existence of a preference for animate (animals) over inanimate stimuli (artifacts; DeLoache, Bloom Pickard, & LoBue, 2011).

Interestingly, in addition to preferential attention toward animals over other objects, recent studies have shown that infants by 18 months exhibit an avid interest in live animals compared to attractive toys (LoBue et al, 2013). In free play approach-avoidance paradigm, children interacted with animals, including both non-threatening animals like a hamster and a fish and threatening animals like a snake and a spider, more often than with the toys. Importantly, parents were shown to play a crucial role in mediating these effects by spending more time directing their child's attention toward animals compared to the control stimuli. In fact, unlike for toys, children spent more time interacting with animals when their parents were present then when they were alone.

Young infants readily rely on parents or other adults when deciding between approach and avoidance toward objects, in particular when the objects are novel or ambiguous (Baldwin & Moses, 1996; Feinman, 1982; Kim & Kwak, 2011). The well-established phenomenon of infant social referencing is an example of the beneficial transfer of information from a knowledgeable adult to a vulnerable and naïve infant. In this communicative process, infants build interpretations of the objects around them based on the emotional reactions of adults (Feinman, 1992). Using social cues when learning about the environment is especially beneficial when the costs of asocial learning (e.g., experimenting via trial and error) are high (Boyd & Richerson, 1988; Laland, 2004). The costs of failing to identify entities that are dangerous may be critically high. Therefore, social learning has been suggested to be a crucial aspect of learning about threat, especially in infancy when humans can gain knowledge from more knowledgeable conspecifics. Consistently, infants readily use social information when confronted with potentially threatening entities, such as novel objects (Gerull & Rapee, 2002), visual cliffs (Sorce et al., 1985) or strangers (De Rosnay et al., 2006).

In summary, studying infants is informative given our interest in exploring the response to threat early in ontogeny when the influence of the previous experiences is minimal.

III. Why investigate infants' responses to threat from plants?

Plants comprise an important environmental threat that humans have to negotiate (Wertz & Moya, 2019; Wertz & Wynn, 2014a; 2014b). Studies of the archeological record and of modern hunter-gatherer populations show that plants were critical part of human life over evolutionary time. Plants have been source of food (Harris & Hillman, 2014; Henry, Brooks, & Piperno, 2014; Peters et al., 1981; Ungar & Sponheimer, 2011) anti-predator and sleeping shelters (Sikes, 1994) and raw material for construction of tools and weapons (Lee, 1993; Kortlandt, 1980). In modern small-scale societies, both adults and young children interact with plants during foraging activities, with children helping with obtaining relatively less challenging sources such as berries or fruits (Crittenden, Conklin-Brittain, Marlowe, Schoeninger, & Wrangham, 2009).

Plants produce an array of defenses against herbivores, some of which are dangerous or life-threatening to humans (Karban & Baldwin, 1997; Keeler & Tu, 1983; Palo & Robbins, 1991). These defenses are either not visible, such as toxic chemical compounds (e.g., neurotoxins and noxious oils), or are visually detectable, physical structures (e.g., thorns or stinging hairs). Notably, the fact that a plant has no visible defenses does not mean that it is safe. Identifying which plant is safe and which is not is particularly difficult because plants do not reliably signal whether they are edible or toxic to humans (e.g., via a particular leaf shape or color). This is because plants are in coevolutionary relationships with many different types animal species, mainly insects, and have evolved their defenses accordingly (Palo & Robbins, 1991). Thus, interacting with plants entails choices made under uncertainty with high costs of false negative errors (cf. Haselton & Buss, 2000; Haselton & Nettle, 2006; Johnson, Blumstein, Fowler, & Haselton, 2013).

Consequently, plants have posed serious recurrent problems to all plant-eating animals, including humans, across evolutionary time. Not surprisingly, this has leads to the evolution of a myriad of physiological and behavioral mechanisms for negotiating plant dangers across the animal kingdom. These mechanisms include breaking down toxins by means of particular enzymes or symbiotic relationships with microbes (Hagen et al., 2009; Fürstenberg-Hägg, Zagrobelny, & Bak, 2013), purging toxins with vomiting (Kingsbury, 1983) and some behavioral avoidance mechanisms like taste aversions after adverse events and neophobia (Cashdan, 1994, 1998; Rioux, Picard, & Lafraire, 2016).

Importantly, unlike other kinds of threatening stimuli like dangerous animals or angry conspecifics, plants are not intentional agents that can move on their own and attack. Plants are rooted to the ground, which means they cannot inflict harm unless they are approached and touched. As a result, a simple behavioral strategy of avoiding physical contact with plants can be an effective way of minimizing exposure of plant threats, particularly during periods of vulnerability like infancy. Recent studies investigating this proposal showed that infants are reluctant to touch benign-looking plants compared to other entities (Elsner & Wertz, 2019; Wertz & Wynn, 2014a). This behavioral strategy would minimize infants' physical contact with unknown plants and therefore reduce their exposure to potential plant dangers. However, there is much about infants' responses to plants that remains unknown. The Wertz & Wynn (2014a; 2014b) studies were the first experimental steps in the process of uncovering the proposed plant-specialized behavioral avoidance strategies and social learning mechanisms that facilitate the safe acquisition of information about plants in infancy.

One outstanding question is whether infants respond differently to plants with easily-observable dangerous parts—sharp-looking thorns—than to the benign-looking plants that have been investigated thus far. The natural landscapes of our ancestors were full of thorny vegetation (Bakker et al., 2016). Importantly, these landscapes lacked concrete pavements and streets that would provide safe passage. Although it may seem counterintuitive, spiny thickets may have been as dangerous as the sharp canines of predators in case of entrapment or inattentive movement. Both situations may have led to serious injuries that could become quite dangerous in a world without modern medicine or sanitation (Gurven, Allen-Arave, Hill, & Hurtado, 2000; Gurven, Stieglitz, Hooper, Gomes, & Kaplan, 2012). Therefore, recognizing the sharp-angled shape of thorns as dangerous may have been an advantage for humans coexisting with plant life. Further, avoidance behavior towards spiky elements seems a plausible solution for a potential puncture problem.

Research on low-level human visual perception provides evidence that the pointed form of thorns may be privileged in human processing. For example, adults have more difficulty disengaging their attention from pointed geometrical shapes and rate them as more aversive compared to circle shapes (Larson, Aronoff, & Stearns, 2007). The preference for curved contours over the sharp ones is shared by both adults and infants (Bar & Neta, 2006; Fantz & Miranda, 1975). Newborn babies were already shown to preferentially fixate on curved contours compared to the pointed ones (Fantz & Miranda, 1975). However, this preference in adults depends on the conditions under which the pointed shapes are presented (brief presentation time vs. free-viewing; Munar, Gómez-Puerto, Call, & Nadal, 2015). Additionally, the perceptual sensitivity for pointed forms in children is influenced by their previous experience. They are perceptually sensitive to the presence of pointed-shaped objects (i.e., syringes), but only after they have had a negative experience with the object (LoBue, 2010b). However, infants' reactions to pointed-shaped objects in naturalistic contexts—in this case as part of plants—remain to be investigated.

IV. What are the big questions this thesis is going to answer?

This thesis investigates several unexplored aspects of the proposed behavioral strategy for avoiding plant threats in infancy (Wertz & Wynn, 2014a; Wertz & Wynn, 2014b). Four broad questions will be investigated:

First, the thesis will consider the question of the potential threat-relevant meaning of thorns that could trigger this avoidance strategy. Specifically, the experiment in Chapter 1 (Włodarczyk et al, 2018) will test *whether infants treat observable and unobservable plant threats differently.*

Further, previous research investigated how long it took infants to touch plants compared to other object categories (Elsner & Wertz, 2019; Wertz & Wynn, 2014a), yet it did not look at the subsequent stages of infants' object exploration. Therefore, Chapter 1 will also investigate whether *in addition to initial reluctance to reach for plants the avoidance behavioral strategy comprises of the minimized subsequent manual exploration.* Specifically, we will test two additional measures of manual exploration – the time infants spend in contact with objects and the frequency of touches to particular parts of objects (thorny versus non-thorny) to check if they remain consistent with the logic of behavioral avoidance strategy toward plants.

Second, given the advantage of using social information from adults to learn about threat in infancy and the readiness to guide their behavior based on the reactions and information from the others, it is probable that infants may also use social cues to learn about plant threats. Accordingly, human adaptations for plants are predicted to include social learning rules as an integral part of their design (Wertz and Wynn, 2014a, 2014b). Previous studies have shown that infants differentially seek out social information before contacting plants (Elsner & Wertz, 2019) and use social cues to learn about some aspects of plants (e.g., edibility; Wertz & Wynn, 2014b). The remaining question is of the influence of social information on infants' response to plant threats when it is presented with plants and other stimuli objects. Particularly, the aim of study in Chapter 2 is to test *whether infants react differently to negative and positive social information in the context of plants and other object types.*

Third, there is evidence that the human perceptual system is sensitive to low-level cues of threatening entities such as the sinusoidal shape of snakes or the ''V'' shaped brow attribute of angry faces, and that these simple shapes may play a role in human reactions to threatening objects (LoBue & DeLoache, 2011; LoBue & Larson, 2010). The final broad question concerning infants' responses to plant threats explores a possible underlying low-level attentional mechanism related to the behavioral avoidance strategy. Thus, the final study in

Chapter 3 is an attempt to investigate whether *infants' visual attention is captured and held by pointed elements of plants*.

Having finished reading this thesis, the reader will have a broader view on novel aspects of the behavioral avoidance strategy toward plant threats, including responses to visible plant threats, and will learn about the avenues for future work on the possible low-level perceptual mechanisms underlying this strategy.

References

Bakker, E. S., Gill, J. L., Johnson, C. N., Vera, F. W., Sandom, C. J., Asner, G. P., & Svenning, J. C. (2016). Combining paleo-data and modern exclosure experiments to assess the impact of megafauna extinctions on woody vegetation. *Proceedings of the National Academy of Sciences*, *113*(4), 847-855.

Baldwin, D. A., & Moses, L. J. (1996). The ontogeny of social information gathering. *Child Development*, *67*(5), 1915-1939.

Bar, M., & Neta, M. (2006). Humans prefer curved visual objects. *Psychological Science*, *17*(8), 645-648.

Barrett, H. C. (2005). Adaptations to predators and prey. *The Handbook of Rvolutionary Psychology,* 200-223.

Barrett, H. (2015). Adaptations to predators and prey. *The Handbook of Evolutionary Psychology, Volume 1: Foundation*, *1*, 246.

Barrett, H.C., & Broesch, J. (2012). Prepared social learning about dangerous animals in children. *Evolution and Human Behavior,* 33, 499-508.

Barrett, H. C., Peterson, C. D., & Frankenhuis, W. E. (2016). Mapping the cultural learnability landscape of danger. *Child Development*, 87(3), 770-781.

Blanchette, I. (2006). Snakes, spiders, guns, and syringes: How specific are evolutionary constraints on the detection of threatening stimuli? *The Quarterly Journal of*

Experimental Psychology, 59(8), 1484-1504Boyd, R., & Richerson, P. J. (1988). *Culture and the evolutionary process*. University of Chicago press.

Boyer, P., & Bergstrom, B. (2011). Threat-detection in child development: An evolutionary perspective. *Neuroscience & Biobehavioral Reviews*, *35*(4), 1034-1041.

Broesch, J., Barrett, H. C., & Henrich, J. (2014). Adaptive content biases in learning about animals across the life course. *Human Nature*, *25*(2), 181-199.

Brosch, T., & Sharma, D. (2005). The role of fear-relevant stimuli in visual search: a comparison of phylogenetic and ontogenetic stimuli. *Emotion,* 5(3), 360.

Buss, D. M. (Ed.). (2005). The Handbook of Evolutionary Psychology. John Wiley & Sons.

Buss, D. M. (Ed.). (2015). The Handbook of Evolutionary Psychology, Volume 1: Foundation (Vol. 1). John Wiley & Sons.

Calvo, M. G., Avero, P., & Lundqvist, D. (2006). Facilitated detection of angry faces: Initial orienting and processing efficiency. *Cognition and Emotion,* 20(6), 785-811.

Cashdan, E. (1994). A sensitive period for learning about food. *Human Nature*, 5(3), 279-291.

Cashdan, E. (1998). Adaptiveness of food learning and food aversions in children. *Social Science Information*, *37*(4), 613-632.

Coelho, C. M., & Purkis, H. (2009). The origins of specific phobias: Influential theories and current perspectives. *Review of General Psychology*, 13(4), 335.

Cosmides, L., & Tooby, J. (1997). Evolutionary psychology: A primer.

Cosmides, L., & Tooby, J. (2000). Evolutionary psychology and the emotions. Handbook of *Emotions*, 2(2), 91-115.

Crittenden, A. N., Conklin-Brittain, N. L., Marlowe, F. W., Schoeninger, M. J., Wrangham, R.W. (2009). Foraging strategies and diet composition of Hadza children. *American Journal of Physical Anthropology, 138(S48): 112.*

Daly, M., & Wilson, M. (1988). Evolutionary social psychology and family homicide. *Science*, 242(4878), 519-524.

Daly, M., & Wilson, M. (1998). The evolutionary social psychology of family violence. *Handbook of evolutionary psychology: Ideas, issues and applications*, 431-456.

Darwin, C. (1871). The descent of man and selection in relation to sex. London: Murray.

DeLoache, J. S., & LoBue, V. (2009). The narrow fellow in the grass: Human infants associate snakes and fear. Developmental Science, 12(1), 201-207.

DeLoache, J. S., Pickard, M. B., & LoBue, V. (2011). How very young children think about animals? *How animals affect us: Examining the influence of human–animal interaction on child development and human health*, 85-99.

De Rosnay, M., Cooper, P. J., Tsigaras, N., & Murray, L. (2006). Transmission of social anxiety from mother to infant: An experimental study using a social referencing paradigm. *Behaviour Research and Therapy*, *44*(8), 1165-1175.

Eastwood, J. D., Smilek, D., & Merikle, P. M. (2001). Differential attentional guidance by unattended faces expressing positive and negative emotion. *Perception & psychophysics*, *63*(6), 1004-1013.

Elsner, C. & Wertz, A.E. (2019). The seeds of social learning: Infants exhibit more social referencing for plants than other types. Cognition

Fantz, R. L., & Miranda, S. B. (1975). Newborn infant attention to form of contour. *Child Development*, 224-228.

Feinman, S. (1982). Social referencing in infancy. *Merrill-Palmer Quarterly (1982-)*, 445-470.

Feinman, S. (1992). Social referencing and conformity. In *Social Referencing and the Social Construction of Reality in Infancy* (pp. 229-267). Springer, Boston, MA.

Fenske, M. J., & Eastwood, J. D. (2003). Modulation of focused attention by faces expressing emotion: Evidence from flanker tasks. *Emotion*, 3, 327–343.

Flykt, A. (2005). Visual search with biological threat stimuli: Accuracy, reactions times, and heart rate changes. *Emotion,* 5, 349–353.

Forbes, S. J., Purkis, H. M., & Lipp, O. V. (2011). Better safe than sorry: Simplistic fear-relevant stimuli capture attention. *Cognition & Emotion*, *25*(5), 794-804.

Fürstenberg-Hägg, J., Zagrobelny, M., & Bak, S. (2013). Plant defense against insect herbivores. *International Journal of Molecular Sciences*, *14*(5), 10242-10297.

Geary, D. C. (2005). *The origin of mind: Evolution of brain, cognition, and general intelligence*. American Psychological Association.

Gerull, F. C., & Rapee, R. M. (2002). Mother knows best: effects of maternal modelling on the acquisition of fear and avoidance behaviour in toddlers. *Behaviour Research and Therapy*, *40*(3), 279-287.

Gigerenzer, G., & Selten, R. (Eds.). (2002). *Bounded rationality: The adaptive toolbox.* MIT press.

Gurven, M., Allen-Arave, W., Hill, K., & Hurtado, M. (2000). “It's a wonderful life”: signaling generosity among the Ache of Paraguay. *Evolution and Human Behavior*, *21*(4), 263-282.

Gurven, M., Stieglitz, J., Hooper, P. L., Gomes, C., & Kaplan, H. (2012). From the womb to the tomb: the role of transfers in shaping the evolved human life history. *Experimental Gerontology*, *47*(10), 807-813.

Hagen, E. H., Sullivan, R. J., Schmidt, R., Morris, G., Kempter, R., & Hammerstein, P. (2009). Ecology and neurobiology of toxin avoidance and the paradox of drug reward. *Neuroscience*, *160*(1), 69-84.

Hahn-Holbrook, J., Holbrook, C., & Haselton, M. G. (2011). Parental precaution: Neurobiological means and adaptive ends. *Neuroscience & Biobehavioral Reviews*, *35*(4), 1052-1066.

Hamilton, W. D. (1964). The evolution of social behavior. *Journal of Theoretical Biology*, 7, 1-52.

Hansen, C. H., & Hansen, R. D. (1988). Finding the face in the crowd: an anger superiority effect. *Journal of Personality and Social Psychology*, *54*(6), 917.

Harris, D. R., & Hillman, G. C. (Eds.). (2014). *Foraging and farming: The evolution of plant exploitation* (Vol. 31). Routledge.

Haselton, M. G., & Buss, D. M. (2000). Error management theory: a new perspective on biases in cross-sex mind reading. *Journal of Personality and Social Psychology*, *78*(1), 81.

Haselton, M. G., Bryant, G. A., Wilke, A., Frederick, D. A., Galperin, A., Frankenhuis, W. E., & Moore, T. (2009). Adaptive rationality: An evolutionary perspective on cognitive bias. *Social Cognition*, *27*(5), 733-763.

Haselton, M. G., & Nettle, D. (2006). The paranoid optimist: An integrative evolutionary model of cognitive biases. *Personality and social psychology Review*, *10*(1), 47-66.

Hayakawa, S., Kawai, N., & Masataka, N. (2011). The influence of color on snake detection in visual search in human children. *Scientific Reports*, 1, 1–4.

Henry, A. G., Brooks, A. S., & Piperno, D. R. (2014). Plant foods and the dietary ecology of Neanderthals and early modern humans. *Journal of Human Evolution*, *69*, 44-54.

Horstmann, G., Scharlau, I., & Ansorge, U. (2006). More efficient rejection of happy than of angry face distractors in visual search. *Psychonomic Bulletin & Review*, *13*(6), 1067-1073.

Hrdy, S. B. (1977). Infanticide as a primate reproductive strategy. *American Scientist*, *65*(1), 40-49.

Johnson, D. D., Blumstein, D. T., Fowler, J. H., & Haselton, M. G. (2013). The evolution of error: Error management, cognitive constraints, and adaptive decision-making biases. *Trends in Ecology & Evolution*, *28*(8), 474-481.

Karban, R. B., & Baldwin, I. T. (1997) *Induced Responses to Herbivory*. University of Chicago Press.

Keeler, R.F., & Tu, A. T. (Eds.). (1983). *Handbook of natural toxins: Plant and fungal toxins. (Vol. 1).* New York, NY: Marcel Dekker Inc.

Kim, G., & Kwak, K. (2011). Uncertainty matters: impact of stimulus ambiguity on infant social referencing. *Infant and Child Development*, *20*(5), 449-463.

Kingsbury J.M. (1983). The evolutionary and ecological significance of plant toxins. In: Keeler RF, Tu AT, editors. *Handbook of natural toxins: Plant and fungal toxins*. Vol. 1. New York, NY: Marcel Dekker, Inc; pp. 675–706.

Kortlandt, A. (1980). How might early hominids have defended themselves against large predators and food competitors? *Journal of Human Evolution, 9*(2), 79-112.

Larson, C. L., Aronoff, J., & Stearns, J. J. (2007). The shape of threat: simple geometric forms evoke rapid and sustained capture of attention. *Emotion, 7*(3), 526.

Laland, K. N. (2004). Social learning strategies. Animal Learning & Behavior, 32(1), 4-14.

Lee, R. B. (1993). The Dobe Ju/'hoansi (2nd edition). Fort Worth, TX: Harcourt Brace College Publishers.

Leppänen, J. M., Moulson, M. C., Vogel-Farley, V. K., & Nelson, C. A. (2007). An ERP study of emotional face processing in the adult and infant brain. *Child Development*, *78*(1), 232-245.

Lipp, O. V., & Derakshan, N. (2005). Attentional bias to pictures of fear-relevant animals in a dot probe task. *Emotion,* 5, 365–369.

Lipp, O. V., Derakshan, N., Waters, A. M., & Logies, S. (2004). Snakes and cats in the flower bed: fast detection is not specific to pictures of fear-relevant animals. *Emotion*, *4*(3), 233.

LoBue, V. (2009). More than just a face in the crowd: Detection of emotional facial expressions in young children and adults. *Developmental Science*, 12, 305–313.

LoBue, V. (2010a). And along came a spider: Superior detection of spiders in children and adults. *Journal of Experimental Child Psychology*, 107, 59–66.

LoBue, V. (2010b). What's so scary about needles and knives? Examining the role of experience in threat detection. *Cognition and Emotion*, 24(1), 180-187.

LoBue, V. (2014). Deconstructing the snake: The relative roles of perception, cognition, and emotion on threat detection. *Emotion*, 14(4), 701.

LoBue, V., & DeLoache, J. S. (2008). Detecting the snake in the grass: Attention to fear relevant stimuli by adults and young children. *Psychological Science,* 19, 284–289.

LoBue, V., & DeLoache, J. S. (2010). Superior detection of threat-relevant stimuli in infancy. *Developmental Science*, 13(1), 221-228.

LoBue, V., Bloom Pickard, M., Sherman, K., Axford, C., & DeLoache, J. S. (2013). Young children's interest in live animals. *British Journal of Developmental Psychology*, *31*(1), 57-69.

LoBue, V., Rakison, D. H., & DeLoache, J. S. (2010). Threat perception across the life span: Evidence for multiple converging pathways. *Current Directions in Psychological Science*, *19*(6), 375-379.

LoBue, V., & DeLoache, J. S. (2011). What so special about slithering serpents? Children and adults rapidly detect snakes based on their simple features. *Visual Cognition*, 19, 129–143.

LoBue, V., & Larson, C. L. (2010). What makes angry faces look so. . .angry? Examining visual attention to the shape of threat in children and adults. *Visual Cognition*, 18, 1165–1178.

LoBue, V., & Rakison, D. H. (2013). What we fear most: A developmental advantage for threat-relevant stimuli. *Developmental Review*, *33*(4), 285-303.

Masataka, N., & Shibasaki, M. (2012). Premenstrual enhancement of snake detection in visual search in healthy women. *Scientific Reports*, *2*, 307.

Munar, E., Gómez-Puerto, G., Call, J., & Nadal, M. (2015). Common visual preference for curved contours in humans and great apes. *PLoS One, 10*(11), e0141106.

Nesse, R. M. (1994). Fear and fitness: An evolutionary analysis of anxiety disorders. *Ethology and Sociobiology*, *15*(5-6), 247-261.

Nesse, R. M. (2001). The smoke detector principle. *Annals of the New York Academy of Sciences*, *935*(1), 75-85.

Nesse, R. M. (2005). Natural selection and the regulation of defenses: A signal detection analysis of the smoke detector principle. *Evolution and Human Behavior*, *26*(1), 88-105.

New, J., Cosmides, L., & Tooby, J. (2007). Category-specific attention for animals reflects ancestral priorities, not expertise. *Proceedings of the National Academy of Sciences*, *104*(42), 16598-16603.

New, J. J., & German, T. C. (2015). Spiders at the cocktail party: An ancestral threat that surmounts inattentional blindness. *Evolution and Human Behavior*, *36*(3), 165-173.

Öhman, A. (2009). Of snakes and faces: An evolutionary perspective on the psychology of fear. *Scandinavian Journal of Psychology*, *50*(6), 543-552.

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology: General*, *130*(3), 466.

Öhman, A., & Mineka, S. (2001). Fear, phobias, and preparedness: Toward an Evolved module of fear and fear learning. *Psychological Review*, 108, 453-552.

Öhman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: a threat advantage with schematic stimuli. *Journal of Personality and Social Ssychology*, *80*(3), 381.

Palo, R. T., & Robbins, C. T. (1991). *Plant defenses against mammalian herbivory*. CRC Press.

Peters, C. R., O'Brien, E. M., Boaz, N. T., Conroy, G. C., Godfrey, L. R., Kawanaka, K., ... & Smith, E. O. (1981). The early hominid plant-food niche: insights from an analysis of plant exploitation by Homo, Pan, and Papio in eastern and southern Africa [and Comments and Reply]. *Current Anthropology*, *22*(2), 127-140.

Rakison, D. H., & Derringer, J. (2008). Do infants possess an evolved spider-detection mechanism? *Cognition*, *107*(1), 381-393.

Rioux, C., Picard, D., & Lafraire, J. (2016). Food rejection and the development of food categorization in young children. *Cognitive Development*, *40*, 163-177.

Seligman, M. E. (1971). Phobias and preparedness. *Behavior Therapy*, 2(3), 307-320.

Sikes, N. E. (1994). Early hominid habitat preferences in East Africa: paleosol carbon isotopic evidence. *Journal of Human Evolution*, 27(1), 25-45.

Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences*, *105*(2), 809-813.

Sorce, J. F., Emde, R. N., Campos, J. J., & Klinnert, M. D. (1985). Maternal emotional signaling: Its effect on the visual cliff behavior of 1-year-olds. *Developmental Psychology*, *21*(1), 195.

Tooby, J., & Cosmides, L. (1992). The psychological foundations of culture. *The adapted mind: Evolutionary psychology and the generation of culture*, *19*.

Ungar, P. S., & Sponheimer, M. (2011). The diets of early hominins. *Science, 334*(6053), 190-193.

Waters, A. M., & Lipp, O. V. (2008). The influence of animal fear on attentional capture by fear-relevant animal stimuli in children. *Behaviour Research and Therapy*, 46, 114–121.

Wertz, A.E. & Moya, C. (2019). Pathways to cognitive design. *Behavioral Processes.* https://doi.org/10.1016/j.beproc.2018.05.013

Wertz, A. E., & Wynn, K. (2014a). Thyme to touch: Infants possess strategies that protect them from dangers posed by plants. *Cognition*, *130*(1), 44-49.

Wertz, A. E., & Wynn, K. (2014b). Selective social learning of plant edibility in 6-and 18-month-old infants. *Psychological Science*, *25*(4), 874-882.

Williams, G. C. (1966). *Adaptation and natural selection: A critique of some current* *evolutionary thought. Princeton*, NJ: Princeton University Press.

Włodarczyk, A., Elsner, C., Schmitterer, A., & Wertz, A.E. (2018). Every rose has its thorn: Infants' responses to pointed shapes in naturalistic contexts. *Evolution & Human* Behavior. https://doi.org/10.1016/j.evolhumbehav.2018.06.001

Wood, B., & Collard, M. (1999). The human genus. *Science*, 284(5411), 65-71.

Chapter 1. Every rose has its thorn: Infants' responses to pointed shapes in naturalistic contexts.

Publication 1

Włodarczyk, A., Elsner, C., Schmitterer, A., & Wertz, A.E. (2018). Every rose has its thorn: Infants' responses to pointed shapes in naturalistic contexts. *Evolution & Human Behavior.* https://doi.org/10.1016/j.evolhumbehav.2018.06.001

Abstract

Plants produce dangerous chemical and physical defenses that have shaped the physiology and behavior of the herbivorous predators that feed on them. Here we explore the impact that these plant defenses may have had on humans by testing infants' responses to plants with and without sharp-looking thorns. To do this, we presented 8- to 18-month-olds with plants and control stimuli and measured their initial reaching behavior and subsequent object exploration behavior. Half of the stimuli had sharp-looking thorns or pointed parts while the other half did not. We found that infants exhibited both an initial reluctance to touch and minimized subsequent physical contact with plants compared to other object types. Further, infants treated all plants as potentially dangerous, whether or not they possessed sharp-looking thorns. These results reveal novel dimensions of a behavioral avoidance strategy in infancy that would mitigate potential harm from plants.

Keywords: threat; behavioral avoidance; infancy; cognitive development

1. Introduction

Plants are dangerous. This fact may seem counterintuitive in the context of WEIRD societies (Western, Educated, Industrialized, Rich, and Democratic; Henrich, Heine, & Norenzayan, 2010) in which people generally do not have to put a lot of thought into their interactions with plants. Cities and suburbs consist of concrete building and streets, and the people living in them spend significant portions of their lives indoors. Unsurprisingly, under these conditions, human interactions with vegetation can be rare and limited in scope, blinding us to the very real threats that plants can present.

The lives of our hunter-gatherer human ancestors were quite different. The archeological record and studies of modern small-scale societies that rely on hunting and gathering show that plants played a significant role throughout human evolution. Early humans consumed plant foods (Harris & Hillman, 2014; Henry, Brooks, & Piperno, 2014; Peters et al., 1981; Ungar & Sponheimer, 2011) and constructed artifacts from plant materials (Hardy, 2008; Lee, 1993). Modern hunter-gatherer and hunter-horticulturalist societies forage a wide variety of different plant foods from wild environments, specializing in extractive foraging of high energy plant parts (e.g., fruits, tubers, nuts; Cordain et al., 2000; Kaplan, Hill, Lancaster, & Hurtado, 2000), use plant materials to build tools and shelters (Kortlandt, 1980; Lee, 1993; Sikes, 1994), and extract (often toxic) plant chemicals to aid in hunting and fishing, as well as for medicinal and ritual use (Begossi, Hanazaki, & Tomashiro, 2002). These interactions are not limited to adulthood. For example, in modern hunter-gatherer societies children as young as 3 to 5 years of age actively engage in foraging activities, particularly with resources that are easy to obtain such as berries and fruits (Crittenden, Conklin-Brittain, Marlowe, Schoeninger, & Wrangham, 2009; Hawkes, O'Connell, & Jones, 1995; Greenwald, Eerkens, & Bartelink, 2016). In these circumstances, humans have frequent and intensive contact with plant life and, as a consequence, regular exposure to the kinds of threats that plants pose. Here we will begin by sketching out two broad categories of plant threat—poisoning and physical injury—and outlining the responses to those threats that have evolved in humans and other animals. Then we will present a novel empirical investigation of a recently-discovered response to plant threat in human infants.

1.1. Plant threats and protective adaptations in herbivores

Plants are dangerous because they have evolved a variety of different defenses to protect themselves from the herbivorous predators that feed on them. Plants, of course, cannot flee when herbivores begin to attack. Instead they rely on chemical and physical defenses aimed at deterring the damage herbivores can inflict.[1] An important group of plant defenses are secondary metabolites. All plants produce these chemical compounds, which have a variety of negative effects on herbivores including interfering with their growth, development, and fecundity (Karban & Baldwin, 1997; Keeler & Tu, 1983; Palo & Robbins, 1991). For example, terpenoids are the largest group of plant compounds and can have toxic, inhibitory effects on a wide variety of herbivores (Langenheim, 1994). Terpenoids in conifer resins can trap and drown invading insects, and even remain toxic after evaporation (Keeling & Bohlmann, 2006). Further, some plant defenses trigger complex behavioral changes in their attackers. For example, tomato plants produce chemicals that induce cannibalism in generalist insects, leading them to consume significantly less plant biomass (Orrock, Connolly, & Kitchen, 2017).

---

[1] Plants have also evolved mechanisms that exploit herbivores to serve their own ends (e.g., seed dispersal). These mechanisms are an integral part of the dynamics between plants and herbivores, but they are beyond the scope of the current paper.

Herbivores, and omnivores that feed on plants, have evolved countermeasures in response to these toxic chemical compounds. These include detoxification via specific enzymatic pathways and symbiotic relationships with microbes that break down plant toxins (Hagen et al., 2009; Fürstenberg-Hägg, Zagrobelny, & Bak, 2013), the capacity to detect plant toxins by means of bitter taste receptors (Wiener, Shudler, Levit, & Niv, 2011), purging the gut with vomiting after ingesting high quantities of toxins (Kingsbury, 1983), and increased nausea during developmental phases that are particularly vulnerable to disruption by toxins (e.g., pregnancy sickness; Profet, 1992). In addition, behavioral avoidance mechanisms like neophobia, and conditioned taste aversions protect animals from ingesting poisonous substances, and may be particularly responsive to plant toxins (Cashdan, 1994, 1998; Lin, Arthurs, & Reilly, 2017; Reilly, & Schachtman, 2008; Rioux, Picard, & Lafraire, 2016). These kinds of mechanisms enable herbivores and omnivores, including humans, to cope with the dangers posed by toxic compounds in plants.

However, toxic chemical substances are not the only dangers that plants pose. Plants also employ physical structures such as thorns[2] or stinging hairs to deter herbivores. These physical defenses can wound the mouths, digestive systems, and other body parts of large herbivores, leading to chronic mouth injuries and subsequent infestations of parasitic flies (Janzen, 1986). Additionally, thorns may cause septic inflammation themselves by injecting various toxic or pathogenic bacteria into large mammalian herbivores (Halpern, Raats, & Lev-Yadun, 2007). Herbivores, in turn, have evolved protective countermeasure to avoid contact

---

[2] English botanical usage distinguishes between a prickle (a pointy emergence from the cortex), a spine (a pointy part of a leaf), and a thorn (a pointy branch). For the sake of clarity, we are referring to these categories with the single word “thorns” throughout this paper.

with thorns. For example, there is evidence that some species of horses, elephants, and tapirs are reluctant to harvest fruits or leaves from thorny plants (Janzen, 1986). Moreover, browsing ungulates modulate their feeding behavior in the presence of thorns by decreasing and slowing down their biting rates (Cooper & Owen-Smith, 1986; Gowda, 1996).

It is likely that ancestral humans were confronted with thorny plant physical defenses in addition to plant chemical defenses. The natural ecology of hominids likely contained an abundance of thorny vegetation (Bakker et al., 2016). Indeed, archeological evidence suggests thorny plant structures evolved and were present in multiple regions long before the first human populations in those areas (Guo, Sha, Bian, & Qiu, 2009; Olivier et al., 2009). Without modern medicine or sanitation, injuries from thorny plant structures—similar to other physical injuries—could become quite costly (Gurven, Allen-Arave, Hill, & Hurtado, 2000; Gurven, Stieglitz, Hooper, Gomes, & Kaplan, 2012; Sugiyama, 2004). Therefore, recognizing the sharp-angled shape of thorns as dangerous may have been advantageous.

1.2. Responses to ancestrally-recurrent threats in infancy and early childhood

A growing body of work provides convergent evidence that infants and young children are sensitive to ancestrally-recurrent naturalistic threats. For example, children as young as three years of age more quickly detect the presence of snakes and spiders compared to control stimuli (LoBue & DeLoache, 2008; LoBue, 2010a); an advantage that persists into adulthood (New & German, 2015; Öhman, Flykt, & Esteves, 2001). Similar results have been found with infants. For example, 8- and 14-month-olds turn more quickly to look at snakes compared to flowers when presented with pairs of stimulus images side by side (LoBue & DeLoache, 2010), and 5-month-olds look longer in a preferential looking paradigm at schematic spider images than at scrambled versions of the same stimuli (Rakison & Derringer, 2008). This propensity to quickly orient toward ancestrally-recurrent threatening stimuli appears to play an important role in facilitating learning about danger (LoBue, Rakison, & DeLoache, 2010), and prepared learning about dangerous animals has been shown in young children across cultures (Barrett & Broesch, 2012; Barrett, Peterson, & Frankenhuis, 2016; Broesch, Barrett, & Henrich, 2014).

In addition to facilitated detection of and learning about ancestrally-recurrent threats, research on low-level human visual perception provides evidence that pointy forms may be detected more quickly and, in some cases, avoided. For instance, adults perceive pointy geometrical shapes as more aversive than round shapes in a subjective rating task, and have more difficulty disengaging their visual attention from them (Larson, Aronoff, & Stearns, 2007). Further, adults prefer curved contours over sharp angles (Bar & Neta, 2006; Silvia & Barona, 2009)—a preference is shared by nonhuman primates (Munar, Gómez-Puerto, Call, & Nadal, 2015)—and newborn infants preferentially fixate on curved contours compared to sharp-angled ones (Fantz & Miranda, 1975). This preference applies not only to abstract judgments, but extends to the design of consumer products (Westerman et al., 2012), architecture (Vartanian et al., 2013), and social judgments (Hess, Gryc, & Hareli, 2013).

However, a systematic avoidance of sharp-angled forms is not found in all circumstances. Some studies show that the preference for curved forms over sharp-angled forms depends on the conditions under which they are presented. Curved forms are preferred when briefly presented but not under free-viewing conditions in humans, but the reverse pattern is found in great apes (Munar et al., 2015), and, notably, an observational study showed that adults walk closer to pointy shaped plants compared to rounded ones (Coss, 2003). Further, experience influences the perception of sharp-angled forms in interesting ways. For example, young children are perceptually sensitive to the presence of pointy-shaped objects (e.g., they more quickly detect syringes in an array of images), but only after they have had a negative experience with the object (e.g., an injection at a doctor's office; LoBue, 2010b).

1.3. Infants' responses to plant threats

The existing literature provides evidence that plant threats shaped the physiology and behavior of many animals, including humans, and that human infants are responsive to other ancestrally-recurrent threats. Therefore, the current experiment aims to explore behavioral avoidance strategies that humans use to avoid plant dangers early in ontogeny. Indeed, there is evidence that human infants possess behavioral strategies that protect against plant dangers (Wertz & Wynn, 2014a). There were two critical aspects of plants that were used to predict the structure of this behavioral avoidance strategy: (1) Plants do not locomote. Therefore, avoiding plant threats can be achieved simply by an infant minimizing their own physical contact with plants. (2) Because plants are in coevolutionary relationships with many different species, primarily insect species that have very different sensory systems and physiologies than humans, plants do not have visual properties that reliably signal human-relevant toxicity (Keeler &Tu, 1983; Palo & Robins, 1991). Therefore, the best strategy, especially in periods of vulnerability like early ontogeny, is to minimizing physical contact with all unknown plants, regardless of how they look, until one has some additional information about their properties.

To test this, Wertz & Wynn (2014a) presented 8- to 18-month-olds with benign-looking plants (e.g., parsley), novel manmade artifacts matched to shape and color features of the plants, familiar artifacts (e.g., a small lamp), and natural objects (e.g., shells) and their reaching behavior was assessed. As predicted, infants exhibited a striking reluctance to touch plants compared to the other types of entities. Avoiding physical contact with plants in this way would protect infants from the dangers posed by plants' chemical and physical defenses. Moreover, separate studies showed that infants use social information to guide their interactions with plants (e.g., to learn which plants can be eaten; Wertz & Wynn, 2014b).

1.4. The current study

The previous study investigated one aspect of infants' behavioral avoidance strategy toward plants: namely, the initial reluctance to touch benign-looking plants (Wertz & Wynn, 2014a). Here we explore two novel aspects of the proposed strategy. First, we test whether infants' behavioral avoidance strategy extends to their manual exploration of plants *after* they make contact with them. If so, in addition to the previously-discovered reluctance to touch plants, this predicts that infants should spend less time in physical contact with plants once they first touch them and touch plants less frequently than other types of entities. Second, we examine whether infants respond differently to observable physical plant threats—visibly pointy thorns—compared to benign-looking plants that could nevertheless contain unobservable toxic chemical defenses. One possibility is that infants treat observable and unobservable plant threats the same since both types of threats have been present across evolutionary time, and avoiding physical contact would effectively mitigates both types. Alternately, because there is less uncertainty about the presence of physically observable plant threats like thorns compared to unobservable toxic chemical compounds, infants may show increased behavioral avoidance of plants when they possess sharp-looking thorns.

To test these questions, we used a paradigm adapted from Wertz & Wynn (2014a) in which 8- to 18-month-old infants were presented with three categories of stimulus objects: plants, novel artifacts matched to shape and color features of the plants, and familiar artifacts. Half of the stimulus objects in each category had thorns or pointed parts while the other half did not. We assessed infants' initial reaching behavior toward, and subsequent manual exploration of, each stimulus object.

2. Materials and Methods

2.1. Participants

Participants were healthy, full term 8- to 18-month-old infants (N = 42, 19 females, M_{age} = 13 months, 5 days; range = 7;30–17;27) recruited from a large city in Germany. This age range and sample size were based on Wertz & Wynn (2014a). The study was approved by the responsible Ethics Committee and parents gave written consent for their child's participation. Families were compensated with €10 and infants were given a participation certificate.

2.2. Stimuli

The stimulus set consisted of three types of objects: realistic-looking artificial plants, novel manmade artifacts, and familiar manmade artifacts. There were four objects of each stimulus type grouped into matched pairs. One stimulus object in each pair had thorns or pointed parts while the other was identical except that it lacked thorns or pointed parts (see *Figure 1*). The thorns used in our stimulus set had two different shapes: a triangular shape similar to a rose thorn, and a thin needle shape similar to a cactus thorn (see *Figure 1 insets*). The thorns on the plants and novel artifacts were made out of a soft child-safe modeling clay to ensure that children could not be injured. The familiar objects had child-safe pointed parts that matched the two thorn shapes used on the plants and novel artifacts.

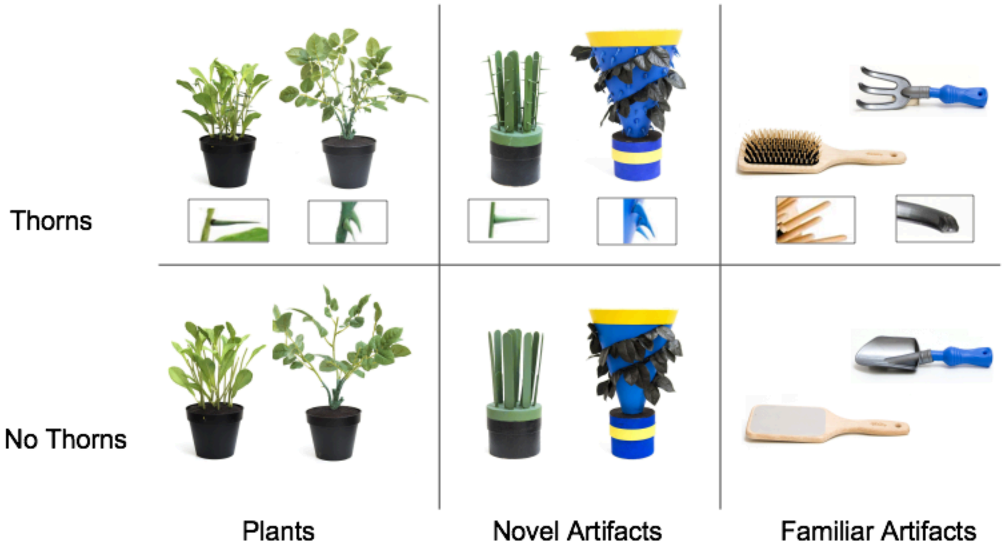


Figure 1. Stimulus set used in the experiment. The stimuli depicted in the top row have thorns (plants and novel artifacts) or pointed parts (familiar artifacts). The stimuli depicted in the bottom row are matched to those on the top row but have no thorns or pointed parts; close-up insets depict the thorn or pointed part shapes used on each thorny object.

The stimuli plants were four realistic-looking artificial plants of two different types, made out of plastic stems and fabric leaves arranged in black plastic pots, purchased from a large chain store (see left column of *Figure 1*). One of the plants of each type had thorns glued to the stems and branches while the other did not. We used only realistic-looking artificial plants in this stimulus set so that infants were not exposed to potentially harmful thorns on real plants, however previous studies have shown that infants of this age respond similarly to real and artificial plants (Elsner & Wertz, 2019; Wertz & Wynn, 2014a).

There were two types of novel artifacts designed to match shape and color features of the stimulus plants (see middle column of *Figure 1*). The first type of novel artifact matched the size and green color of one of the plant types. It was made from a cylinder-shaped green and black cardboard box base with green popsicle sticks protruding from the top; one of these green novel artifacts had cactus-like green thorns. The second type of novel artifact matched the size and leaf shape of the other plant type. It was made from a blue and yellow cardboard cone arranged on top of a blue and yellow cylinder-shaped cardboard box base, and wrapped with black leaves of the exact shape used on one type of stimulus plant; one of these blue novel artifacts had blue curved downward rose-like thorns.

The familiar artifacts were included in the stimulus set in order to examine whether infants respond differently to broader classes of familiar compared to unfamiliar objects. The plant stimuli would be relatively more familiar to infants than our novel artifact stimuli. Therefore, we included exemplars of artifacts that would also be relatively more familiar to infants. There were two pairs of familiar artifacts, with one object in each pair containing thorn-like shapes (see right column of Figure 1). The first pair included a wooden hairbrush and a wooden hand mirror, and the second pair consisted of a children's plastic rake and plastic shovel.

See Supplementary Information (SI) Sections 1.1.-1.3. for further details of the stimuli.

The focus of our investigation was infants' behavior towards plants and their thorns in particular, not towards the pots in which the plants were presented. Therefore, we treated the top parts of all stimulus objects as our area of interest. The "top parts" of the stimuli were defined as (i) the stems, leaves, and thorns (when applicable) of the plants, (ii) the cones, fabric leaves, popsicle sticks, and thorns (when applicable) of the novel artifacts, and (iii) the flat, wide (i.e., non-handle) parts of the familiar artifacts including the pointed parts (when applicable; see *Figure 1* and SI Section *2* for further details).

2.3. Procedure

Infants sat on their parents' laps on the opposite side of the table from the experimenter approximately 145 cm away. The experimenter placed the twelve stimulus objects one at a time approximately 25 cm away from the infant, while saying in German, *"Look, what I've got!"* (*"Schau mal, was ich hier habe!"*; see Video S1 and Video S2*).* The experimenter touched only the bottom parts of the objects throughout the session (i.e., the plant pots, the bases of the novel artifacts, and the handles of the familiar artifacts) so as not to cue infants' touching behavior toward the top parts of the stimulus objects. Parents were instructed to keep their eyes closed during the stimulus presentation. The experimenter looked down at the table and maintained a neutral facial expression while each stimulus object was in front of the infant. Each stimulus object remained in front of the infant until (i) 5 seconds elapsed after the infant first touched the top part of the object, (ii) 30 seconds elapsed in the case where the infant touched only the bottom part of the object and failed to touch any other part or (iii) 30 seconds elapsed without a touch. When one of these three criteria were met, the trial was ended.

The order of presentation of the stimulus objects was blocked into thorny and non-thorny stimulus objects and randomized within each block. That is, the six objects with thorns were presented serially in one block and the six objects without thorns were presented serially in another block. Whether infants were presented with thorny or non-thorny objects first was counterbalanced across participants. The order of presentation of the six objects in the first block of the presentation was randomized, and then adjustments were made to ensure that each object type (plant, novel artifact, familiar artifact) appeared first roughly equally across participants. Complete randomization across all the objects within each block was not possible due to the number of presented stimuli. The order of presentation in the second block was the mirror image of the presentation order of the second block. Additionally, the side on which the handle of the familiar artifacts was presented (left vs. right) was counterbalanced across those stimulus objects within each block.

After the object presentation phase concluded, parents completed a battery of questionnaires (see Section 2.5 below).

2.4. Coding infant behavior

2.4.1. Video recording

Infants' behavior during the session was recorded on video with four GoPro Hero 4, Black Edition cameras. Each session was recorded from four different angles: a front-view of the infant and the stimulus object, a side-view of the experimenter placing each object in front of the infant, as well as two close up side views (i.e., left and right) of the object and infants' hands. Recorded videos were imported into ELAN, a program for annotating multi-media recordings (v.4.9.1; Lausberg & Sloetjes, 2009) for subsequent behavioral coding.

2.4.2. Coding procedure

Infants' touch behavior toward to the top part of the stimulus object was coded during each trial. Each trial began when the experimenter released her hands from the stimulus object after placing it on the table in front of the infant (as in Elsner & Wertz, 2019; Wertz & Wynn, 2014a) and ended as outlined in Section 2.3. A "touch" was coded as any part of the infant's hand coming into contact with the stimulus object. Eight individual trials (out of the total 504 trials) were excluded from further analysis due to procedure error (two trials), failure to present a stimulus object by the experimenter (one trial), infants throwing a stimulus object on the ground (three trials), and infants leaving their mothers' laps (two trials).

2.4.3. Coding infants' touch behavior

Three aspects of infants' touch behavior to the top parts of the stimulus object were coded during each trial: (i) Latency: the elapsed time before infants first made contact with the stimulus object; if infants did not touch the object during the trial, this was coded as the maximum trial length of 30 seconds, (ii) First Touch Duration: the duration of infants' first touch of the stimulus object, (iii) Touch Frequency (thorny stimuli only): how frequently infants touched the different parts of the stimulus object in the 5 second window after their initial contact with it (i.e., number of touches to thorny areas, non-thorny areas, and both types of areas simultaneously).

Latency and First Touch Duration were initially coded for infants' first touch to the top part of all of the stimulus objects regardless of whether that touch contacted a thorny or non-thorny part of that object. Subsequently, infants' Latency and First Touch Duration were coded separately for first touches to the thorny and non-thorny parts of the stimulus objects (e.g., latency to the first touch of a thorny area, and latency to the first touch of a non-thorny area). Touch Frequency was coded only for the thorny stimulus objects because these were the only stimulus objects with separate thorny and non-thorny parts.

2.4.4. Interrater reliability

A randomly selected 25% of the videos were coded by a second independent coder. Coder agreement was high for all dependent variables: Latency (Pearson's correlation $r = .97$), First Touch Duration (Pearson's correlation $r = .94$), and Touch Frequency ($\kappa = .91$).

2.4.5 Coding experimenter behavior

In order to assess whether the experimenter's behavior during the object presentation phase may have inadvertently influenced infants, a randomly selected third of the videos were coded by two independent coders who rated the experimenter's behavior during each trial. The videos were first edited to remove the portion that showed the stimulus object so that the coders were blind to trial type. Based on the experimenter's facial expressions and movements the coders rated the expected object type that was presented (plant vs. non-plant). A binomial test indicated that the proportion of correctly rated objects was not significantly different from chance (Coder 1 = 51%, Coder 2 = 60%, chance level of 56% given the proportion of plant to non-plant objects in the stimulus set; *p's* > .05 for both coders). In addition, the agreement between the two coders was very low for the presented objects (Cohen's $\kappa = -.10$) suggesting that the experimenter did not systematically give cues to participants that could systematically affect their responses.

2.5. Parent questionnaires

After the presentation phase of the study, parents completed questionnaires assessing their infants' prior experience with plants generally (Elsner & Wertz, 2019; Wertz & Wynn, 2014a; 2014b), thorny plants specifically, and the familiar artifacts used in the study. The set of questions related to infants' general experience with plants was assessed separately for indoor and outdoor plants as well as for two time points (last summer vs. last several months). Parents also completed questionnaires assessing their own knowledge about plants, as well as 5 subscales of an infant temperament questionnaire (IBQ-R; Gartstein & Rothbart, 2003). The order of the questionnaires was randomized across participants (See Supplementary Section *6* for further details).

3. Results

In order to test whether infants exhibit a behavioral avoidance strategy for plants, and examine whether such a strategy is influenced by the presence of thorns, we assessed infants' initial reaching for and subsequent manual exploration of the presented stimulus objects. Descriptive statistics for our outcome variables, Latency, First Touch Duration, and Touch Frequency, are provided in Table 1. Preliminary analyses showed that there were no main effects of block order, except in the case of the touch frequency analysis. The analyses were performed with R (R version 3.3.2; R Core-Team, 2016). In all analyses, we used a linear mixed-effects approach (Baayen, Davidson, & Bates, 2008; Bates, Mächler, Bolker, & Walke, 2014).

3.1. Latency

In order to test the prediction that infants would take longer to touch plants compared to other objects, we assessed the effect of Object Type on the time elapsed before infants first made contact with the different types of stimulus objects (Latency; see Table 1 for the descriptive statistics). Latency values were log transformed to correct for non-normality and analyzed with a linear mixed-effects model using a Gaussian distribution (*lmer* function from R-package *lme4;* Bates et al., 2014). In the model, participants were treated as random effects, whereas Object Type (Plants, Novel Artifacts, Familiar Artifacts) and Thorniness (Thorny vs. Non-thorny Objects) as well as their interaction served as within participant fixed-effects. In addition, Age was included in the models as a control variable to examine whether infants responded differently across our 8- to 18-month-old age range. Omnibus effects were calculated based on Type II model comparisons (using the ANOVA function in the R-package *car*; Fox & Weisberg, 2011). Post hoc analyses were carried out using single-degree-of-freedom contrasts based on the cell mean estimates in separate models with the same parameters (*glth* function from R-package *multicomp;* Hothorn, Bretz, & Westfall, 2008).

Table 1. Descriptive statistics for latency, first touch duration, and touch frequency

	Latency		First Touch Duration		Touch Frequency (Thorny Objects Only)		
	Thorny Objects	Non-thorny Objects	Thorny Objects	Non-thorny Objects	Thorny Parts	Both Parts	Non-thorny Parts
Plants	13649 (3861)	9628 (2723)	705 (166)	666 (157)	0.3 (0.1)	0.4 (0.2)	0.9 (0.3)
Novel Artifacts	3684 (1042)	4062 (1149)	564 (115)	1854 (409)	0.8 (0.3)	1.2 (0.3)	2.2 (0.5)
Familiar Artifacts	5371 (1519)	6407 (1833)	953 (194)	1554 (331)	1.8 (0.4)	0.8 (0.2)	1.1 (0.3)

Note. Standard errors are provided in parentheses.

Main and interaction effects are presented in Table 2. The results showed a significant main effect of Object Type. As predicted, infants took significantly longer to touch plants than other object types. The latency for plants was significantly longer than the latency for both novel artifacts ($t = 5.14$, $p < .001$) and familiar artifacts ($t = 3.16$, $p < .01$; see *Figure 2*). In addition, there was a trend that the latency for familiar objects was longer than the latency for novel artifacts ($t = 1.96$, $p = .05$). There was no main effect of Thorniness nor was there a Thorniness by Object Type interaction. There was also no main effect of infant age.

Table 2. ANOVA results for linear mixed-effect models for the latency and first touch duration.

Effect	Latency	First Touch Duration

	F(df, dfres)	*p*	F(df, dfres)	*p*
Thorniness	0.02(1,204)	>.05	14.33(1,167)	<.001***
Object Type	13.43(2,204)	<.001***	4.63(2,165)	<.05*
Age	1.11(1,40)	>.05	0.003(1,37)	>.05
Thorniness x Object Type	0.89(2,204)	>.05	5.39(2,162)	<.01**

Note. F values (latency and first touch duration) for effects using Type II Wald F tests with Kenward-Roger df. Asterisks indicate significant results.

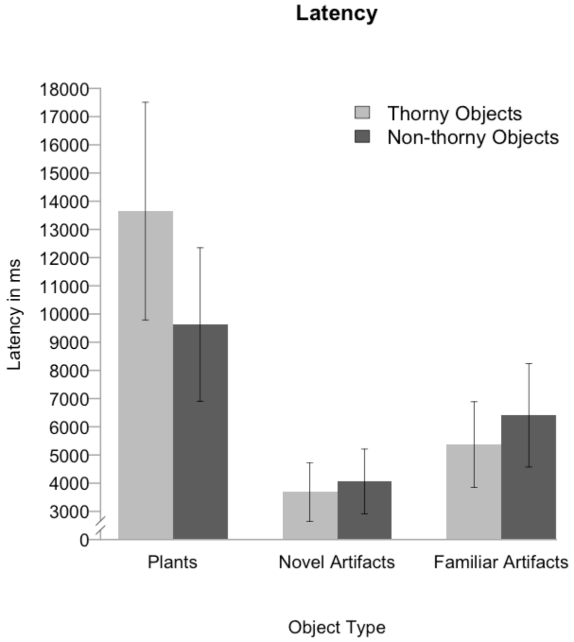


Figure 2. Back-transformed mean latency until the first touch to any top part of the different object types. Error bars represent standard errors.

In addition, consistent with the prediction that infants minimize physical contact with plants, a nonparametric Friedman's ANOVA indicated that the number of trials without a touch was significantly affected by Object Type ($\chi2(2) = 14.11$, $p < .01$). The percentage of "no-touch" trials per object type were as follows: 25% for novel artifacts, 20% for familiar artifacts, and 42% for plants. Wilcoxon sign-ranked tests showed that there were significantly more no-touch trials for plants (Mdn = 1.5) compared to novel artifacts (Mdn = 0; Z = -3.49, $p < .001$, $r = - .38$) and familiar artifacts (Mdn = 0; Z = -3.28, $p < .01$, $r = - .36$), but there was no difference between the amount of no-touch trials for novel artifacts (Mdn = 0) and familiar artifacts (Mdn = 0; Z = -.96, $p > .05$, $r = - .10$). Because our main prediction was that infants would avoid touching plants we anticipated that there would be no-touch trials and therefore included these no-touch trials in the linear mixed effects model above. However, analyzing the latency data excluding the no-touch trials yielded a similar pattern of results (see SI section *4* for further details).

These results show that as predicted, infants take longer until they make contact with plants compared to both novel artifacts and familiar artifacts, replicating previous results (Wertz & Wynn, 2014a). However, the presence of thorns did not significantly impact the timing of infants' initial reach for any of our stimulus objects, including the plants.

3.2. First touch duration

Next, in order to examine whether infants showed minimized subsequent physical contact with plants in addition to an initial reluctance to touch, we analyzed the effects of Object Type and Thorniness on the duration of infants' first touch to the top part of the objects (i.e., First Touch Duration). In this analysis, we were interested in the duration of the touches that occurred, therefore we excluded trials without a touch from the analysis. Again, raw durations were log transformed and analyzed with a linear mixed-effects model using a Gaussian distribution. Infant participants were modeled as random effects, whereas Object Type (Plants, Novel Artifacts, Familiar Artifacts) and Thorniness (Thorny vs. Non-thorny

Objects) as well as their interaction were treated as within participant fixed-effects. We also used Age as a control variable.

Main and interaction effects are presented in Table 2. The results showed a significant main effect of Object Type and Thorniness, as well as a significant interaction effect for Object Type and Thorniness. As in the latency analyses, there was no effect of infant age. Consistent with the prediction that infants minimize subsequent physical contact with plants, infants spent less time in contact with plants compared to non-plant objects. Post-hoc cell-mean comparisons revealed that First Touch Duration was shorter for plants compared to both novel artifacts (t = 2.08, $p < .05$) and familiar artifacts (t = 3.01, $p < .01$; see *Figure 3*).

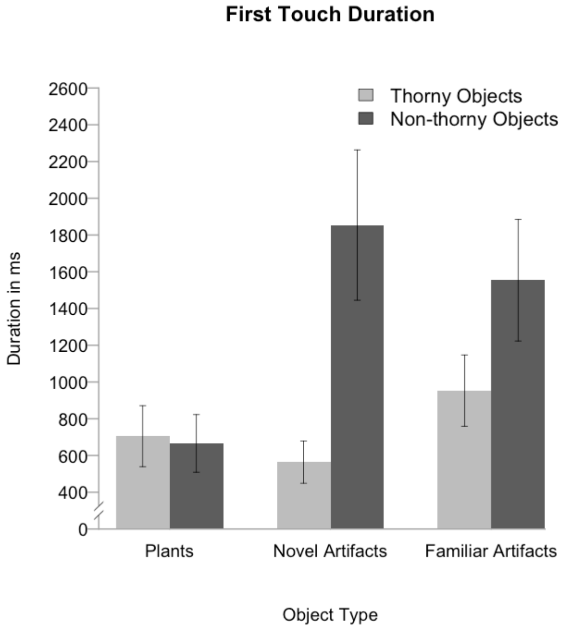


Figure 3. Back-transformed mean first touch duration for the different object types. Error bars represent standard errors.

Moreover, infants spent less time in contact with the thorny objects than the non-thorny objects ($t = 3.52$, $p < .001$). However, the interaction effect of Object Type and Thorniness was explained by different effects of thorniness across the object types. Thorniness affected infants' behavior towards artifacts but not plants. Infants spent significantly less time touching thorny novel artifacts than non-thorny novel artifacts ($t = 4.63$, $p < .001$). The same trend was found for familiar artifacts ($t = 1.93$, $p = .05$). Yet, the duration of the first touch did not differ significantly between thorny and non-thorny plants ($t = 0.20$, $p > .05$), mirroring the results from the latency analysis indicating that infants treat all plants as potentially dangerous.

Follow-up comparisons further support this interpretation. Although infants spent less time in contact with thorny objects than with non-thorny objects, we did not find differences in First Touch Duration between thorny plants compared to both thorny novel and thorny familiar artifacts (*p's* >.05); there was a difference between thorny novel and thorny familiar artifacts ($t = 2.12$, $p < .05$). However, for the non-thorny objects, First Touch Duration was shorter for plants compared to novel artifacts ($t = 3.72$, $p < .001$) and familiar objects ($t = 3.12$, $p < .01$), but First Touch Duration did not differ between novel and familiar artifacts ($t = .67$, $p > .05$).

Taken together, these results are consistent with the prediction that infants minimize their subsequent physical contact with plants compared to novel and familiar artifacts. Moreover, although infants spend less time touching thorny artifacts, they treat thorny and non-thorny plants the same.

3.3. Touch frequency to specific parts of the objects (thorny objects only)

To investigate the effect of thorns on infants' subsequent manual exploration in more detail, we assessed the effect of Object Type on touch frequency to specific parts of the thorny objects (i.e., the number of touches to thorny parts, non-thorny parts, and touches that contact both parts at the same time; see Figure 4). The data were analyzed using generalized linear models with a Poisson distribution and a correction for overdispersion due to zero-inflation (g*lmer* function from R-package *lme4;* Bates et al., 2014). In the model, infant participants and an individual variable correcting for over dispersion were treated as random effects, whereas Object Type (Plants, Novel Artifacts, Familiar Artifacts) and Place of Touch (Thorny, Non-thorny, Both) as within participant fixed-effects. In addition, Age and Block Order was included as a control variable.

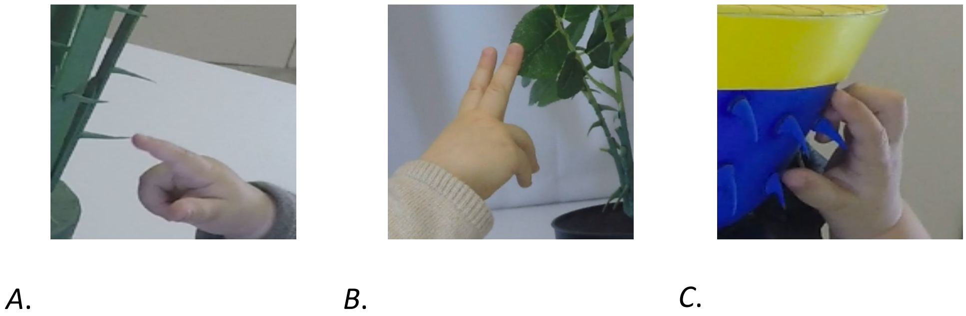


Figure 4. Different types of touches to the thorny objects included in the touch frequency analysis. These were touches that contacted thorny parts (Panel *A*) non-thorny parts (Panel *B*), and both parts at the same time (Panel *C*).

Main and interaction effects are presented in Table 3. The results showed a main effect of Object Type, and a main effect of Place of Touch, as well as an interaction effect of Object Type and Place of Touch. Overall, consistent with the prediction that infants minimize physical contact with plants, infants touched plants less frequently compared to both novel artifacts ($t = 5.89$, $p < .001$) and familiar artifacts ($t = 5.007$, $p < .001$; see *Figure 5*). There was no difference in amount of touches between the non-plant objects ($t = 1.42$, $p > .05$). As in the previous analyses, there was no effect of age. However, unlike the other analyses, we found a main effect of presentation order (thorny objects presented first vs. non-thorny objects presented first). Infants touched the stimuli more frequently when non-thorny objects were presented first compared to when thorny objects were presented first ($t = 2.90$, $p < .01$).

Table 3. ANOVA results for generalized linear mixed-effects models for touch frequency.

Effect	Frequency	
	$\chi 2$(df)	*p*
Place of Touch	19.62(2)	<.001***
Object Type	42.09(2)	<.001***
Age	0.01(1)	>.05
Order	5.10(1)	<.05*
Place of Touch x Object Type	33.84(4)	<.001***

Note. $\chi 2$ values (frequency) for effects using Type II Wald F tests with Kenward-Roger df. Asterisks indicate significant results.

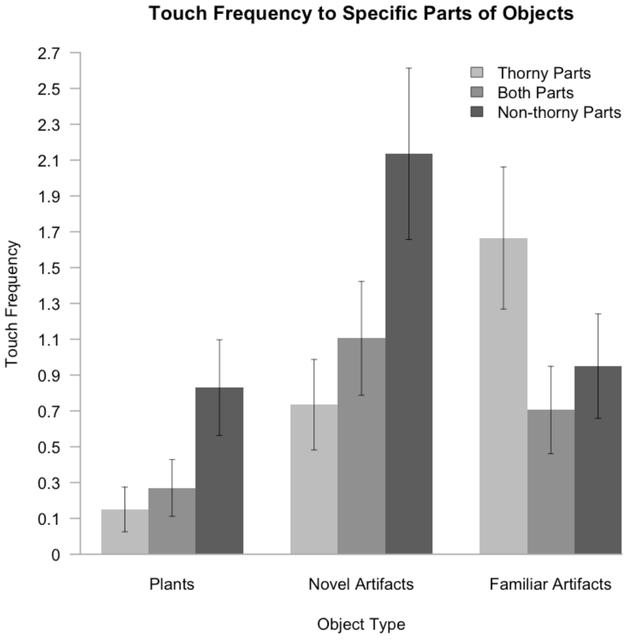


Figure 5. Back-transformed touch frequency to specific parts of the objects (thorny objects only). Error bars represent standard errors.

Next, we directly compared infants' touch frequencies to specific object parts. Infants touched thorny parts of plants less frequently than the thorny parts of novel artifacts (*t* = 3.20, *p* < .01) and familiar artifacts (*t* = 4.50, *p* < .001). Interestingly, infants touched the thorny parts of familiar artifacts more often compared to novel artifacts (*t* = 2.93, *p* < .01), indicating that they do not systematically avoid thorny shapes in all contexts. The results were similar for infants' touches that contact both thorny and non-thorny parts simultaneously (hereafter "both" touches). Infants touched both parts of plants less frequently than both parts of novel artifacts (*t* = 4.11, *p* < .001) and familiar objects (*t* = 2.52, *p* < .05). However, there was no difference in the amount of both touches to novel and familiar artifacts (*t* = 1.88, *p* = .10). Finally, infants touched the non-thorny parts of plants (*t* = 4.24, *p* < .001) and familiar artifacts (*t* = 3.76, *p* <

.001) less often than novel artifacts. There was no difference in touch frequency for the non-thorny parts of plants and familiar artifacts ($t = 0.56$, $p = 0.60$).

These results provide additional support for the prediction that infants minimize subsequent physical contact with plants: Infants touched plants less frequently overall than other object types. The comparisons of touches to specific parts of the thorny objects suggest that infants particularly avoid touching thorny parts of plants compared to the thorny parts of novel and familiar artifacts.

Given that we found the first hint that infants particularly avoid touching the thorny parts of plants, we decided to do a more fine-grained analysis of how the location of infants' touch impacts the latency and the first touch duration. We provide a brief summary here and report the full results in Supplementary Section 5. When analyzing the latency until infants' first touch to specific parts of the objects (i.e., thorny parts of the thorny objects, non-thorny parts of the thorny objects, and the non-thorny objects), the results showed additional evidence of the impact of thorns on infants' behavior. Infants' took longer to touch the thorny and non-thorny parts of the thorny plants compared to their first touch of the non-thorny plants. Infants showed a similar pattern of response for novel artifacts, even though they took longer overall to touch plants. However, infants reached more quickly for the thorny parts of familiar artifacts, suggesting that infants do not avoid thorns in all contexts.

Similarly, when analyzing the duration of infants' first touch to specific parts of the objects, infants did not differ in the amount of time they remained in contact with the different parts of plants after first touching them. In contrast, infants spent less time in contact with thorny novel artifacts compared to non-thorny ones, but spent more time touching the thorny parts of the thorny familiar artifacts than the non-thorny parts. In fact, infants spent the same amount of time in contact with the thorny parts of familiar artifacts after first touching them as the non-thorny familiar artifacts (see Supplementary Section *5* for further details).

3.5. Questionnaire analyses

These analyses assessed whether infants' prior experiences influenced their behavior toward our stimulus objects. We were particularly interested in infants' prior experience with plants generally, thorny plants specifically, and the familiar artifacts used in the study. Additionally, we assessed parents' self-reported knowledge about plants, as well as an infant temperament (IBQ-R; Gartstein & Rothbart, 2003) in relation to infants' responses.

Correlational analyses revealed that most of the questionnaire measures used in the study were not systematically related to Latency, First Touch Duration, and Touch Frequency (see Supplementary Section *6* for further details of the questionnaire analyses). Among a small number of significant correlations which held after the correction for multiple comparisons, the majority were related to infants' behavior towards novel and familiar artifacts, but not plants (e.g., infants who scored higher on the Approach subscale of the temperament questionnaire had shorter latencies to touch familiar artifacts; see Supplementary Section *6* for further details).

Importantly, our questionnaires asked about how often parents stopped their infant from touching plants. We asked this question about plants generally and thorny plants specifically. Almost none of the correlations between parental prohibition and infants' behavior towards plants (or any of the other stimulus objects) were significant. The only significant correlations between parental prohibition and infants' behavior towards plants which persisted after the correction for multiple comparisons (p-value < .0042) were the correlation between parental prohibition of touching outdoor plants in the last summer months and touch frequency for the non-thorny parts of thorny plants (*r* = -.60, *p* = .003), as well as the correlation between parental prohibition of touching outdoor plants in the last several months and the touch frequency for the non-thorny parts of thorny plants (*r* = -.67, *p* = .0005). Additionally, there was a significant correlation between parental prohibition of touching outdoor plants in the last summer months and infants' touch frequency for the non-thorny parts of thorny familiar artifacts (*r* = .57, *p* = .004).

Further, although the correlations did not persist through the corrections for multiple comparisons, a hint of a relationship was found in positive correlations between parental prohibition of touching plants generally and infants' latency to touch thorny plants (prohibit touching indoor plants in the last several months *r* = .34, *p* = .03; prohibit touching outdoor plants in the last several months *r* = .36, *p* =.02; prohibit touching outdoor plants in the last summer months *r* = .33, *p* =.03), but there was no correlation with infants' latency to touch non-thorny plants (all *p's* > .05). However, it is important to keep in mind that these correlations did not persist after the correction for multiple testing, and we found no correlation between parental prohibition to touch thorny plants specifically and infants' latency to touch thorny plants or infants' touch frequency for non-thorny as well as thorny plants (all *p's* > .05).

In summary, we found some evidence that prohibition experience influences infants' subsequent manual exploration of thorny plants—although the correlations only held for the non-thorny parts of these thorny plants. The more often infants were prohibited from touching outdoor plants in general the less frequently they touched non-thorny parts of thorny plants. We also found the hints that parental prohibition may be associated with increased reluctance to touch thorny plants. However, these relationships were weak and there is no evidence that prohibition experience influences infants' behavior toward non-thorny plants. This lack of association with non-thorny plants is consistent with previous datasets that also looked for, but failed to find a relationship between parental prohibition and infants' initial reaching behavior towards benign-looking plants (Elsner & Wertz, 2019; Wertz & Wynn, 2014a).

4. Discussion

The findings presented here provide evidence that 8- to 18- month-old infants possess a behavioral avoidance strategy that minimizes their exposure to plant threats. The results replicate previous findings showing that infants are reluctant to touch plants compared to other types of entities (Elsner & Wertz, 2019; Wertz & Wynn, 2014a) and reveal two important and novel dimensions to this behavioral avoidance strategy. First, the current results show that the behavioral avoidance strategy towards plants in infancy includes both an initial reluctance to touch and a minimization of subsequent physical contact with plants. Specifically, infants spend less time in contact with plants after first touching them and touch plants less frequently than other types of entities. Second, infants treat all plants as potentially dangerous, whether or not the plant possesses observable threats (i.e., thorns).

4.1. Implications for the design of human adaptations to mitigate plant dangers

The current findings add to a growing body of literature on responses to ancestrally-recurrent threats in infancy and early childhood (e.g., Barrett & Broesch, 2012; Barrett et al., 2016; LoBue & DeLoache, 2008; LoBue, 2010a; Rakison & Derringer, 2008) and support our argument that the structure of the behavioral avoidance strategy is designed around the fact that plants are rooted to the ground and therefore cannot inflict costs unless they are approached. Avoiding contact with plants in the way we have demonstrated here would be an effective protective strategy because it reduces the risk of poisoning and physical injury from chemical and physical plant defenses. This type of strategy operates alongside other protective mechanisms (e.g., enzymatic detoxification pathways, Hagen et al., 2009; neophobia, Rioux at al., 2016; pregnancy sickness, Profet, 1992) to mitigate the dangers that plants pose.

Prior to running the current experiment, it was unclear whether the reluctance infants showed towards touching benign-looking plants found in previous studies (e.g., Wertz & Wynn, 2014a) would become more pronounced for plants that possessed observable visible indicators of threat (i.e., sharp-looking thorns). Our results indicate that visible indicators of plant threat in fact do not significantly increase infants' reluctance to touch plants nor significantly reduce the duration of infants' initial physical contact with plants. This suggests that the structure of the behavioral avoidance strategy in infancy is to initially treat all plants as potentially dangerous—whether they are benign-looking or covered in thorns. We argue that this design likely reflects the fact that plants (i) manufacture a variety of chemical defenses against herbivores, but (ii) do not reliably signal human-relevant toxicity via predictive color patterns or shapes (Keeler & Tu, 1983; Palo & Robbins, 1991). Therefore, the visual appearance of a plant is not a good indicator of whether or not it is dangerous.

While infants treat plants with and without thorns similarly, our results show that 8- to 18-month-olds nevertheless do appear to be sensitive to the potential harm that pointed thorns can inflict. Interestingly, this is evident at the later stages of object exploration. Even as infants touch plants less frequently overall than other object types, they particularly avoid touching sharp-looking thorns on both plants and novel artifacts, similar to previous findings demonstrating an avoidance of sharp-angled forms (e.g., Bar & Neta, 2006; Munar et al., 2015; Silvia & Barona, 2009). This pattern of results suggests that infants avoid all plants during their initial approach when the uncertainty regarding plant properties is the highest, and then show a more fine-grained avoidance of potentially injurious forms on plants and novel artifacts. This strategy would protect infants from the risk of being hurt initially and prevent further damage during subsequent contact. However, infants in our experiment did not simply avoid pointed shapes in any context: They touched the pointed parts of the familiar artifacts more frequently than the non-pointed parts of those objects. This is consistent with previous work showing that, in the case of manmade artifacts, infants only avoid pointed shapes after having an adverse experience with them (LoBue, 2010b).

It is important to underline that despite arguing that infants possess a behavioral avoidance strategy for plants, we do not claim that avoiding plants entails an affective fear response. Work investigating the physiological correlates of infants' responses to snakes—another ancestrally recurrent danger—found that infants' perceptual sensitivity to snakes was not accompanied by physiological indicators of fear or aversion (Thrasher & LoBue, 2016). Therefore, fear is not necessarily a reaction to all types of ancestrally recurrent dangers. However, we did not specifically measure affective or autonomic responses in the current study so this question remains to be investigated in future studies.

4.2. Is the behavioral avoidance strategy about plants per se?

We argue that infants in the current experiment are exhibiting a behavioral avoidance of plants, but is it possible that infants are responding to some other category of entity? The design of our stimuli allows us to speak to several alternate explanations for our findings. First, infants' avoidance of plants cannot be explained by avoidance of more general shape or color features. The novel artifacts were designed to match to the overall shape of the plants, the shapes of specific plant parts (i.e., leaves), and the green color of the plants. Infants did not avoid these features when they were present in the novel artifacts, but they did avoid the plant stimuli. It is still an open question what combination of features infants use to identify an object as a plant, but our results show that infants' avoidance is not merely a consequence of reacting to specific shape or color features. Second, infants in our study did not respond differently to novel compared to familiar entities more generally, ruling out explanations that infants were simply responding to a broader category of familiar compared to unfamiliar entities. Overall, there is now growing evidence for a plant-specific behavioral avoidance strategy across several studies using a range of different stimuli (Elsner & Wertz, 2019; Wertz & Wynn, 2014a). Nevertheless, it may be that future work uncovers a plausible alternative account of these findings.

4.3. Limitations and future directions

The present study has certain limitations. It was conducted in a large urban area with infants whose everyday interactions with plants are limited. It is unclear whether infants and young children who have much richer direct contact with plants and can learn about them from adults who have extensive knowledge about the local vegetation would respond differently. Future cross-cultural work can address this question by assessing the responses to plants in infants and children from modern hunter-gatherer or horticultural societies using a similar experimental design. Additionally, the current study was conducted in a controlled laboratory environment in which infants were seated comfortably on their parent's lap while an adult placed plants and other objects within their reach. Therefore, it is unclear whether we have captured the maximum level of avoidance towards plants that infants may exhibit in real-world environments—if anything, the current study may underestimate the magnitude of the avoidance. An important future direction will be to explore how the behavioral avoidance strategy for plants we observed in the lab operates in more naturalistic settings.

Moreover, the current results reflect infants' baseline responses to plants prior to receiving specific social cues from adults. A critical future step will be to assess infants' responses after they have received clear social information that a plant is harmful to touch. It is well established that infants use information from others to regulate their own behavior (e.g., Baldwin & Moses, 1996) and that social information plays a crucial role in threat perception (LoBue et al., 2010) and danger learning (e.g., Barrett et al., 2016). Importantly, human adaptations for plants are predicted to include social learning procedures as an integral part of their design (Wertz & Wynn, 2014a; 2014b). Correspondingly, there is evidence that infants differentially seek out social information when confronted with plants (Elsner & Wertz, 2019) and use social information to learn about plants (e.g., learning about plant edibility; Wertz & Wynn, 2014b).

The current study provided some evidence that social information may impact infants' responses to thorny plants. Specifically, infants whose parents reported prohibiting them from touching plants exhibited fewer touches to thorny plants. Interestingly, there was no correlation between parental prohibition and infants' responses to benign-looking plants. This lack of correlation with parental prohibition and benign-looking plants is consistent with previous results (Elsner & Wertz, 2019; Wertz & Wynn, 2014a), and suggests that social cues from adults may play a particular role in infants' responses specifically to thorny plants. Clearly, there is much left to explore about influence of social information on infants' responses to plants.

4.4. Conclusion

Our findings add to a growing body of evidence about infants' responses to ancestrally-recurrent threats by demonstrating novel aspects of infants' behavioral avoidance strategy for plants. This strategy serves to mitigate potential harm from plants, whether or not they possess visible indicators of threat, and provides a base from which subsequent social learning processes can operate.

Acknowledgements

This work was funded by the Max Planck Society.

References

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and* Language, 59(4), 390-412.

Bakker, E. S., Gill, J. L., Johnson, C. N., Vera, F. W., Sandom, C. J., Asner, G. P., & Svenning, J. C. (2016). Combining paleo-data and modern exclosure experiments to assess the impact of megafauna extinctions on woody vegetation. Proceedings of the National Academy of Sciences, 113(4), 847-855.

Baldwin, D. A., & Moses, L. J. (1996). The ontogeny of social information gathering. Child *Development*, *67*(5), 1915-1939.

Bar, M., & Neta, M. (2006). Humans prefer curved visual objects. *Psychological Science*, *17*(8), 645-648.

Barrett, H.C., & Broesch, J. (2012). Prepared social learning about dangerous animals in children. *Evolution and Human Behavior, 33,* 499-508.

Barrett, H. C., Peterson, C. D., & Frankenhuis, W. E. (2016). Mapping the cultural learnability landscape of danger. *Child Development*, *87*(3), 770-781.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. arXiv preprint arXiv:1406.5823.

Begossi, A., Hanazaki, N., & Tamashiro, J. Y. (2002). Medicinal plants in the Atlantic Forest

(Brazil): knowledge, use, and conservation. *Human Ecology*, *30*(3), 281-299.

Broesch, J., Barrett, H. C., & Henrich, J. (2014). Adaptive content biases in learning about animals across the life course. *Human Nature*, *25*(2), 181-199.

Cashdan, E. (1994). A sensitive period for learning about food. *Human Nature*, *5*(3), 279-291.

Cashdan, E. (1998). Adaptiveness of food learning and food aversions in children. *Social Science Information*, *37*(4), 613-632.

Cooper, S. M., & Owen-Smith, N. (1986). Effects of plant spinescence on large mammalian herbivores. *Oecologia*, *68*(3), 446-455.

Cordain, L., Miller, J. B., Eaton, S. B., Mann, N., Holt, S. H., & Speth, J. D. (2000). Plant-animal subsistence ratios and macronutrient energy estimations in worldwide hunter-gatherer diets. *The American Journal of Clinical Nutrition*, *71*(3), 682-692.

Coss, R. G. (2003). The role of evolved perceptual biases in art and design. In *Evolutionary aesthetics* (pp. 69-130). Springer, Berlin, Heidelberg.

Crittenden, A. N., Conklin-Brittain, N. L., Marlowe, F. W., Schoeninger, M. J., Wrangham, R.W. (2009). Foraging strategies and diet composition of Hadza children. *American Journal of Physical Anthropology*, 138(S48): 112.

Elsner, C., & Wertz, A.E. (2019). The seeds of social learning: Infants exhibit more social referencing for plants than other object types.

Fantz, R. L., & Miranda, S. B. (1975). Newborn infant attention to form of contour. *Child Development*, 224-228.

Fox, J. & Weisberg, S. (2011). An {R} Companion to Applied Regression (2nd Ed). Sage: Thousand Oaks CA. Retrieved from http://socserv.socsci.mcmaster.ca/jfox/Books/Companion

Fürstenberg-Hägg, J., Zagrobelny, M., & Bak, S. (2013). Plant defense against insect herbivores. *International Journal of Molecular Sciences*, *14*(5), 10242-10297.

Gartstein, M. A., & Rothbart, M. K. (2003). Studying infant temperament via the revised infant behavior questionnaire. *Infant Behavior and Development*, *26*(1), 64-86.

Gowda, J. H. (1996). Spines of Acacia tortilis: what do they defend and how? *Oikos*, 279-284.

Greenwald, A. M., Eerkens, J. W., & Bartelink, E. J. (2016). Stable isotope evidence of juvenile foraging in prehistoric Central California. *Journal of Archaeological Science: Reports*, *7*, 146-154.

Guo, S.X., Sha, J.G., Bian, L.Z., & Qiu, Y.L. (2009). Male spike strobiles with Gnetum affinity from the Early Cretaceous in western Liaoning, Northeast China. *Journal of Systematics and Evolution*, *47*(2), 93-102.

Gurven, M., Allen-Arave, W., Hill, K., & Hurtado, M. (2000). “It's a wonderful life”: signaling generosity among the Ache of Paraguay. *Evolution and Human Behavior*, *21*(4), 263-282.

Gurven, M., Stieglitz, J., Hooper, P. L., Gomes, C., & Kaplan, H. (2012). From the womb to the tomb: the role of transfers in shaping the evolved human life history. *Experimental Gerontology*, *47*(10), 807-813.

Hagen, E. H., Sullivan, R. J., Schmidt, R., Morris, G., Kempter, R., & Hammerstein, P. (2009). Ecology and neurobiology of toxin avoidance and the paradox of drug reward. *Neuroscience*, *160*(1), 69-84.

Halpern, M., Raats, D., & Lev-Yadun, S. (2007). Plant biological warfare: thorns inject pathogenic bacteria into herbivores. *Environmental Microbiology*, *9*(3), 584-592.

Hardy, K. (2008). Prehistoric string theory. How twisted fibers helped to shape the world. *Antiquity*, *82*(316), 271-280.

Harris, D. R., & Hillman, G. C. (Eds.). (2014). *Foraging and farming: The evolution of plant exploitation* (Vol. 31). Routledge.

Hawkes, K., O'Connell, F., & Jones, N. B. (1995). Hadza children's foraging: juvenile dependency, social arrangements, and mobility among hunter-gatherers. *Current Anthropology*, *36*(4), 688-700.

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world ? *Behavioral and Brain Sciences*, 33, 1-23.

Henry, A. G., Brooks, A. S., & Piperno, D. R. (2014). Plant foods and the dietary ecology of

Neanderthals and early modern humans. *Journal of Human Evolution*, *69*, 44-54.

Hess, U., Gryc, O., & Hareli, S. (2013). How shapes influence social judgments. *Social Cognition*, *31*(1), 72-80.

Hothorn, T., Bretz, F., Westfall, P. (2008). Multicomp: Simultaneous inference for general linear hypotheses. R Package Version 1.3-6. Retrieved from http:// CRAN.R-project.org

Janzen, D. H. (1986). Chihuahuan desert nopaleras: defaunated big mammal vegetation. *Annual Review of Ecology and Systematics*, *17*(1), 595-636.

Kaplan, H., Hill, K., Lancaster, J., & Hurtado, A. M. (2000). A theory of human life history evolution: diet, intelligence, and longevity. *Evolutionary Anthropology: Issues, News, and Reviews*, *9*(4), 156-185.

Karban, R. B., & Baldwin, I. T. (1997) *Induced Responses to Herbivory*. University of Chicago Press.

Keeler, R.F., & Tu, A. T. (Eds.). (1983). *Handbook of natural toxins: Plant and fungal toxins. (Vol. 1).* New York, NY: Marcel Dekker Inc.

Keeling, C. I., & Bohlmann, J. (2006). Genes, enzymes and chemicals of terpenoid diversity in the constitutive and induced defence of conifers against insects and pathogens. *New Phytologist*, *170*(4), 657-675.

Kingsbury J.M. (1983). The evolutionary and ecological significance of plant toxins. In: Keeler RF, Tu AT, editors. *Handbook of natural toxins: Plant and fungal toxins*. Vol. 1. New York, NY: Marcel Dekker, Inc; pp. 675–706.

Kortlandt, A. (1980). How might early hominids have defended themselves against large predators and food competitors? *Journal of Human Evolution, 9*(2), 79-112.

Langenheim, J. H. (1994). Higher plant terpenoids: a phytocentric overview of their ecological roles. *Journal of Chemical Ecology*, *20*(6), 1223-1280.

Larson, C. L., Aronoff, J., & Stearns, J. J. (2007). The shape of threat: simple geometric forms evoke rapid and sustained capture of attention. *Emotion, 7*(3), 526.

Lausberg, H., & Sloetjes, H. (2009). Coding gestural behavior with the NEUROGES-ELAN system. *Behavior Research Methods*, *41*(3), 841-849.

Lee, R. B. (1993). The Dobe Ju/'hoansi (2nd edition). Fort Worth, TX: Harcourt Brace College Publishers.

Lin, J. Y., Arthurs, J., & Reilly, S. (2017). Conditioned taste aversions: From poisons to pain to drugs of abuse. *Psychonomic Bulletin & Review*, *24*(2), 335-351.

LoBue, V. (2010a). And along came a spider: An attentional bias for the detection of spiders in young children and adults. *Journal of Experimental Child Psychology, 107*(1), 59-66.

LoBue, V. (2010b). What's so scary about needles and knives? Examining the role of experience in threat detection. *Cognition and Emotion, 24*(1), 180-187.

LoBue, V., & DeLoache, J. S. (2008). Detecting the snake in the grass: Attention to fear-relevant stimuli by adults and young children. *Psychological Science*, *19*(3), 284-289.

LoBue, V., & DeLoache, J. S. (2010). Superior detection of threat-relevant stimuli in infancy. *Developmental Science*, *13*(1), 221-228.

LoBue, V., Rakison, D. H., & DeLoache, J. S. (2010). Threat Perception Across the Life Span: Evidence for Multiple Converging Pathways. *Current Directions in Psychological Science, 19*(6), 375-379.

Munar, E., Gómez-Puerto, G., Call, J., & Nadal, M. (2015). Common visual preference for curved contours in humans and great apes. *PLoS One, 10*(11), e0141106.

New, J. J., & German, T. C. (2015). Spiders at the cocktail party: An ancestral threat that surmounts inattentional blindness. *Evolution and Human Behavior*, *36*(3), 165-173.

Olivier, J., Otto, T., Roddaz, M., Antoine, P. O., Londoño, X., & Clark, L. G. (2009). First macrofossil evidence of a pre-Holocene thorny bamboo cf. Guadua (Poaceae: Bambusoideae: Bambuseae: Guaduinae) in south-western Amazonia (Madre de Dios—Peru). *Review of Palaeobotany and Palynology*, *153*(1-2), 1-7.

Orrock, J., Connolly, B., & Kitchen, A. (2017). Induced defences in plants reduce herbivory by increasing cannibalism. *Nature Ecology & Evolution*, *1*(8), 1205.

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology: General*, *130*(3), 466.

Palo, R. T., & Robbins, C. T. (1991). *Plant defenses against mammalian herbivory*. CRC Press.

Peters, C. R., O'Brien, E. M., Boaz, N. T., Conroy, G. C., Godfrey, L. R., Kawanaka, K., ... & Smith, E. O. (1981). The early hominid plant-food niche: insights from an analysis of plant exploitation by Homo, Pan, and Papio in eastern and southern Africa [and Comments and Reply]. *Current Anthropology*, *22*(2), 127-140.

Profet, M. (1992). Pregnancy sickness as adaptation: A deterrent to maternal ingestion of teratogens. In Barkow, J. H., Cosmides, L., & Tooby, J. (Eds.). *The adapted mind: Evolutionary psychology and the generation of culture.* Oxford University Press, USA.

Rakison, D. H., & Derringer, J. (2008). Do infants possess an evolved spider-detection mechanism? *Cognition*, *107*(1), 381-393.

Reilly, S., & Schachtman, T. R. (Eds.). (2008). *Conditioned taste aversion: Neural and behavioral processes*. Oxford University Press.

Rioux, C., Picard, D., & Lafraire, J. (2016). Food rejection and the development of food categorization in young children. *Cognitive Development*, *40*, 163-177.

Sikes, N. E. (1994). Early hominid habitat preferences in East Africa: paleosol carbon isotopic evidence. *Journal of Human Evolution, 27(1),* 25-45.

Silvia, P. J., & Barona, C. M. (2009). Do people prefer curved objects? Angularity, expertise, and aesthetic preference. *Empirical Studies of the Arts*, *27*(1), 25-42.

Sugiyama, L. S. (2004). Illness, injury, and disability among Shiwiar forager-horticulturalists: Implications of health-risk buffering for the evolution of human life history. *American Journal of Physical Anthropology*, *123*(4), 371-389.

Team, R. C. (2016). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2016.

Thrasher, C., & LoBue, V. (2016). Do infants find snakes aversive? Infants' physiological responses to "fear-relevant" stimuli. *Journal of Experimental Child Psychology*, *142*, 382-390.

Ungar, P. S., & Sponheimer, M. (2011). The diets of early hominins. *Science, 334*(6053), 190-193.

Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L. B., Leder, H., Modroño, C., ... & Skov, M. (2013). Impact of contour on aesthetic judgments and approach-avoidance decisions in architecture. *Proceedings of the National Academy of Sciences*, *110*(Supplement 2), 10446-10453.

Wertz, A. E., & Wynn, K. (2014a). Thyme to touch: Infants possess strategies that protect them from dangers posed by plants. *Cognition*, *130*(1), 44-49.

Wertz, A. E., & Wynn, K. (2014b). Selective social learning of plant edibility in 6-and 18-month-old infants. *Psychological Science*, *25*(4), 874-882.

Westerman, S. J., Gardner, P. H., Sutherland, E. J., White, T., Jordan, K., Watts, D., & Wells, S. (2012). Product design: Preference for rounded versus angular design elements. *Psychology & Marketing*, *29*(8), 595-605.

Wiener, A., Shudler, M., Levit, A., & Niv, M. Y. (2011). BitterDB: a database of bitter compounds. *Nucleic Acids Research*, *40*(D1), D413-D419.

Supplementary Information

Contents of Supplementary Information

1. *Stimulus Set*

1.1. Plants

All plants were presented in black plastic pots (8.5 cm high, 12 cm in diameter). The top part of the pots was filled with modeling clay and covered with an artificial soil mat. One of the two plant types was made with 29 elongated fabric leaves. Its leafy parts were approximately 16 cm high and 20 cm in diameter. One plant of this type included 52 green pointy-shaped, cactus-like thorns (approximately 2 cm long and 4 mm in diameter).

The other of the two plant types was made with 48 small oval fabric leaves. Its leafy parts were approximately 24 cm high and approximately 28 cm in diameter. One plant of this type had 53 green curved downward, rose-like thorns (approximately 1.5 cm long and 0.5 cm in diameter). All thorns were made from a child-safe modeling clay that remains soft and pliable when it is dry.

1.2. Novel Artifacts

The two novel artifact types were matched to features of the artificial plants. One of the novel artifact types was made from a cylinder-shaped cardboard box (10 cm high, 10.5 cm in diameter) painted green on the top and black on the bottom. Each of these two novel artifacts had 10 wooden popsicle sticks painted green (14 cm high and 1.8 cm wide) protruding from the top part of the cardboard box. One of these green novel artifacts included 52 green pointy elements similar to the thorns on one of the plants (approximately 2 cm long and 4 mm in diameter). These elements were made from child-safe soft-drying modeling clay and glued to the popsicle sticks.

The second novel artifact type was made from the same 48 small oval leaves as one of the plant types. The leaves were painted black and arranged in a spiral along a blue and yellow cardboard cone (21 cm high, 19 cm diameter at the top of the cone and 5 cm diameter at the bottom) set in a blue and yellow cylinder-shaped cardboard box (10 cm high, 10.5 cm in diameter). One of these blue artifacts had 53 blue curved downward thorns that were similar to the thorns on one of the plants (approximately 1.5 cm long and 0.5 cm in diameter). These elements were also made from a child-safe modeling clay and glued to the surface of the cone among the leaves.

1.3. Familiar Artifacts

The familiar artifacts were two pairs of objects. Half of them contained pointed parts that matched the two thorn shapes used on the plants and novel artifacts. All of the familiar artifacts were similar in overall shape. The first pair of familiar artifacts included a wooden hairbrush and a wooden hand mirror. The hairbrush was 25.5 cm long, with a handle (3 cm wide and 11.5 cm long) and pointy-shaped bristles (1.5 cm long) set in a rubber-cushioned pad (7.5 cm wide, 11.5 cm long) glued to the flat wooden part (8 cm wide, 12 cm long). The hand mirror had exactly the same size and color as the hairbrush but instead of the bristles, it had a rectangle (7.5 cm wide, 11.5 cm long) of mirror-like silver wrap glued in the place of the pad with pointy elements. We used this foil instead of a real mirror surface to exclude the possibility that infants would become attracted by their own reflection.

The second pair of familiar artifacts consisted of a children's plastic rake and plastic shovel. The rake was 18.5 cm long, with a 1.5 cm diameter pale blue handle, and three 7.5 cm long pointed grey tines. The shovel had exactly the same size and color as the rake but had a 7.5 cm grey round-shaped bowl instead of tines.

2. Video coding

2.1.Coding „Top" versus „Bottom" part of the stimuli

As we were primarily interested in infant's behavior toward plants not the pots or the soil, we predefined area of interest that contained the "top part" of all stimulus objects including the thorns. These were: the leaves, branches and stems, and thorns of the plants; green popsicle sticks and the thorns of the green artifacts; black leaves, blue and yellow cones and the thorns on the blue artifacts; the grey non-handle parts of the rake and shovel, including the pointed tines on the rake; the flat (non-handle) surface of the hand mirror and the hair brush, including the pointy-shaped bristles on the hair brush.

Touches to the "bottom parts" of the objects were also coded. These were: the pots and the soil of the plants, the cardboard boxes of the novel artifacts, and the handles of the familiar objects.

Infants frequently touched objects with one hand touching both the "top part" and the "bottom part" of the object. Because our predictions and analyses were focused on the "top parts" of the stimuli, we prioritized touches to the "top parts" over the touches of the "bottom parts" of the stimulus objects in the coding scheme when both touch types occurred simultaneously.

3. Data reduction

The start time of each stimulus object presentation and the start time of the first touch to each stimulus object were exported from the ELAN behavioral coding program. We calculated the latency by subtracting the start time of the first touch to the "top part" of each stimulus object from the start time of the particular object presentation in Excel. We also directly exported from ELAN first touch durations to each stimulus object. Based on the exported first touch durations we calculated touch frequency in Excel. Then, we used R (version 3.2.3; https://www.r-project.org/) and SPSS (v.23) to perform the statistical analyses.

4. Latency analysis with "no touch" trials excluded

To assess whether the different amount of "no touch" trials across the object types influenced our Latency results, we analyzed the Latency data excluding the "no touch" trials. As in the Latency analysis with the "no touch" trials included reported in the main text, the raw Latency data with "no touch" trials excluded was log transformed and analyzed with a linear mixed-effects model using a Gaussian distribution and identical R functions. Infant participants were modeled as random effects, whereas Object Type (Plants, Novel Artifacts, Familiar Artifacts) and Thorniness (Thorny vs. Non-thorny Objects) as well as their interaction were treated as within participant fixed-effects. We also used Age as a control variable. Descriptive statistics for Latency is provided in Table 1.

The results showed a significant main effect of Object Type ($F(2, 164) = 8.47$, $p < .001$). Consistent with the latency analysis reported in the main text, infants took significantly longer to touch plants than other object types even when the "no touch" trials are excluded. The latency for plants was significantly longer than the latency for both novel artifacts ($t = 4.14$, $p < .001$) and familiar artifacts ($t = 2.08$, $p < .05$). In addition, the latency for familiar objects was longer than the latency for novel artifacts ($t = 2.22$, $p < .05$). There was no main effect of Thorniness ($F(1,166) = .32$, $p > .05$) nor was there a Thorniness by Object Type interaction ($F(2, 162) = .63$, $p > .05$). There was also no effect of infant age.

This pattern of results is consistent with the analysis of Latency with the "no touch" trials included reported in the main text. As predicted, infants take longer until they make contact with plants compared to both novel artifacts and familiar artifacts, replicating previous results

(Wertz & Wynn, 2014a). However, the presence of thorns did not significantly impact the timing of infants' initial reach for any of our stimulus objects, including the plants.

Table S1. Descriptive statistics for latency with the "no touch" trials included

	Latency	
	Thorny Objects	Non-thorny Objects
Plants	10239 (3591)	6671 (2255)
Novel Artifacts	3004 (895)	2604 (837)
Familiar Artifacts	4475 (1332)	5187 (1591)

Note. Standard errors are provided in parentheses.

5. Analyses of the place of first touch

The results of the Latency and First Touch Duration analyses presented in the main text showed that the presence of thorns did not seem to affect infants' responses to plants. However, the results of the Touch Frequency analysis suggested that infants may avoid touching thorns compared to other parts of plants and novel artifacts. Therefore, we analyzed how the location of infants' touch impacts Latency and First Touch Duration. We included both the thorny and non-thorny stimulus objects in this analysis.

Table S2. Descriptive statistics for infants' latency to touch different parts of the thorny and non-thorny stimulus objects.

	Latency		

	Thorny Parts (Thorny Objects)	Non-thorny Parts (Thorny Objects)	Non-thorny Objects Only
Plants	27371 (5796)	17607 (3729)	9627 (2039)
Novel Artifacts	19669 (4165)	8455 (1790)	4062 (860)
Familiar Artifacts	10237 (2168)	19005 (4024)	6391 (1370)

Note. Standard errors are provided in parentheses.

First, we assessed the effect of Place of First Touch (i.e., thorny parts of the thorny objects, non-thorny parts of the thorny objects, and non-thorny objects) and Object Type on infants' latency to touch. Main and interaction effects are presented in Table S3. Descriptive statistics are provided in Table S2.

Table S3**.** ANOVA results for linear mixed-effect models of the place of first touch analyses for latency and first touch duration.

Effect	Latency		First Touch Duration	
	F(df, dfres)	p	F(df, dfres)	p
Place of First Touch	27.46(2,327)	<.001***	17.74(2,216)	<.001***
Object Type	10.09(2,327)	<.001***	4.09(2,215)	<.05*
Age	0.80(1,40)	>.05	0.11(1,37)	>.05
Place of Touch x Object Type	4.89(4,327)	<.001***	3.29(4,215)	<.05*

Note. F values (latency and first touch duration) for effects using Type II Wald F tests with Kenward-Roger df. Asterisks indicate significant results.

The results showed a significant main effect of Object Type, and a main effect of Place of First Touch, as well as an interaction effect of Object Type and Place of First Touch. Similar to the results for the Latency analysis reported in the main text, infants took significantly longer to touch plants compared to novel artifacts ($t = 4.39$, $p < .001$) and familiar objects ($t = 3.00$, $p < .01$). There was no difference between infants' latency for novel artifacts and familiar artifacts ($t = 1.39$, $p > .05$). Infants' age did not significantly influence latency.

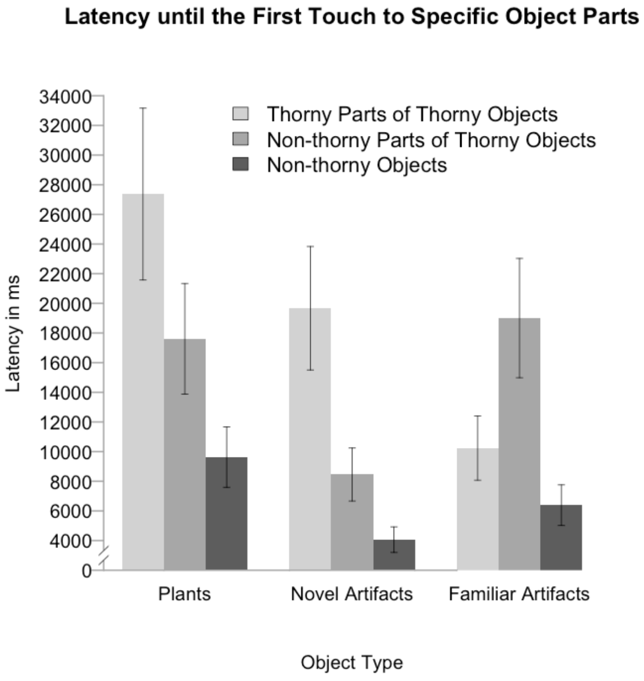
The main effect of Place of First Touch seemed to be driven by the presence or absence of thorns on the stimulus objects. Infants' latency to touch the thorny parts of thorny objects compared to the non-thorny parts of thorny objects was not significantly different ($t = 1.52$, $p > .05$). However, compared to non-thorny objects, infants' exhibited a longer latency to touch the thorny parts of thorny objects ($t = 7.04$, $p < .001$) and the non-thorny parts of thorny objects ($t = 5.52$, $p < .001$).

The significant Object Type and Place of First Touch interaction indicated that infants' latency to touch the different parts of the objects varied by object type (see *Figure 2*). Infants' latency to touch the thorny parts of thorny plants was significantly longer than their latency to touch the non-thorny plants ($t = 4.13$, $p < .001$), but it did not significantly differ from their latency to touch the non-thorny parts of thorny plants ($t = 1.74$, $p > .05$). Additionally, infants took longer to touch the non-thorny parts of thorny plants compared to the non-thorny plants ($t = 2.39$, $p < .05$).

We found a similar pattern of results for novel artifacts. In comparison to their latency to touch the non-thorny novel artifacts, infants took longer to touch the non-thorny parts of thorny novel artifacts ($t = 2.90$, $p < .01$) and the thorny parts of thorny novel artifacts ($t = 6.23$, $p < .001$). However, unlike in the case of plants, infants' latency to touch the thorny parts of thorny novel artifacts was significantly longer than infants' latency to touch the non-thorny parts of thorny novel artifacts ($t = 3.34$ $p < .001$). Importantly, as reported above, overall, infants took significantly longer to touch plants compared to novel artifacts.

Infants' pattern of response was different for the familiar artifacts. In this case, infants' latency to touch thorny parts of thorny familiar artifacts and latency to touch non-thorny familiar artifacts did not differ (*t* = 1.85, *p* > .05). Instead, infants took longer to touch the non-thorny parts of thorny familiar artifacts compared to both the thorny parts of thorny familiar artifacts (*t* = 2.44, *p* < .05) and the non-thorny familiar artifacts (*t* = 4.28 *p* < .001).

Taken together, our results suggest that regardless of the place of first touch, overall, infants take longer to reach out and touch plants compared to other object types. The presence of thorns on plants seems to influence infants' behavior toward the whole object yet not necessarily toward its particular sub-parts (i.e., thorny parts vs. non-thorny parts of the thorny plants). Infants' behavior toward novel artifacts is also influenced by the presence of thorns, however, here thorns influence infants' behavior toward the whole object as well as its specific parts. Although the presence of thorns on familiar artifacts also impacts infants' responses towards these objects, infants appear to readily approach the pointed parts of familiar artifacts.



Latency until the First Touch to Specific Object Parts

Figure2. Back-transformed mean latency for infants' first touch to thorny vs. non-thorny parts of the thorny objects and the non-thorny objects.

Next, we assessed the effect of Place of First Touch (i.e., thorny parts of the thorny objects, non-thorny parts of the thorny objects, and the non-thorny objects) and Object Type on the duration of infants' first touch to the stimulus objects. These analyses included both the thorny and non-thorny stimulus objects. Main and interaction effects are presented in Table S3. Descriptive statistics are provided in Table S4. The results showed significant main effects of Object Type and Place of First Touch, as well as a significant interaction effect of Object Type and Place of First Touch. Additionally, infants' first touch duration was not influenced by age.

The main effect of Object Type was driven by infants' first touch duration being significantly shorter for plants compared to familiar artifacts (t = 2.23, p <.05). However, infants' first touch duration was not different for plants compared to novel artifacts (t = 1.16, p >.05). There was also no difference between infants' first touch duration for novel artifacts and familiar artifacts (t = 1.24, p > .05).

Table S4. Descriptive statistics for infants' first touch duration for different parts of the thorny and non-thorny stimulus objects..

	First Touch Duration		
	Thorny Parts (Thorny Objects)	Non-thorny Parts (Thorny Objects)	Non- thorny Objects Only
Plants	525 (248)	434 (126)	725 (181)

Novel Artifacts	366 (106)	534 (126)	1798 (426)
Familiar Artifacts	1035 (250)	407 (116)	1650 (373)

Note. Standard errors are provided in parentheses.

Similar to the results of the latency analysis reported above the main effect of Place of First Touch again appeared to be due to whether or not the stimulus object had thorns. The duration of infants' first touch was not significantly different for the thorny parts of thorny objects compared to the non-thorny parts of thorny objects ($t = 1.13$, $p > .05$). However, compared to the non-thorny objects, the duration of infants' first touch was shorter for the thorny parts of thorny objects ($t = 3.78$, $p < .001$) and the non-thorny parts of thorny objects ($t = 5.63$, $p < .001$).

The significant interaction showed that the duration of infants' first touch to particular parts of the stimulus objects varied across the different object types (see *Figure 3*). Although infants spent less time in contact with plants overall, there were no differences in first touch duration for any of the places of first touch for both the thorny and non-thorny plants (all *p*'s >.05). Instead, infants spent the same minimal amount of time in contact with plants regardless of where they touched them.

In contrast, the presence of thorns influenced infants behavior towards our novel artifact stimuli. For novel artifacts, consistent with the results reported in the main text, infants seem to particularly minimize contact with thorny novel artifacts. Specifically, compared to the time they spent in contact with the non-thorny novel artifacts, infants spent less time in contact with both the thorny parts of thorny novel artifacts ($t = 4.80$, $p < .001$) and the non-thorny parts of thorny novel artifacts ($t = 4.04$, $p < .001$). However, infants' first touch duration for the thorny parts of thorny novel artifacts was not significantly different from the non-thorny parts of thorny novel artifacts ($t = 1.14$, $p > .05$).

The pattern of response for familiar artifacts was again different. Infants did not minimize contact with the thorny parts of familiar artifacts. In fact, infants spent as much time touching the thorny parts of thorny familiar artifacts as they did touching the non-thorny familiar artifacts ($t = 1.57$, $p > .05$). Further, infants spent less time in contact with the non-thorny parts of thorny familiar artifacts than the thorny parts of thorny familiar artifacts ($t = 2.82$, $p < .01$) and non-thorny familiar artifacts ($t = 4.34$, $p < .001$).

Altogether, consistent with the results reported in the main text, these additional analyses show that the time that infants spend in contact with plants after first touching them is overall lower than the time they spend in contact with artifacts, but does not differ based on the place of touch. Once again, infants do not show different responses to thorny and non-thorny plants. However, there were differences across the different places of touch for the novel and familiar artifacts. Our results suggest that infants minimize contact with thorny novel artifacts, including both their thorny and non-thorny parts. In contrast, infants do not avoid contact with the of thorny parts of familiar artifacts, but instead treat them the same as the non-thorny familiar artifacts.

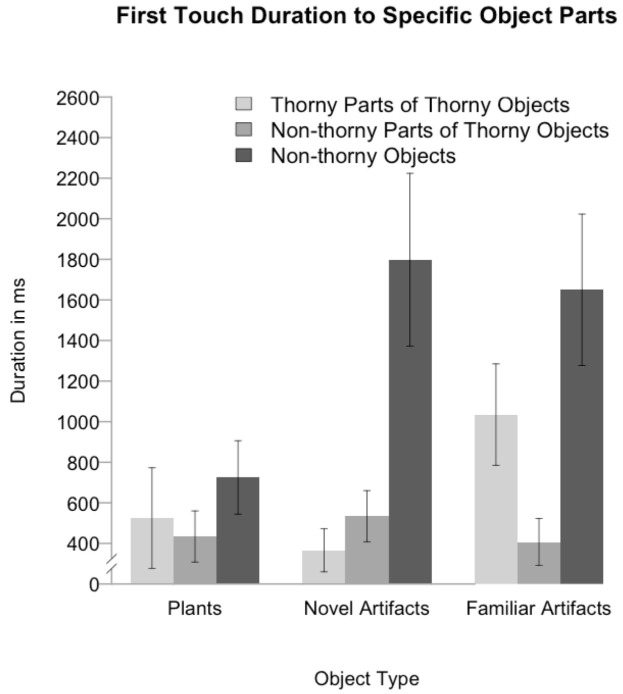


Figure 3. Back-transformed mean touch durations for infants' first touch to the thorny vs. non-thorny parts of the thorny objects and the non-thorny objects.

6. Parent Questionnaires

6.1. Description of questionnaire items

The Plant Interaction Questionnaire (Elsner & Wertz, 2019; Wertz & Wynn, 2014a; 2014b) assessed infants' experience with indoor and outdoor plants during the last several months and during the last summer months. Parents were asked: (i) how often their infant interacts with plants, (ii) how often parents point out or name different plants for their infant, (iii) how often their infant sees them caring for plants, (iv) how often their infant eats from plants, (v) how often their infant tries to touch plants, (vi) how often they stop their child from touching plants. Answers were rated on a five point Likert scale (1 = never, to 5 = nearly every day), separately for in- and outdoor plants as well as two time points (last summer vs. last several months).

Parents also filled out a questionnaire assessing their infants' experience with plants containing thorns, specifically: (i) how often their child tried to touch thorny plants, (ii) how often they have ever stopped their infant from touching thorny plants, (iii) how often they have encouraged their child to touch thorny plants, (iv) how often they have showed their child thorny plants or named them, (v) how often their infant have seen them caring for thorny plants. The items were rated on a five point Likert scale (1 = never, to 5 = nearly every day).

We also asked parents to fill out a questionnaire rating the following questions about their infant's experience with hair brushes, hand mirrors, children's rakes and shovels, specifically: (i) how often their child interacts with X, (ii) how often their child sees their parent interacting with X. The answers were rated on a five point Likert scale (1= never, to 5 = nearly every day).

A questionnaire examining parents' own prior knowledge about plants included the following questions: (i) how much their free time parents spend with plants, (ii) how much their professional time parents spent with plants, (iii) how much on average does the parent know about plants, (iv) how much on average does the parent know about names and different characteristics of plants, (v) how much on average does the parent know about dangerous plants, (vi) how much on average does the parent know about how plants grow. The questions 1 and 2 were rated on a five point Likert scale (1=one or two times per month, to 5= nearly every day) and questions 3- 6 were rated on a three-point scale.

Finally, parents filled out five subscales of the Revised Infant Behavior Questionnaire (IBQ-R; Garstein & Rothbart, 2003): activity level, fear, perceptual sensitivity, approach and duration of orienting. Each of these subscales assesses infants' behavior that could potentially affect the way they manually explore objects (see Table S1 for further details).

Table S5. Scale definitions and the examples of the relevant items on the Revised Infant Behavior Questionnaire.

Activity Level	Gross motor activity, including movement of arms and legs, squirming and locomotor activity. ("When put into the bath water, how often did the baby splash or kick?"
Fear	Startle or distress to sudden changes in stimulation, novel physical objects or social stimuli; inhibited approach to novelty. ("How often during the last week did the baby startle to a sudden or loud noise?"
Duration of Orienting	Attention to and/or interaction with a single object for extended periods of time. ("How often during the last week did the baby stare at a mobile, crib bumper or picture for 5 min or longer?"
Perceptual Sensitivity	Detection of slight, low intensity stimuli from the external environment. ("How often did the baby notice fabrics with scratchy texture (e.g., wool)?")
Approach	Rapid approach, excitement, and positive anticipation of pleasurable activities. ("When given a new toy, how often did the baby get very excited about getting it?")

6.2 Questionnaire analyses

Tables S6-S26 include all the correlations we ran for Latency, First Touch Duration, and Touch Frequency. Here, we discuss all significant correlations which held after the correction for multiple comparisons (corrected alpha level = .0042) that were not discussed in the main text. These correlations capture infants' behavior toward novel and familiar artifacts.

Parents' knowledge about plant names and properties was positively correlated with infants' latency to touch thorny novel artifacts (*r* = .45, *p* = .003), and the amount of parental free time spent with plants was positively correlated with infants' first touch durations for smooth novel artifacts (*r* = .54, *p* = .001). The frequency with which infants tried to touch thorny plants in the last summer months was positively correlated with infants' first touch durations for thorny novel artifacts (*r* = .44, *p* = .005). The frequency with which parents showed their child thorny plants or named them in the last summer months was negatively correlated with infants' touch frequency for thorny parts of thorny familiar artifacts (*r* = -.45, *p* = .009).

Finally, there was also a marginally significant correlation (corrected alpha level .01) between infants' score on the Approach subscale of the infant temperament questionnaire and latency, such that infants who scored higher on the Approach scale were less reluctant to reach out and touch the smooth familiar artifacts (r = -.40, *p* = .01). Infants' score on the Approach subscale was also negatively correlated with infants' touch frequency for "both" parts of thorny familiar artifacts, such that infants who scored higher on the Approach scale touched less often "both" parts of familiar artifacts (*r* = -.54, *p* = .006).

Table S6**.** Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last several months (12 questionnaire items; corrected alpha level 0.0042) and the latency for the thorny and non-thorny objects.

		Latency					
		Plants		Novel Artifacts		Familiar Artifacts	
		Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
	How often…						
Indoor plants	Infant interacts with plants	.11	.27	.24	.01	-.02	-.18
	Parents point out/name plants	.03	.10	.11	.07	.08	-.29
	Infant sees parents caring for plants	.17	.03	.17	.13	.14	-.42 *p* =.01
	Infant eats from plants	.30	.07	.24	.23	.17	.004
	Infant tries to touch plants	.27	.21	.33 *p* =.03	.14	.26	-.24
	Parents stop infant from touching plants	.34 *p* =.03	.10	.28	.35 *p* =.02	.14	-.13
Outdoor plants	Infant interacts with plants	.01	.05	-.01	-.03	-.04	.13
	Parents point out/name plants	.03	-.01	.11	-.03	.09	.14
	Infant sees parents caring for plants	.001	.15	-.11	.04	-.06	.30
	Infant eats from plants	-.14	-.07	.004	-.10	.02	.18
	Infant tries to touch plants	.14	.10	.13	.06	.23	.25
	Parents stop infant from touching plants	.36 *p* =.02	.18	.20	.22	.02	.12

Table S7. Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last summer months (12 questionnaire items; corrected alpha level 0.0042) and the latency for the thorny and non-thorny objects

		Latency					
		Plants		Novel Artifacts		Familiar Artifacts	
		Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
	How often…						
Indoor plants	Infant interacts with plants	.06	.09	.10	-.05	-.10	.05
	Parents point out/name plants	-.06	.02	-.04	-.001	-.13	-.05
	Infant sees parents caring for plants	.11	.05	-.01	-.08	-.05	-.01
	Infant eats from plants	.17	.09	.12	.20	.02	-.02
	Infant tries to touch plants	.01	.001	-.05	-.08	-.10	.12
	Parents stop infant from touching plants	.27	.08	.19	.22	.12	.11
Outdoor plants	Infant interacts with plants	-.02	.05	-.11	-.04	-.11	.27
	Parents point out/name plants	-.07	-.06	-.12	-.17	-.01	.21
	Infant sees parents caring for plants	-.07	.14	-.17	-.04	-.18	.17
	Infant eats from plants	-.16	-.09	-.07	-.14	-.03	.13
	Infant tries to touch plants	-.03	.10	-.08	-.03	-.02	.36 $p = .02$
	Parents stop infant from touching plants	.33 $p = .03$	.17	.18	.08	-.07	.26

Table S8. Summary of the correlations between infant's experiences with the thorny plants in the last several months (5 questionnaire items; corrected alpha level 0.01) and the latency for the thorny and non-thorny objects.

	Latency

	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Infant tries to touch thorny plants	-.16	.09	-.09	-.02	-.03	-.01
Parents stop infant from touching thorny plants	.09	.20	-.03	.19	.01	.22
Parents encourage to touch thorny plants	.05	.14	.10	.05	.18	.09
Parents point out/name thorny plants	-.04	-.02	-.05	.04	.03	-.03
Infant sees parents caring for thorny plants	-.14	-.10	-.11	.01	-.11	-.06

Table S9. Summary of the correlations between infant's experiences with the thorny plants in the last summer months (5 questionnaire items; corrected alpha level 0.01) and the latency for the thorny and non-thorny objects.

	Latency					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Infant tries to touch thorny plants	-.27	-.05	-.29	-.20	-.14	.14
Parents stop infant from touching thorny plants	-.03	.05	-.22	.19	.02	.29
Parents encourage to touch thorny plants	.09	.18	-.08	-.13	-.26	.20
Parents point out/name thorny plants	.07	.04	-.10	.03	-.03	.04
Infant sees parents caring for thorny plants	-.08	-.12	-.11	.12	-.22	-.07

Table S10. Summary of the correlations between parent experience and knowledge about plants (6 questionnaire items; corrected alpha level 0.0083) and the latency for the thorny and non-thorny objects.

	Latency					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Free time spent with plants	.01	.13	.14	-.07	.18	-.08
Professional time spent with plants	.12	-.14	.04	.07	-.17	-.14
Knowledge about plants	-.07	-.21	.17	.09	-.03	-.25
Knowledge about names and properties of plants	.19	-.01	.45* *p* = .003	.17	-.13	-.19
Knowledge about the dangerous properties of plants	.24	.04	.18	.19	.03	.10

Knowledge about plant growth	.04	.12	.12	.12	-.06	-.10

Table S11. Summary of the correlations between infant's experiences with the familiar objects used in the study (8 questionnaire items; corrected alpha level 0.0063) and the latency for the thorny and the non-thorny objects.

	Latency					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Infant interacts with shovel	-.01	.06	-.28	-.09	-.14	.31 *p* = .05
Infant interacts with rake	.09	.21	-.15	.06	.02	.18
Infant interacts with hairbrush	.23	.03	.08	.13	-.003	-.35 *p* = .03
Infant interacts with mirror	.05	.05	.18	.17	.10	-.24
Infant sees parent interacting with shovel	-.21	-.16	-.22	-.18	-.14	.23
Infant sees parent interacting with rake	-.03	-.07	-.15	-.10	-.06	.03
Infant sees parent interacting with hairbrush	-.06	-.15	-.16	.04	-.02	-.20
Infant sees parent interacting with mirror	.02	-.13	.15	.15	.07	-.33 *p* = .03

Table S12. Summary of the correlations between infants' temperament (5 questionnaire items; corrected alpha level 0.01) and the latency for the thorny and non-thorny objects.

	Latency					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Activity Level	-.13	-.07	-.24	-.13	-.17	.30
Fear	-.09	-.09	.06	-.02	-.08	.32 *p* = .04
Duration of Orientation	.08	.06	.11	-.07	-.11	-.18

Perceptual Sensitivity	.23	.27	.26	.10	.18	.03
Approach	-.13	.23	-.13	.04	-.24	-.40* *p* = .01

Table S13. Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last several months (12 questionnaire items; corrected alpha level 0.0042) and the first touch duration for the thorny and non-thorny objects.

		First Touch Duration					
		Plants		Novel Artifacts		Familiar Artifacts	
		Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
	How often…						
Indoor plants	Infant interacts with plants	-.08	-.17	.06	-.25	-.06	.21
	Parents point out/name plants	.07	-.01	.04	.07	.02	.16
	Infant sees parents caring for plants	-.10	-.08	-.05	.08	-.10	.12
	Infant eats from plants	-.15	-.06	.13	-.33	-.17	-.08
	Infant tries to touch plants	-.08	-.16	.11	-.30	-.14	.16
	Parents stop infant from touching plants	-.13	.19	.12	.18	-.10	-.17
Outdoor plants	Infant interacts with plants	.04	.20	.003	.16	-.02	.23
	Parents point out/name plants	-.01	.11	-.18	.06	-.08	.20
	Infant sees parents caring for plants	.01	.16	.17	.10	.11	-.14
	Infant eats from plants	.15	-.03	.19	.18	-.11	-.01
	Infant tries to touch plants	-.03	.24	-.23	.24	-.12	.23
	Parents stop infant from touching plants	-.28	.22	-.02	.25	.05	.09

Table S14. Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last summer months (12 questionnaire items; corrected alpha level 0.0042) and the first touch duration for the thorny and non-thorny objects.

		First Touch Duration

		Plants		Novel Artifacts		Familiar Artifacts	
		Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
	How often…						
Indoor plants	Infant interacts with plants	.06	.21	.25	-.12	-.01	.01
	Parents point out/name plants	.13	.22	.11	.36 *p* = .04	.25	.05
	Infant sees parents caring for plants	-.08	.12	-.04	-.02	-.12	.04
	Infant eats from plants	.11	.11	.29	-.15	.07	-.14
	Infant tries to touch plants	.11	.06	.08	-.05	.14	.13
	Parents stop infant from touching plants	-.08	.27	.15	.32	-.08	-.05
Outdoor plants	Infant interacts with plants	-.05	.13	.15	.01	.21	.04
	Parents point out/name plants	-.02	.06	.17	.06	.14	.07
	Infant sees parents caring for plants	.18	.15	.21	.07	.25	-.05
	Infant eats from plants	.15	-.06	.28	.11	.05	.01
	Infant tries to touch plants	.03	.19	.09	.07	.23	.07
	Parents stop infant from touching plants	-.15	.35	-.05	.08	-.09	.03

Table S15. Summary of the correlations between infant's experiences with the thorny plants in the last several months (5 questionnaire items; corrected alpha level 0.01) and the first touch duration for the thorny and non-thorny objects.

	First Touch Duration					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Infant tries to touch thorny plants	-.13	-.02	.02	-.04	.17	-.10
Parents stop infant from touching thorny plants	-.17	.28	.02	.22	.01	-.16

Parents encourage to touch thorny plants	.05	.10	.13	-.22	-.26	.15
Parents point out/name thorny plants	-.08	-.10	-.11	-.15	.03	-.05
Infant sees parents caring for thorny plants	.08	.09	.08	-.13	-.13	.05

Table S16. Summary of the correlations between infant's experiences with the thorny plants in the last summer months (5 questionnaire items; corrected alpha level 0.01) and the first touch duration for the thorny and non-thorny objects.

	First Touch Duration					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Infant tries to touch thorny plants	.18	.15	.44* *p* = .005	.09	.22	-.14
Parents stop infant from touching thorny plants	.18	.31	.26	.25	.19	-.16
Parents encourage to touch thorny plants	-.13	-.04	-.04	-.39 *p* = .03	-.16	.20
Parents point out/name thorny plants	.08	.15	.17	-.26	.10	-.04
Infant sees parents caring for thorny plants	.08	.11	.11	-.12	.07	-.06

Table S17. Summary of the correlations between parent experience and knowledge about plants (6 questionnaire items; corrected alpha level 0.0083) and the first touch duration for the thorny and non-thorny objects.

	First Touch Duration					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Free time spent with plants	.22	.21	-.08	.54* *p* = .001	-.05	.24
Professional time spent with plants	.17	.21	.04	.19	.06	.27
Knowledge about plants	.27	.29	-.10	.24	.13	.08
Knowledge about names and properties of plants	.31	.47 *p* = .01	-.07	.03	.05	.09
Knowledge about the dangerous properties of plants	.06	-.18	-.12	-.06	.15	-.06
Knowledge about plant growth	.31	.23	.02	.31	.15	.18

Table S18. Summary of the correlations between infant's experiences with the familiar objects used in the study (8 questionnaire items; corrected alpha level 0.0063) and the first touch duration for the thorny and the non-thorny objects.

	First Touch Duration					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Infant interacts with shovel	-.03	.04	.06	-.05	.01	.10
Infant interacts with rake	-.12	.11	.01	-.06	-.07	-.09
Infant interacts with hairbrush	.04	-.38 *p* = .04	.31	-.04	.18	.29
Infant interacts with mirror	-.06	-.01	-.10	-.32	-.16	.08

Infant sees parent interacting with shovel	.24	.17	.08	.41	-.05	-.07
Infant sees parent interacting with rake	-.07	.10	-.04	.19	-.14	-.11
Infant sees parent interacting with hairbrush	.03	-.37 *p* = .05	.20	.19	.30	.44 *p* = .008
Infant sees parent interacting with mirror	.10	.12	-.16	-.17	.07	.19

Table S19. Summary of the correlations between infants' temperament (5 questionnaire items; corrected alpha level 0.01) and the first touch duration for the thorny and non-thorny objects.

	First Touch Duration					
	Plants		Novel Artifacts		Familiar Artifacts	
	Thorny	Non-thorny	Thorny	Non-thorny	Thorny	Non-thorny
Activity Level	.11	.09	-.01	.04	.03	.13
Fear	-.10	-.17	-.25	-.07	-.10	-.14
Duration of Orientation	-.11	-.18	.18	-.07	.05	.08
Perceptual Sensitivity	-.11	.10	-.10	.01	.09	.26
Approach	-.05	-.08	.04	.14	.38 *p* = .02	.03

Table S20. Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last several months (12 questionnaire items; corrected alpha level 0.0042) and the touch frequency to specific parts of the thorny objects.

		Touch Frequency								
		Plants			Novel Artifacts			Familiar Artifacts		
		Thorny	Both	Non-thorny	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny
	How often…									
Indoor plants	Infant interacts with plants	.28	-.22	-.02	.18	-.39 *p* = .04	-.21	-.04	-.19	-.02
	Parents point out/name plants	.52	-.39	.08	.02	-.24	-.04	-.01	-.22	-.10
	Infant sees parents caring for plants	.16	-.03	-.19	.02	.13	.02	.07	-.18	-.04
	Infant eats from plants	-.16	-	.19	-.15	.15	.10	-.13	-.22	-.37

	Infant tries to touch plants	<.001	-.05	-.08	<.001	-.24	-.31	-.01	-.39	-.09
	Parents stop infant from touching plants	.24	-.19	-.33	.28	.23	-.45 *p* = .007	.07	-.29	.08
Outdoor plants	Infant interacts with plants	.41	.01	-.35	.14	-.15	.19	-.23	-.06	-.15
	Parents point out/name plants	.53	-.04	-.14	.11	-.19	.30	-.25	.06	-.08
	Infant sees parents caring for plants	.67 *p* = .03	.27	-.27	-.05	.24	.17	-.26	-.06	-.10
	Infant eats from plants	.17	.43	.18	-.13	.33	.13	-.01	.003	-.14
	Infant tries to touch plants	.38	.28	-.42 *p* = .05	.16	-.09	.17	-.06	-.21	-.31
	Parents stop infant from touching plants	.53	-.17	-.67* *p*=.0005	.36	<.001	-.19	.03	-.05	.12

Table S21. Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last summer months (12 questionnaire items; corrected alpha level 0.0042) and the touch frequency to specific parts of the thorny objects.

		Touch Frequency								
		Plants			Novel Artifacts			Familiar Artifacts		
		Thorny	Both	Non-thorny	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny
	How often…									
Indoor plants	Infant interacts with plants	.23	.13	-.08	.13	-.08	-.26	-.20	-.03	.14
	Parents point out/name plants	.43	.03	-.16	-.03	-.02	-.01	-.17	.10	-.01
	Infant sees parents caring for plants	-.07	.26	-.23	-.19	.10	.07	-.04	.16	.30
	Infant eats from plants	-.24	-.07	.35	-.27	.19	.01	-.24	-.15	-.32
	Infant tries to touch plants	.16	.14	-.38	.22	-.15	-.22	-.12	-.03	.08
	Parents stop infant from touching plants	.40	-.14	-.54 *p* = .008	.31	.08	-.44 *p* = .009	.13	-.18	.02
Outdoor plants	Infant interacts with plants	.38	.14	-.30	.04	.14	.10	-.19	.05	-.12
	Parents point out/name plants	.53	.34	-.17	.002	.10	.10	-.27	.10	.02
	Infant sees parents caring for plants	.62	.65 *p* =.04	-.23	-.05	.12	.19	-.32	-.08	-.04
	Infant eats from plants	.05	.49	.17	-.04	.13	.11	-.13	.07	-.17
	Infant tries to touch plants	.38	.26	-.33	.05	.06	.02	-.14	.06	-.13
	Parents stop infant from touching plants	.16	-.14	-.59 *p* = .003	.26	-.10	-.31	.05	.25	.57 *p*=.004

Table S22. Summary of the correlations between infant's experiences with the thorny plants in the last several months (5 questionnaire items; corrected alpha level 0.01) and the touch frequency to specific parts of the thorny objects.

	Touch Frequency								
	Plants			Novel Artifacts			Familiar Artifacts		
	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny
Infant tries to touch thorny plants	.33	-.36	.26	-.09	-.18	.15	-.13	-.19	-.07
Parents stop infant from touching thorny plants	.57	.02	-.33	-.06	.30	-.01	-.06	-.14	-.16
Parents encourage to touch thorny plants	-.16	.38	.15	-.25	-.30	.07	-.18	-.06	-.10
Parents point out/name thorny plants	.27	-.51	.08	-.19	-.09	.32	-.32	-.27	-.41 *p* = .045
Infant sees parents caring for thorny plants	-.20	.21	.14	-.14	.18	.30	-.06	-.06	-.34

Table S23. Summary of the correlations between infant's experiences with the thorny plants in the last summer months (5 questionnaire items; corrected alpha level 0.01) and the touch frequency to specific parts of the thorny objects.

	Touch Frequency								
	Plants			Novel Artifacts			Familiar Artifacts		
	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny
Infant tries to touch thorny plants	.23	.46	.12	.00	.04	-.14	-.06	-.01	-.17

Parents stop infant from touching thorny plants	.57	.02	-.17	-.06	.33	-.12	-.09	-.14	-.24
Parents encourage to touch thorny plants	-.16	.38	-.23	-.20	-.26	.13	.04	.48 *p* = .016	.37
Parents point out/name thorny plants	.19	.22	-.25	-.09	-.04	.06	-.45* *p* = .009	.03	-.19
Infant sees parents caring for thorny plants	-.16	.11	.16	-.05	.04	.31	-.16	.25	-.17

Table S24. Summary of the correlations between parent experience and knowledge about plants (6 questionnaire items; corrected alpha level 0.0083) and the touch frequency to specific parts of the thorny objects.

	Touch Frequency								
	Plants			Novel Artifacts			Familiar Artifacts		
	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny
Free time spent with plants	.17	.15	-.10	-.39	.15	.17	-.13	-.01	-.04
Professional time spent with plants	-	.07	-.23	.19	.03	.13	-.02	.14	.24
Knowledge about plants	.00	.04	.25	-.23	-.18	.02	.01	.05	-.11
Knowledge about names and properties of plants	-.07	.03	.04	.19	-.20	-.24	-.10	.05	.15
Knowledge about the dangerous properties of plants	.32	.26	.04	.05	-.19	-.08	-.36 *p* = .04	.15	-.05
Knowledge about plant growth	-.11	-.03	.17	-.34	.06	.03	.22	-.01	.10

Table S25. Summary of the correlations between infant's experiences with the familiar objects used in the study (8 questionnaire items; corrected alpha level 0.0063) and the touch frequency to specific parts of the thorny objects.

	Touch Frequency								
	Plants			Novel Artifacts			Familiar Artifacts		
	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny
Infant interacts with shovel	-.09	.11	-.22	.25	.04	.02	.02	-.01	-.12
Infant interacts with rake	-.03	-.06	-.31	-.01	.03	-.08	.02	-.11	-.30
Infant interacts with hairbrush	-.43	.19	.33	-.25	-.04	.09	.14	-.24	-.49 *p* = .02

Infant interacts with mirror	.29	-.21	.09	-.06	-.18	.10	.28	-.18	-.29
Infant sees parent interacting with shovel	-.19	.38	-.04	.05	.36	-.02	.09	-.13	-.29
Infant sees parent interacting with rake	-.12	.22	-.30	.08	.14	-.13	.11	-.24	-.30
Infant sees parent interacting with hairbrush	-.38	-.07	.24	-.28	.29	.27	.21	-.14	-.39
Infant sees parent interacting with mirror	-.07	-.14	-.10	.21	-.12	.05	.22	-.25	-.34

Table S26. Summary of the correlations between infants' temperament (5 questionnaire items; corrected alpha level 0.01) and the touch frequency to specific parts of the thorny objects.

	Touch Frequency								
	Plants			Novel Artifacts			Familiar Artifacts		
	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny	Thorny	Both	Non-thorny
Activity Level	-.23	.12	.09	.12	.33	.15	.04	-.11	-.07
Fear	.16	-.33	.22	-.01	-.15	.28	.07	.32	.40
Duration of Orientation	-.03	-.13	.13	-.19	-.11	-.00	.02	.01	.16
Perceptual Sensitivity	.12	-.23	-.28	-.14	-.28	.12	-.13	.06	.19
Approach	.12	-.61	-.11	-.28	.09	.15	-.07	-.54* *p* = .006	-.17

Chapter 2. The role of social information in infants’ behavioral responses to plant threats

Publication 2

A manuscript based on this chapter is currently under review at Cognitive Development.

Włodarczyk, A., Rioux, C., & Wertz, A.E. (under review). Social information reduces infant’s avoidance of plants. *Cognitive Development.*

1. Introduction

Social information plays an important role in learning about threat. As experimentation with danger through trial and error is costly and potentially fatal, social learning about threat is an advantage compared to hazardous asocial learning (Boyd & Richerson, 1985, 1988; Feldman, Aoki & Kumm, 1996; Laland, 2004). Accordingly, there is considerable evidence that both children and adults learn socially about threats such as dangerous conspecifics (Baltazar, Shutts, & Kinzler, 2012; Kinzler, & Shutts, 2008) or wild animals (Barrett & Broesh, 2012; Broesh, Barrett, & Henrich, 2014; DeLoache & LoBue, 2009; LoBue, Rakison, & DeLoache, 2010).

1.1. Social learning in infancy

Learning from others is particularly beneficial early in ontogeny when human beings are especially vulnerable (Laland, 2004). Correspondingly, developmental studies show that infants readily rely on cues provided by adults when broadening their understanding of the world and its dangers (Feinman, 1992). Social learning early in ontogeny is also present in small-scale cultures where formal teaching is rare (Hewlett, Fouts, Boyette, & Hewlett, 2011). Importantly, infants already possess skills that enable them to receive knowledge from social partners (e.g., Csibra & Gergely, 2006; Frith & Frith, 2012). They exhibit a preference for following geometric patterns that resemble faces beginning immediately after they are born (e.g., Farroni, 2005; Johnson & Morton, 1991) and they are able to follow gaze of a social partner in the second half of their first year (e.g., Flom & Johnson, 2011; Moore & Dunham, 1995). Finally, infants have striking ability to imitate novel actions performed by a social other (e.g., Carpenter, Nagell, Tomasello, 1998; Elsner, 2007; Meltzoff, 1988). All these findings show that infants are willing to learn from the others and are well equipped to do so.

A foundational aspect of social learning in infancy is the process of emotional communication called social referencing (Feinman, 1982). In this process, infants use others' emotional interpretations of an object or an event to form their own understanding of that object or event. This newly gained appraisal is followed by relevant regulation of infants' behavior (Feinman, 1992). Social referencing operates primarily under conditions of novelty or otherwise high ambiguity (Baldwin & Moses, 1996; Campos & Stenberg, 1981; Kim & Kwak, 2011). In a standard social referencing paradigm, infants are presented with an ambiguous situation (e.g., a strange toy) to which they frequently respond by seeking out information from others by looking toward them. Infants' behavior typically varies in appropriate ways with different emotional signals displayed by the others. That is, infants observing a person expressing positive affect toward the ambiguous toy will approach the toy, whereas infants observing a person expressing negative affect will avoid the toy (e.g., Hertenstein & Campos, 2004).

Accordingly, there is evidence that young children rapidly learn behavioral avoidance responses via adults' negative reactions towards novel toys (Gerull & Rapee, 2002; Dubi, Rapee, Emerton, & Schniering, 2008), small visual cliffs (Sorce et al., 1985) or strangers (De Rosnay et al., 2006; Feinman & Lewis, 1983; Feinman, Roberts, & Morissette, 1986). Further, infants approach the toy more quickly or more closely when referencing a positive emotional expression compared to infants in a negative emotional expression condition (Camras & Sachs, 1991; Klinnert, Emde, Butterfield, & Campos, 1986). The majority of social referencing studies report infants' behavior regulation being consistent with the affect presented by others, however some experiments did not replicate this effect. For example, Patzwald and colleagues (2018), showed that 18-month-old infants' object exploration was not influenced by a model's emotional expressions. Infants took as much time to touch the objects in a positive affect condition as they did in a negative affect condition. Repacholi's, (2009) findings revealed similar results in 15- and 18-month-old infants, showing that infants took as long to reach for and spent the same amount of time in contact with objects in both emotional expression conditions.

In a typical social referencing study, both facial and vocal cues are presented to guide infants' behavior. Some studies show, however, that negative vocalizations alone are sufficient to elicit appropriate behavior regulation in the context of ambiguous stimuli (Mumme, Fernald, & Herrera, 1996). The ability to react appropriately to both of these social cues types develops early in ontogeny. Infants as young as 4-months can discriminate facial expressions of anger, fear, or surprise (Serrano et al., 1992), 3-month-olds are sensitive to certain co-relationships between visual and acoustic properties, such as body size and sound frequencies (Pietraszewski et al., 2017), and 5-month-old infants are able to discriminate positive versus negative affective vocal expressions in several languages (Fernald, 1993). These findings provide further evidence that young infants are well prepared to learn from the vocalizations of social partners. In the current study, we focus on the behavioral regulation part of the social referencing process. Specifically, we investigate infants' reaching and touching behavior toward different object categories after a display of emotional signals from an adult.

1.2. Infants using social information to learn about threat

Social learning is not used in an indiscriminate way. Instead, humans use social learning strategies, called also "transmission biases" to flexibly decide what, when, and whom to learn from (Kendal, et al., 2018). Threat is one of the prominent domains in which social learning is privileged (Boyd & Richerson, 1985, 1988; Feldman, Aoki & Kumm, 1996) and selectivity in using social cues to learn about danger is exhibited in infancy. For example, DeLoache & LoBue (2009) found that, 7- to 18-month-olds when presented with two videos side by side, one with threatening animals (i.e., snakes) and the other one with non-threatening animals (e.g., elephants, giraffes) while listening to either a happy or fearful voice, looked longer at the snakes when listening to fearful voices than when listening to happy voices. In contrast, infants in the same study did not respond differently to non-threatening animals depending on the valence of the auditory social stimuli. Importantly, these effects hold only when the animal stimuli were presented moving across the screen. While viewing still photos of the animals, infants did not exhibit differential looking behavior toward snakes versus other animals based on what voice they were hearing (DeLoache & LoBue, 2009).

Further, using event-related brain potentials Hoehl & Pauen, (2009), showed that 9-month olds directed increased attention towards spiders and flowers when gaze-cued by an adult with a fearful facial expression, although the effect was more pronounced for spiders compared to flowers. Snakes, however, elicited greater attention than fish regardless of the emotional expression of the face looking at the target stimuli. Selectivity in learning about threat is also shown in older children across cultures (Barrett and Broesch, 2012; Barrett, Peterson, & Frankenhuis, 2016; Broesch, Barrett, & Henrich, 2014). The current study investigates whether infants exhibit selectivity in threat learning about an important, but often overlooked aspect of the natural world: plants.

1.3. Social learning about plants

Despite being beneficial throughout our evolutionary history (Hardy, 2008; Harris & Hillman, 2014; Henry, Brooks, & Piperno, 2014; Peters et al., 1981; Ungar & Sponheimer, 2011; Lee, 1993), plants have also posed real danger to humans. Plants produce chemical and physical defenses against herbivores that can impose a range of serious costs including poisoning and physical injury (Hagen et al., 2013; Kingsbury, 1983; Palo & Robbins, 1991). Accordingly, recent studies have begun providing evidence that human infants use plant-selective behavioral avoidance strategies and prepared social learning mechanisms to safely interact with plants. For example, 8- to 18-month old infants are reluctant to touch benign-looking plants compared to other object types; a behavioral strategy that protects them from potential plant dangers (Elsner & Wertz, 2019; Wertz & Wynn, 2014a). The results of Chapter 1 of this thesis show that infants treat all plants as potentially dangerous, whether or not the plants look benign or are covered in sharp-looking thorns, while still showing sensitivity to visible plant threats by touching the thorny parts of plants significantly less than the thorny parts of the other objects (Chapter 1; Włodarczyk et al., 2018). There is also evidence that some kinds of social information are more easily learned for plants. For example, Wertz & Wynn (2014b) showed that edibility is more readily associated with plants than non-plants. Further, infants exhibit increased social information seeking behavior when confronted with plants compared to other object types (Elsner & Wertz, 2019). Finally, there is some evidence that a certain type of social information, namely parental prohibition, may be related to infants' behaviour toward thorny plants but not benign-looking plants (Chapter 1; Włodarczyk et al., 2018).

1.4. The current study

The existing results are consistent with the prediction that human adaptations for plants include social learning procedures as an essential part of their design (Elsner & Wertz, 2019; Wertz & Moya, 2019; Wertz & Wynn, 2014a; 2014b). Here we explore this proposal in the context of infants' responses to plant threats. The existing results show that the behavioral avoidance strategy toward plant threats in infancy operates without clear social information that plant is harmful to touch (Chapter 1; Elsner & Wertz, 2019; Wertz & Wynn, 2014a; Włodarczyk et al., 2018). Yet, it is unclear whether this strategy can be further modulated by additional social information about plant properties, or whether these existing findings may instead represent a ceiling effect. It is also not known, whether socially learned information about plant threats is transferred to other similar-looking entities. That is, whether infants generalize one instance of social learning to broader array of objects. Therefore, the aim of the current study was to explore the social component of learning about dangerous aspects of plants in more detail by presenting infants with objects accompanied by either a negative or positive emotional expression of an adult.

Based on the social referencing studies showing a decrease in object manipulation based on adults' negative emotional reactions (Gerull & Rapee, 2002; Dubi, Rapee, Emerton, & Schniering, 2008), we may expect that negative social information about plant properties will make infants even more reluctant to touch plants. Further, we examined whether infants' response to the visibly-threatening elements of plants (i.e., thorns) is particularly sensitive to social information. Given the previous results indicating selective avoidance of thorns on plants (Chapter 1; Włodarczyk et al., 2018), we may expect the effect of negative social information to be more clear-cut for thorny plants. Based on the social referencing studies where mainly artifacts were used as the stimuli (e.g., Baldwin, & Moses, 1996; Schmitow & Stenberg, 2013) we may expect that infants' reactions toward non-plant objects will be modulated by negative social information as well. Infants may also be more reluctant to approach the non-plant objects presented with an adult's negative emotional expression, although perhaps not to the same degree as for the plants.

In contrast, infants are expected to approach all objects faster when presented with positive social information (e.g., Camras & Sachs, 1991). However, it is an open question whether the relative reluctance to touch plants compared to other object types will remain in the positive social information conditions. Finally, we were interested in examining whether infants would generalize social information from an adult about one entity to similar-looking entities encountered at a later time.

To investigate these questions, we assessed infants' touch behavior in an adapted version of the object exploration paradigm used in Chapter 1 (Włodarczyk et al., 2018). A series of stimulus objects with and without sharp-looking thorns were presented to infants one at a time by an experimenter seated across a table. In this study, the experimenter conveyed additional social information about the stimulus object by touching each stimulus object and reacting with either pain (negative social information condition) or with delight (positive social information condition); the two different types of social information were presented in between-subjects conditions. To assess whether this social information is generalized, the stimuli in each condition were presented in two within-subjects blocks. The stimuli in the first block was presented with social information while the stimuli in the second block were presented without social information. As in Chapter 1 (Włodarczyk et al., 2018), we measured infants' initial reaching behavior toward, and subsequent manual exploration of, each stimulus object.

2. Materials and Methods

2.1. Participants

The final sample of participants consisted of fifty 8- to 18-month-old infants (24 females, Mean age = 12 months 27 days, range = 7;23 – 18;10). All infants were healthy and born full term. They were recruited from the existing list of parents who had volunteered for research after being contacted by letter after the birth of their child. Infants were tested in the BabyLab at the Max Planck Institute for Human Development in Berlin. An additional 11 infants were tested but excluded because of fussiness (N = 6), recruiting mistake (N = 1), technical difficulties with the video recording (N = 2), and a mistake in the procedure (N = 2).

The study was approved by the Ethics Committee of the Max Planck Institute for Human Development and conducted with the informed consent of each participant's parent.

2.2. Stimuli

There were twenty-four objects in the stimulus set belonging to three categories: eight realistic-looking artificial plants, eight novel manmade artifacts and eight familiar manmade artifacts (see *Figure 1*). We used the same object categories as presented to infants in Chapter 1 (Włodarczyk et al., 2018). Because of the within-subjects block design of social information compared to after social information, we used twice as many objects to keep the same number of items per cell in our statistical analyses. All three object type groups consisted of matched pairs. There was one stimulus object in each pair that had thorns or pointed parts and a second identical stimulus object but without thorns or pointed parts. The thorns on the plants and novel artifacts were made of a pliable child-safe modelling clay not to hurt the participants. The child-safe pointed parts of the familiar objects had the same overall shape as the thorns on the plants and novel artifacts. There were two different thorn shapes used in the study: a triangular shape similar to a rose thorn and a thin needle shape similar to a cactus thorn. The pointed parts on the familiar artifacts were matched to the thorn shapes used on the plants and novel artifacts.

The stimuli plants included four different types of plants that had plastic stems and fabric leaves put in the black plastic pots that measured approximately 10 cm high and 12 cm in diameter (see the top rows of *Figure 1*). Half of the artificial plants had thorns attached to their stems and branches. As infants at this age interact with both real and artificial plants in the same way (Elsner & Wertz, 2019; Wertz & Wynn, 2014a), we were able to present infants with artificial plants with thorns instead of real plants to exclude the possibility of injury. All thorns were made from a child-safe modeling clay that is soft and pliable when it is dry. The first of four plant types (see the first and the third column of the first row of *Figure 1*) was made with

61 linear-shaped fabric leaves. It had leafy parts that were approximately 22 cm high and 29 cm wide. One plant of this type included 50 green, cactus-like thorns (approximately 1.5 cm long and 4 mm cm in diameter). The second plant type included in the stimulus set (see the second and forth column of the first row of *Figure 1*) was made with 22 orbicular fabric leaves. Its leafy parts were approximately 41 cm wide and 26 cm high. One plant of this type had 57 green rose-like thorns (approximately 1.6 cm long and 5 mm cm in diameter). The third plant type (see the first and the third column of the second row of *Figure 1*) was made with 29 elongated fabric leaves. It had leafy parts that were approximately 16 cm high and 20 cm wide. One plant of this type included 52 green cactus-like thorns (approximately 2 cm long and 4 mm in diameter). The fourth plant type (see the second and forth column of the second row of *Figure 1*) was made with 48 heart-shaped fabric leaves. Its leafy parts were approximately 24 cm high and 28 cm wide. One plant of this type had 53 green rose-like thorns (approximately 1.5 cm long and 0.5 cm in diameter).

The novel artifacts used in the study were designed to match features of the plants (see the middle rows of *Figure 1*). Two of the novel artifact types matched the size and green color of the two plant types included in the stimulus set. The first novel artifact of this type (see the first and the third column of the third row of *Figure 1*) was made from a cylinder-shaped cardboard container (approximately 11.5 cm high and 11 cm in diameter) painted green on the top with protruding 13 green straws with green pompoms stuck on the ends (approximately 16 cm high and 1.5 cm in diameter). One of these novel artifacts had 41 cactus-like green thorns (approximately 1.5 cm long and 4 mm in diameter). The second type of novel artifact matching the size and the green color of the plants (see the first and the third column of the fourth row of *Figure 1*) was made from a cylinder-shaped green and black cardboard base (10 cm high, 10.5 cm in diameter) with 10 green wooden popsicle sticks (14 cm high, 1.8 cm wide) coming from the top. One of these novel artifacts had 52 cactus-like green thorns (approximately 2 cm long and 4 mm in diameter).

The two other novel artifacts matched the size and leaf shape of the two of the plant types in the stimulus set. First novel artifact of this type (see the second and the fourth column of the third row of *Figure 1*) was made from the same 22 orbicular fabric leaves as one of the plant types, but pained purple. These leaves were arranged in a spiral along an orange cardboard cylinder (20 cm high, 7 cm in diameter) fixed in an orange plastic pot (13 cm high, 13 cm in diameter). One of these novel artifacts had 63 rose-like orange-colored thorns (approximately 1.5 cm long and 7 mm in diameter). The second type of novel artifacts matching the size and leaf shape of one of the plant types (see the second and the fourth column of the fourth row of *Figure 1*) was made from the same 48 heart-shaped fabric leaves as one of the plant types. These leaves were painted black and arranged in a spiral along a blue and yellow cardboard cone (21 cm high and 19 cm in diameter). The cone was glued to the top of a blue and yellow cylinder-shaped cardboard base (10 cm high, 10.5 cm in diameter). One of these artifacts had 53 blue rose-like thorns. (approximately 1.5 cm long and 0.5 cm in diameter).

The familiar artifacts were included in the stimulus set to control for the possibility that infants would react differently to plants versus novel artifacts due to a sensitivity to broader classes of familiar compared to novel objects. As our plant stimuli were relatively more familiar to infants than the novel artifact stimuli, we decided to include in our stimulus set the artifacts that were also familiar to infants. This object category was grouped into four matched pairs. One object in each pair contained pointed thorn-like shapes matched to the thorn shapes of plants and novel artifacts (see the bottom rows of *Figure 1*). The first pair (see the first and the third column in the fifth row of *Figure 1*) consisted of a kitchen knife and a butter knife. They were both 3D printed child-safe objects with blunt edges made of plastic. They were 25.5 cm long, with 9.4 cm long handles painted green and 15 to 16 cm long blades painted silver. The kitchen knife had a pointy-shaped blade that was 4.4 cm wide at its base. The butter knife had an oval-shaped 3 cm wide blade. The second pair of familiar artifacts (see the second and the fourth column in the fifth row of *Figure 1*) included a door key and a toy key. The keys were 13 cm long 3D printed plastic objects. They had painted-green bows that were 5.2 cm in diameter and 7.8 cm long painted silver blades. The blade of the door key had eight 7 mm long pointy cuts. The toy key also had eight cuts but they were oval-shaped 7 mm in diameter. The third pair of familiar artifacts (see the first and the third column in the sixth row of *Figure 1*) consisted of a wooden hairbrush and a wooden hand mirror. They were both 25.5 cm long, with a handle (3 cm wide and 11.5 cm long) and a flat wooden part (8 cm wide and 12 cm long). The hairbrush had pointy-shaped wooden bristles (1.5 cm long) arranged in a rubber-cushioned pad (7.5 cm wide, 11.5 cm long) glued to the flat wooden part. The hand mirror had a rectangular mirror-like foil (7.5 cm wide, 11.5 cm long) glued on the flat wooden part, instead of the pad with pointy elements. The last pair of familiar artifacts (see the second and the fourth column in the sixth row of *Figure 1*) included a children's plastic rake and a plastic shovel. They were both 18.5 cm long, with a 1.5 cm diameter blue handle. The rake had a grey 7.5 cm long head with three pointed tines glued to the handle. The shovel had a 7.5 cm grey round-shaped bowl instead of a head with tines.

Similar to the study described in Chapter 1 (Włodarczyk et al., 2018), we were interested in infants' reactions to plants and their thorns and not the pots in which they were arranged. Consequently, only the top parts of objects with thorns or pointed parts were our areas of interest. Infants behavior toward the plant pots, the bases of the novel artifacts, and the handles of the familiar artifacts was excluded from further analysis.

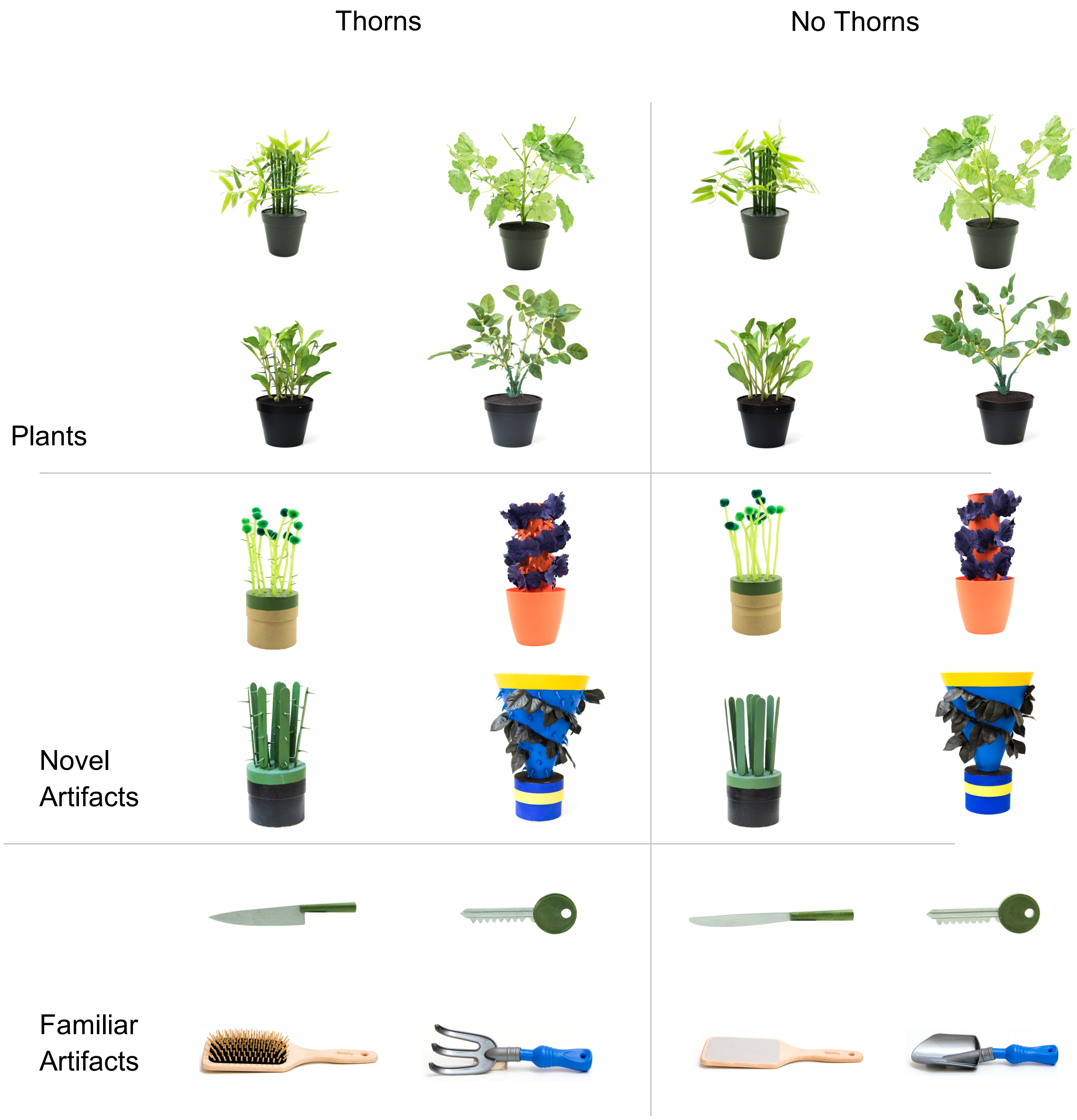


Figure 1. Stimulus objects used in the experiment. Top row: Plants. Middle row: Novel Artifacts. Bottom row: Familiar artifacts. Left column. Objects with thorns (plants and novel

artifacts) or pointed parts (familiar artifacts). Right column: Objects without thorns or pointed parts matched to the stimuli depicted in the left column.

2.3. Procedure

A series of twenty-four objects was presented to each infant in two sessions of twelve objects each (see *Figure 2*). There were either all thorny or all non-thorny objects in one session. A short break was arranged in between the two sessions. The order of presentation (thorny objects first vs. non-thorny objects first) was counterbalanced across participants. The additional social information was always presented within subjects in the first block of each phase (*see* Figure 2). The different valence of the social information (positive vs. negative) was presented in two between-subjects conditions.

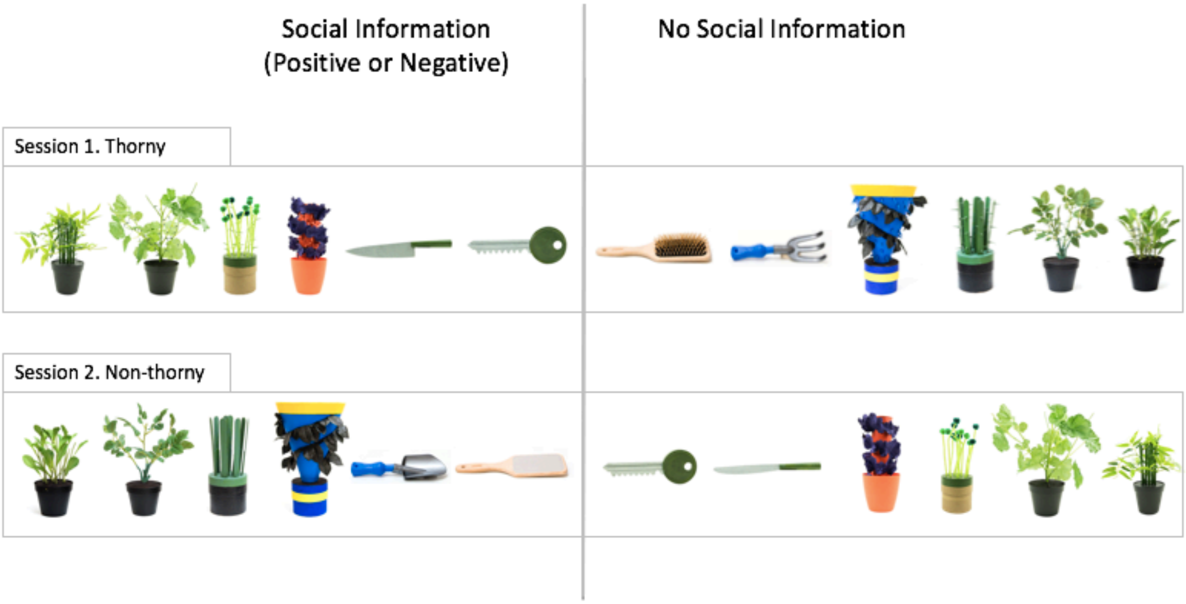


Figure 2. The experimental design used in the study. Stimuli were presented in two sessions (thorny vs. non-thorny objects; order counterbalanced). The additional social information was presented within subjects in the first half of the session. Different valence of the information (positive vs. negative) was presented between subjects.

Infants sat on their parents' laps in front of a table opposite to the experimenter who was sitting approximately 145 cm away. The experimenter handed objects across the table and placed them one at a time approximately 25 cm away from the child. Parents were asked to keep their eyes closed during the entire two sessions so as not to cue infants' responses.

The first six objects in each session were presented with additional social information (block 1) conveyed by an experimenter touching each stimulus and reacting either with pain (negative condition) or with delight (positive condition; see *Figure 3*). The six remaining objects in each session were presented without additional social information (block 2). The two different social information conditions were presented to two age- and sex-matched halves of the participants. The two types of information were closely matched in terms of the length and content of presented social cues.

In the negative social information condition the experimenter first put each of the first six objects in a block on the table approximately 25 cm away from herself, while saying in German "*Look, what I've got*" (*"Schau mal, was ich hier habe!"*; see Panel A. of *Figure 3*). The objects were touched by the experimenter only at the bottom part during this initial phase of the presentation. Then, the experimenter touched the object being presented with her index finger. The place of touch was either a thorn in the case of thorny objects, or in the same but non-thorny region in the case of the non-thorny counterpart stimuli. The experimenter reacted with pain while taking her finger away. The pain reaction consisted of both a facial and a vocal expression. The facial expression included brows dropped and drawn together, upper eyelids dropped covering sclera, and open mouth with lips tensed and drawn back (see *Figure 3*, *Panel A*). The vocal expression was a short exclamation of "*Ow!*" pronounced rapidly with a tense voice that was sharp and slightly high in pitch (cf. Scherer, 1986). After this reaction, the experimenter handed the stimulus object across the table touching only the bottom part of the object and placed it approximately 25 cm away from the infant. While each stimulus object was in front of the infant the experimenter looked down at the table and maintained a neutral facial expression.

In the second block of the negative condition, the last six objects were presented without additional social information. Thus, after putting the stimulus object in front of herself, the experimenter looked down at the object and maintained a neutral facial expression for the time duration of social information presentation. Then the experimenter handed the stimulus object across the table touching only the bottom part of the object and placed it in front of the infant.

In the positive social information condition, the experimenter followed the same procedure as in the negative social information condition except that she reacted with delight instead of pain while taking the finger away for the six objects in the first block. The reaction of delight also consisted of both a facial and a vocal expression. The facial expression included brows raised and expanded, upper eyelids raised showing sclera, and open mouth with lips relaxed and drawn back (see *Figure 3*, *Panel B*). The vocal expression was a short exclamation of "*Wow!*" pronounced gently with a relaxed voice that was slightly high in pitch (cf. Scherer, 1986).

As in the negative condition, in the second block of the positive condition, the last six objects were presented without additional social information. The procedure was identical to the one described above.

Following the procedure used in Chapter 1 (Włodarczyk et al., 2018), each stimulus object was placed in front of the infant until (i) 5 seconds elapsed after the infant first touched the top part of the object, (ii) 30 seconds elapsed in the case where the infant touched only the bottom part of the object and failed to touch any other part or (iii) 30 seconds elapsed without a touch. The trial was ended and the object was taken away, when one of these three criteria was met.

The presentation order of the sessions (thorny vs. non-thorny first) was counterbalanced across participants. The complete counterbalancing of the individual objects was not possible due to the number of presented stimuli. Therefore, we counterbalanced the order of presentation of the six objects in the first block of each session ensuring that each object type (plant, novel artifact, familiar artifact) appeared first roughly equally across participants; the order of the rest of the objects within the first block was randomized. The order of presentation in the second block was the mirror image of the presentation order of the first six objects. The order in the second session was the mirror image of the whole first session but with the thorny or non-thorny counterpart objects, depending on the session order.

Both between and after the two experimental sessions, parents completed a battery of questionnaires (see Section 2.5 below).

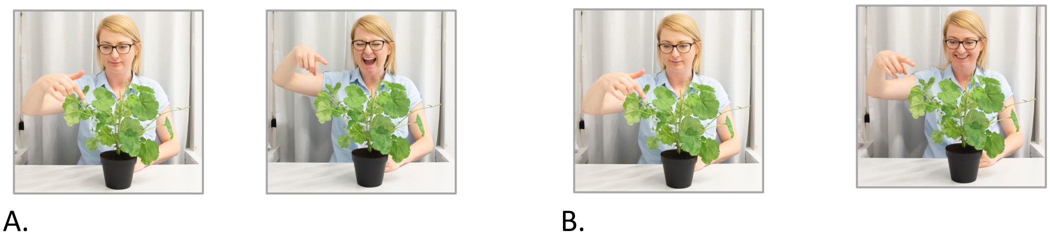


Figure 3. The sequence of the social information presentation in the experiment. *Panel A.* Negative social information presentation. Experimenter touches the object and then reacts with a negative vocal and facial expression saying "*Ow*!". *Panel B.* Positive social information presentation. Experimenter touches the object and then reacts with a positive vocal and facial expression saying "*Wow!*".

2.4. Coding infant behavior

2.4.1. Video recording

Similar to the video recording procedure used in Chapter 1 (Włodarczyk et al., 2018), infants' touch behavior during each experimental session was recorded with four video cameras (GoPro Hero 4, Black Edition). The sessions were recorded from four different angles: a front-view of the infant and the stimulus object, a side-view of the experimenter conveying social information and placing each object in front of the infant, as well as two close up side views (i.e., left and right) of the object and infants' hands. Further, the recorded videos were clustered into one quad-view movie and imported into ELAN (v. 4.9.1, Lausberg, & Sloetjes, 2009) video coding software for behavioral coding.

2.4.2. Coding procedure

In our behavioral coding scheme, a "touch" was coded as any part of the infant's hand coming into contact with the stimulus object. Only infants' touch behavior toward to the top part of the stimulus object was coded. The beginning of the coded trial was defined as the moment when the experimenter released her hands from the stimulus object after placing it on the table in front of the infant (as in Elsner & Wertz, 2019; Wertz & Wynn, 2014a; Włodarczyk et al., 2018). The endpoints of the coded trial are described in detail in Section 2.3.

Twenty-nine individual trials (out of the total 1200 trials) were excluded from further analysis due to infants throwing a stimulus object on the ground (17 trials), parental interference (1 trial), infants having another object in their hand besides the stimulus (8 trials), procedure error (i.e., experimenter presenting the object in a wrong condition; 3 trials).

2.4.3. Coding infants' touch behavior

Following the coding procedure used in Chapter 1, we coded three aspects of infants' infants' touch behavior to the top parts of the stimulus object during each trial: (i) Latency: the elapsed time before infants first made contact with the stimulus object; if infants did not touch the object during the trial, this was coded as the maximum trial length of 30 seconds, (ii) First Touch Duration: the duration of infants' first touch of the stimulus object, (iii) Touch Frequency (thorny stimuli only): how frequently infants touched the different parts of the stimulus object in the 5 second window after their initial contact with it (i.e., number of touches to thorny areas, non-thorny areas, and both types of areas simultaneously).

2.4.4 Reliability coding

A randomly selected 10% of the videos were coded by a second independent coder in order to establish inter-coder reliability. Coder agreement was high for all outcome variables., Latency (Pearson's correlation $r = .99$), First Touch Duration (Pearson's correlation $r = .90$), and Touch Frequency (Kappa coefficient $\kappa = .75$).

2.4.5 Coding experimenter behavior

Two independent coders blind to the specific hypotheses coded a randomly selected third of both positive and negative social information condition videos, rating the experimenter's behavior during each trial. The goal of the coding was to assess whether the experimenter's vocal and facial emotional expressions could have unintentionally cued infants' responses. For this coding, two versions of the videos were created: one containing only the audio recordings of the sessions and no visuals, and the other including only the visuals and no audio recordings. Additionally, the videos with visuals only were edited to remove the portion that showed the stimulus object to keep the coders blind to trial type.

One of the coders rated the experimenter's behavior in the audio only videos and the other coder rated the visual only videos. Based on the experimenter's vocal expressions (audio only videos) and facial expressions and movements (visual only videos) the coders were asked to guess what type of object was being presented to the infant (plant vs. non-plant). The proportion of correctly rated objects was not significantly different from chance for both coders (Coder 1 - audio only videos = 53%, Coder 2 - vision only videos = 62%, chance level of 50%; binomial *p's* > .05). These results suggest that the experimenter's behavior did not systematically cue infants' responses.

2.5. Parent Questionnaires

Parents completed a similar battery of questionnaires as used in Chapter 1 (Włodarczyk et al., 2018). The questionnaires assessed infants' prior experience with plants generally (Elsner & Wertz, 2019; Wertz & Wynn, 2014a; 2014b; Włodarczyk et al., 2018), thorny plants specifically (Włodarczyk et al., 2018), and the familiar artifacts used in the study. Parents were also asked to fill out a questionnaire assessing their own knowledge about plants, as well as 5 subscales of an infant temperament questionnaire (Activity Level, Fear, Duration of Orienting, Perceptual Sensitivity, Approach; IBQ-R; Gartstein & Rothbart, 2003). The order of the questionnaires was randomized across participants.

3. Results

To test whether infants' behavioral avoidance strategy toward plant threats (cf. Chapter 1) is modulated by additional social information received from an adult, we assessed infants' initial reaching for and subsequent exploration behavior of the presented stimulus objects. In contrast to our initial predictions, preliminary analyses showed that there were no significant effects of the valence of the presented social information (positive vs. negative) on any of the outcome variables: Latency, First Touch Duration, and Touch Frequency. Accordingly, further analyses were collapsed across this valence factor.

In order to enable future direct comparisons with the findings from Chapter 1, similar linear mixed-effects approach (Baayen, Davidson, & Bates, 2008; Mates, Mächler, Bolker, & Walke, 2014) was used in all analyses. While testing our hypotheses, we fit several mixed-linear models (Latency and First Touch Duration) and generalized linear models (Touch Frequency) to the data. The models were built by repeatedly adding predictive variables to the null model, which primarily included only the intercept and no predictors. The predictive variables were Object Type (Plants, Novel Artifacts, Familiar Artifacts), Thorniness (Thorny vs. Non-thorny Objects), Social Information (Social Information condition vs. After Social Information condition) and their interactions. Session Order (Thorny Objects Presented First vs. Non-thorny Objects Presented First) and Age (continuous factor) were added as a control variables. The predictive variables were kept in the model when their addition led to a significant decrease of the AIC (Akaike Information Criterion; Hu, 2007) shown by the chi-square test. If there was no decrease of the AIC, the predictive variables were left out of the following iteration. The analyses were performed with R (R version 3.3.2; R Core-Team, 2016) running on RStudio version 0.99.896 (R Studio Team 2016).

3.1. Latency

First, to test whether initial reluctance to touch plants would be modulated by the additional social information presented with the stimuli objects, we assessed the effect of Object Type, Thorniness, and Social Information on the time elapsed before infants first made contact with the different stimuli (Latency; see Table 1 for the descriptive statistics). Log transformed latency values were analyzed with linear mixed-effects models using Gaussian distribution (*lmr* function from R-package *lme4*; Bates et al., 2014). Based on the procedure of decreasing the

AIC criterion, we constructed the model that was the best fit to the data with the Latency as the outcome measure. Our best fit model contained random effects (participant), and within-subjects fixed-effects: Object Type (Plants, Novel Artifacts, Familiar Artifacts), Thorniness (Thorny vs. Non-thorny), Social Information (Social Information block vs. After Social Information block), and a Session Order (Thorny Objects Presented First vs. Non-thorny Objects Presented First) x Thorniness interaction. We calculated Omnibus effects using Type II model comparisons (ANOVA function in the R-package *car;* Fox & Weisberg, 2011). For the post hoc analyses we used single-degree-of-freedom contrasts based on the cell mean estimates in separate models with the same parameters (*ghlt* function from R-package *multicomp*; Hothorn, Bretz, & Westfall, 2008). We report main and interaction effects for the complete best fit model in Table 2.

The results showed a significant main effect of Object Type ($F(2,1116) = 16.38$, $p < .001$). As in the previous investigation (Chapter 1; Włodarczyk et al., 2018), overall, infants took significantly longer to touch plants than the other object types. Across all factors, the latency for plants was significantly longer than the latency for both novel artifacts ($t = 5.74$ $p < .001$) and familiar artifacts ($t = 2.53$, $p < .05$; see *Figure 4*), replicating previous results (Elsner & Wertz, 2019; Włodarczyk et al., 2018; Wertz & Wynn, 2014a).

The results also revealed significant main effect of Thorniness ($F(1,1116) = 18.82$, $p < .001$), as well as a significant Thorniness x Session Order interaction ($F(2,122) = 21.05$, $p < .001$), indicating that infants' latencies for thorny vs. non-thorny objects depended on which objects were presented first. Infants took longer to touch thorny objects when the thorny objects were presented first ($M = 4745$ ms, $SE = 1985$) compared to both thorny objects when the non-thorny objects were presented first ($M = 1863$ ms, $SE = 812$; $t = 2.47$, $p < .05$), and non-thorny objects when thorny objects were presented first ($M = 1456$ ms, $SE = 600$, $t = 7.60$, $p < .001$).

There was also a significant main effect of Social Information (*F*(1,1117) = 61.88, *p* < .001). Infants, overall, exhibited shorter latencies in the After Social Information block than in the Social Information block (*t* = 7.780 *p* < .001), suggesting that infants were less reluctant to touch the stimulus objects after watching an adult interact with similar-looking objects in the previous trial block.

Table 1. Descriptive statistics for latency in Social Information block and in After Social Information block.

	Latency			
	Social Information		After Social Information	
	Thorny Objects	Non-thorny Objects	Thorny Objects	Non-thorny Objects
Plants	6814 (2641)	3170 (1238)	2709 (1277)	1712 (797)
Novel Artifacts	3669 (1422)	2187 (854)	1425 (677)	559 (258)
Familiar Artifacts	3709 (1455)	2590 (1008)	1572 (738)	1469 (699)

Note. Standard errors are provided in parentheses.

Table 2. ANOVA results for best fit linear mixed-effect models for the latency and first touch duration.

Effect	Latency		First Touch Duration	
	F(df, dfres)	*p*	F(df, dfres)	*p*
Object Type	16.38(2,1116)	<.001***	16.19(2,913)	<.001***
Thorniness	18.82(1,1116)	<.001***	24.77(1,936)	<.001***
Social Info	61.88(1,1117)	<.001***	8.95(1,921)	<.01**
Thorniness x Session Order	21.05(2,122)	<.001***	-	-

Note. F values (latency and first touch duration) for effects using Type II Wald F tests with Kenward-Roger df. Asterisks indicate significant results.

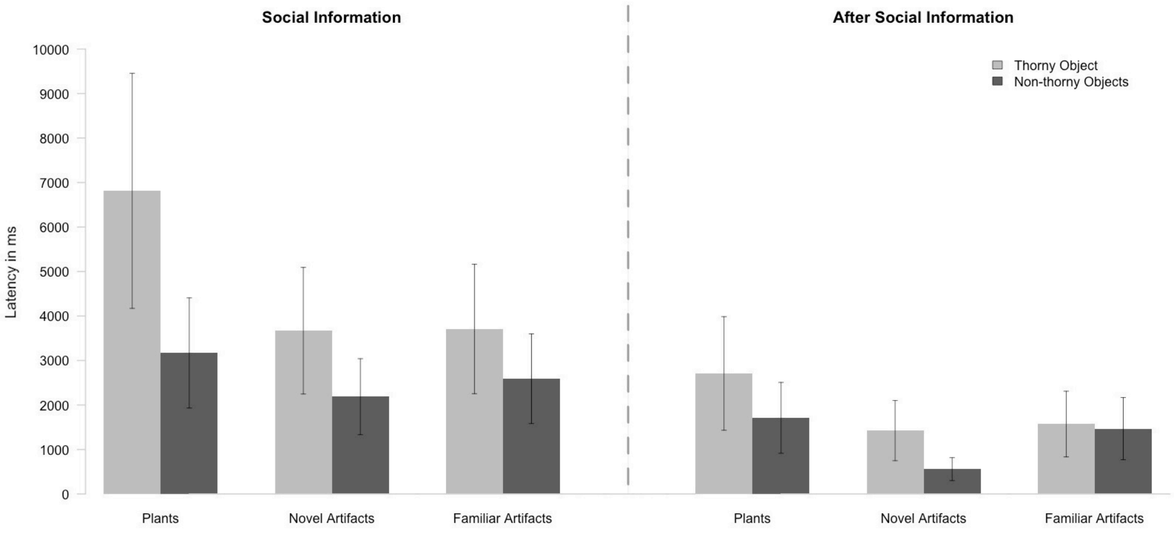


Figure 4. Back-transformed mean latency until the first touch to any top part of the different object types in the Social Information block and the After Social Information block. Error bars depict standard errors.

Taken together, the results from the current study show that even when infants are presented with additional social information about the stimulus objects, they still take longer until they make contact with plants compared to both novel artifacts and familiar artifacts. This pattern of response toward plants is similar to infants' responses when they do not receive additional cues about the objects replicating our previous findings (Chapter 1; Włodarczyk et al., 2018). Surprisingly, infants did not treat positive versus negative social information differently. It seems that they were only responding to a fact that the experimenter was contacting the objects versus not. After observing an adult repeatedly touching the objects in the first trial block, infants reached for the objects even faster during the second trial block during which no social information was presented. Therefore, the information that it is safe to touch objects appears to have been transferred to further trials and used by infants to guide their behavior toward all similar-looking object categories including plants. Interestingly, the relative reluctance to touch plants compared to other object types remains even in these later trials.

3.1.1 Descriptive comparison of the latency findings from Chapter 2 and Chapter 1[3]

In order to preliminarily assess how infants reaching behavior was modulated by presented social information, we juxtaposed the current results with findings presented in Chapter 1 (Włodarczyk et al., 2018) using the same scale (see *Figure 5*).

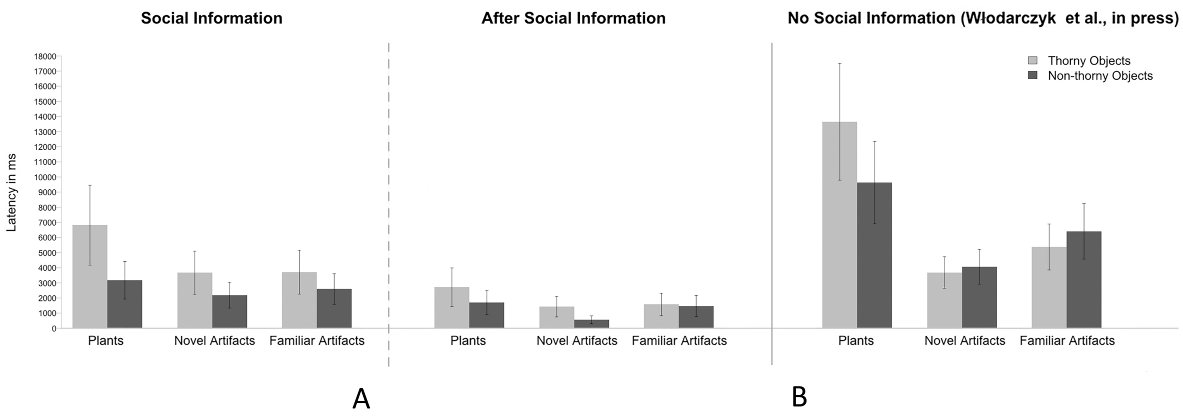


Figure 5. Back-transformed mean latency until the first touch to any top part of the different object types in the Social Information block and the After Social Information block in the current study (Panel A.) and Chapter 1 in which no social information was presented in the (Panel B). Error bars depict standard errors.

---

[3] The statistical analyses directly comparing these two datasets are currently being prepared for the forthcoming manuscript based on this chapter. Therefore, throughout this thesis, the descriptive results will be presented for comparison.

This comparison suggests that social information conveyed by the experimenter touching the objects decreased the time infants took to touch all objects types compared to baseline condition, but the effect appears to be more pronounced for plants.

3.2. First Touch Duration

Further, in addition to an initial reluctance to touch, we were interested in examining infants' subsequent manual exploration behavior as in Chapter 1 (Włodarczyk et al., 2018). In order to investigate whether infants' minimized subsequent physical contact with plants would be modulated by the social information presented with the stimuli objects, we analyzed the effects of Object Type, Thorniness, and Social Information on the duration of infants' first touch to the stimulus objects (First Touch Duration; see Table 3 for the descriptive statistics). Similar to the First Touch analysis we ran in Chapter 1, we excluded trials without a touch from this analysis. Log transformed duration values were analyzed with linear mixed-effects model using Gaussian distribution. Again, we used the procedure of decreasing the AIC criterion to build the model that was the best fit to the duration data. Our best fit model contained random effects (participant), and within participant fixed-effects of Object Type (Plants, Novel Artifacts, Familiar Artifacts), Thorniness (Thorny vs. Non-thorny), and Social Information (Social Information block vs. After Social Information block). The main and interaction effects for the complete best fit model are reported in Table 2.

The results showed a significant main effect of Object Type. Similar to the results reported in Chapter 1 (Włodarczyk et al., 2018), infants spent less time in contact with plants compared to the other object categories. First Touch Duration was shorter for plants compared to both novel artifacts ($t = 4.11$, $p < .001$) and familiar artifacts ($t = 5.41$, $p < .001$; see *Figure 3*). There was no significant difference between durations for novel artifacts and familiar artifacts ($t = 1.36$, $p > .05$).

The results also showed a significant main effect of Thorniness. Overall, infants spent less time in contact with the thorny objects than the non-thorny objects ($t = 4.90$, $p < .001$).

There was also a significant main effect of Social Information ($F(1,1117) = 61.88$, $p < .001$). Infants spent overall more time in contact with the objects in the After Social Information block compared to the Social Information block ($t = 2.90$ $p < .01$), indicating that they are even more willing to remain in contact with the objects after seeing an adult touch similar-looking objects in the previous trial block.

These findings show that, when infants receive additional social cues about the stimuli objects, they minimize their subsequent physical contact with plants compared to novel and familiar artifacts, replicating previous results (Chapter 1; Włodarczyk et al., 2018). The current results also showed that infants spent less time overall touching thorny objects compared to non-thorny ones. Again, we did not find evidence that infants treat positive versus negative social information differently. However, we found evidence that after observing an adult repeatedly touching the objects, infants spent more time exploring objects in the subsequent trial block during which no social information was presented.

Table 3. Descriptive statistics for first touch duration in Social Information block and in After Social Information block.

	First Touch Duration			
	Social Information		After Social Information	
	Thorny Objects	Non-thorny Objects	Thorny Objects	Non-thorny Objects
Plants	493 (93)	538 (92)	449 (71)	892 (137)
Novel Artifacts	559 (98)	926 (152)	897 (135)	1206 (173)
Familiar Artifacts	806 (136)	1030 (173)	781 (117)	1506 (229)

Note. Standard errors are provided in parentheses.

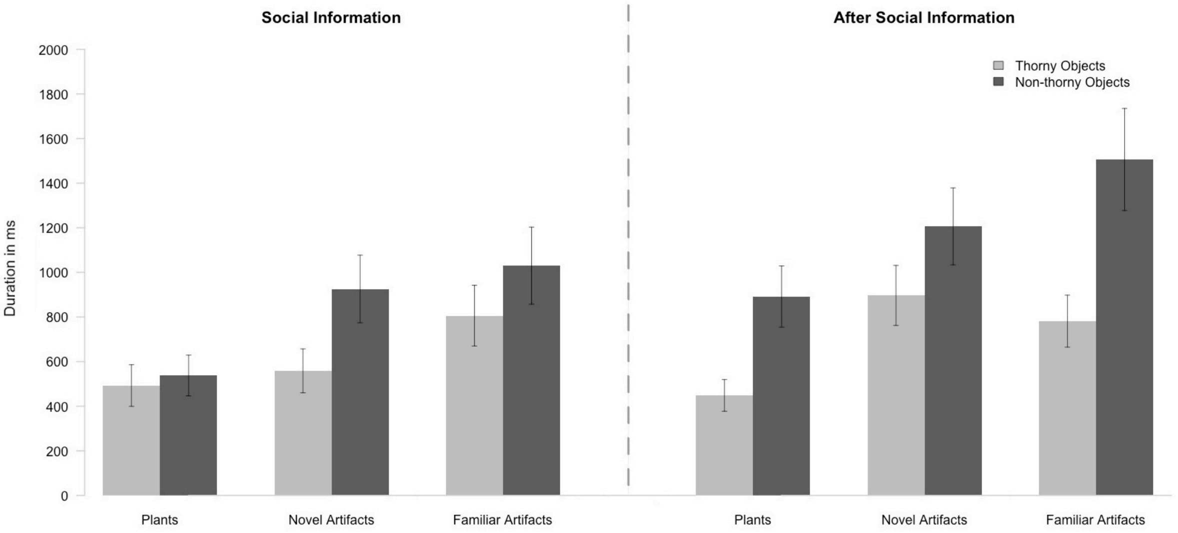


Figure 6. Back-transformed mean first touch duration for the different object types in the Social Information block and the After Social Information block. Error bars depict standard errors.

3.2.1 Descriptive comparison of the first touch duration findings from Chapter 2 and Chapter 1

To preliminarily explore how infants' subsequent physical contact with plants was influenced by the presence of additional social information, we again juxtaposed the current results with findings presented in Chapter 1 (Włodarczyk et al., 2018) using the same scale (see *Figure 7*).

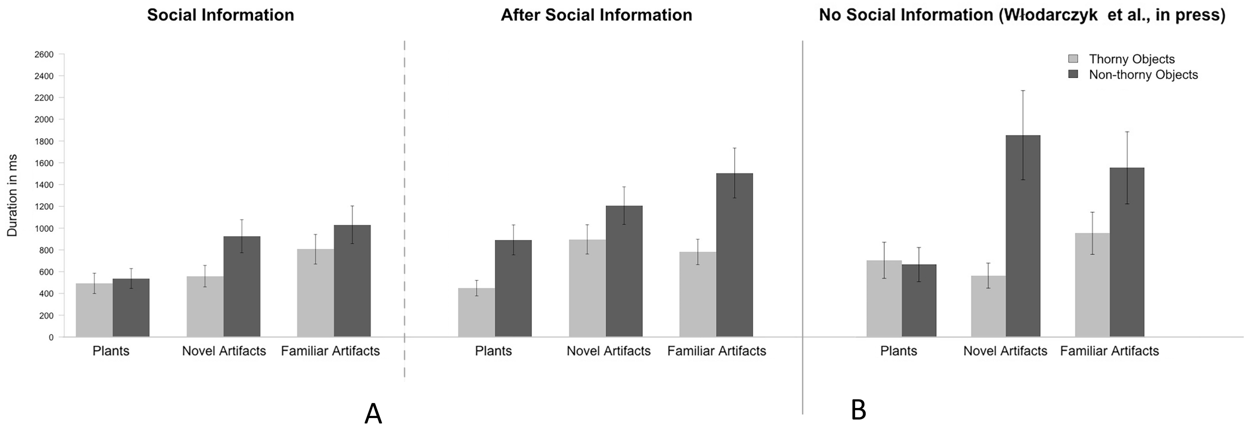


Figure 7. Back-transformed mean first touch duration for any top part of the different object types in the Social Information block and the After Social Information block in the current study (Panel A.) and Chapter 1 in which no social information was presented in the (Panel B). Error bars depict standard errors.

The addition of social information does not appear to change the overall pattern of response for infants' first contact with plants compared to other object types. Like in Chapter 1, infants spend less time touching plants compared to other objects across all presentation conditions. However, compared to the Chapter 1 baseline condition, social information conveyed by the experimenter touching the objects appears to modulate only infants' responses to artifacts, especially the non-thorny novel artifacts.

3.3. Touch frequency to specific parts of the objects (thorny objects only)

Next, in order to explore further infants' subsequent manual exploration of plants, and the thorny parts of plants in particular, when they are presented with social information, we looked at the frequency of touches to particular object parts. We assessed the effects of Object Type, Thorniness, and Social Information on touch frequency to the specific parts of the thorny objects (i.e., the number of touches to thorny parts, non-thorny parts, and touches that contact both parts at the same time; see Table 4 for the descriptive statistics). The frequency data were analyzed with a generalized linear model with a Poisson distribution and a correction for overdispersion due to zero-inflation (g*lmer* function from R-package *lme4;* Bates et al., 2014). Based on the procedure of decreasing the AIC criterion we constructed the model that was the best fit to the data with Touch Frequency as the outcome measure. Our best fit model contained random effects (participant), and within-subjects fixed-effects: Object Type (Plants, Novel Artifacts, Familiar Artifacts), Place of Touch (Thorny, Non-thorny, Both), and their interaction, as well as Social Information (Social Information block vs. After Social Information block), and Session Order (Thorny Objects First vs. Non-thorny Objects First). We report main and interaction effects for the complete best fit model in Table 5.

Table 4. Descriptive statistics for touch frequency in the Social Information block and After Social Information block.

	Touch Frequency					
	Social Information			After Social Information		
	Thorny Parts	Both Parts	Non-thorny Parts	Thorny Parts	Both Parts	Non-thorny Parts
Plants	0.1 (0.04)	0.3 (0.1)	0.9 (0.2)	0.2 (0.1)	0.5 (0.1)	1.1 (0.2)
Novel Artifacts	0.3 (0.1)	0.6 (0.2)	1.0 (0.2)	0.3 (0.1)	0.8 (0.2)	1.1 (0.2)
Familiar Artifacts	0.5 (0.1)	0.3 (0.1)	0.7 (0.2)	0.6 (0.1)	0.4 (0.1)	0.7 (0.2)

Note. Standard errors are provided in parentheses.

Table 5. ANOVA results for the best fit generalized linear mixed-effects model for touch frequency

Effect	Touch Frequency	
	χ2(df)	*p*
Place of Touch	154.04(2)	<.001***
Object Type	16.86(2)	<.001***

Social Info	4.56(1)	<.05*
Session Order	7.32(1)	<.01**
Place of Touch x Object Type	70.29(4)	<.001***

Note. χ2 values (frequency) for effects using Type II Wald F tests with Kenward-Roger df. Asterisks indicate significant results.

The results revealed a significant main effect of Object Type, and a significant main effect of Place of Touch, as well as their interaction. Overall, infants touched plants less frequently compared to both novel artifacts ($t = 6.04$, $p < .001$) and familiar artifacts ($t = 4.32$, $p < .001$; see *Figure 8*) replicating previous results (Chapter 1; Włodarczyk et al., 2018). Infants also touched familiar artifacts less frequently than novel artifacts ($t = 2.20$, $p < .05$).

The effect of the Place of Touch depended on the Object Type. Overall, across other factors, infants touched thorny parts of plants less frequently than the thorny parts of novel artifacts ($t = 4.66$, $p < .001$) and familiar artifacts ($t = 6.61$, $p < .001$). Additionally, infants touched the thorny parts of familiar artifacts more often compared to novel artifacts ($t = 2.95$, $p < .01$), indicating that infants do not avoid thorns in all contexts. This pattern of response for thorny touches replicates previous results (Chapter 1; Włodarczyk et al., 2018). For infants' touches that contact both the thorny and non-thorny parts simultaneously (hereafter "both parts"), infants touched both parts of plants less frequently than both parts of novel artifacts ($t = 4.20$, $p < .001$), yet not less frequently than the familiar artifacts ($t = 0.30$, $p = 0.76$). Additionally, infants touched both parts of novel artifacts more frequently than both parts of familiar artifacts ($t = 4.004$, $p < .001$). For infants' touches to non-thorny parts of the objects, there was no difference in touch frequency for the non-thorny parts of plants and the non-thorny parts of novel artifacts ($t = 0.77$, $p = 0.44$), yet infants touched the non-thorny parts of plants more frequently than the non-thorny parts of familiar artifacts ($t = 2.74$, $p < .01$). Infants also touched non-thorny parts of novel artifacts more frequently than the non-thorny parts of familiar artifacts ($t = 3.68$, $p < .001$).

The results also showed a significant main effect of Social Information. Infants touched objects in the After Social Information block more often compared to Social Information block, revealing that infants are more willing to touch objects after seeing an adult touch similar-looking objects in the previous trial block ($t = 3.31$, $p < .001$).

Finally, we found a significant main effect of Session Order. Infants touched the stimulus objects less frequently when the thorny objects were presented first, compared to when the non-thorny objects were presented first ($t = 2.81$, $p < .01$).

Taken together, these results show that, even when additional social information is present, infants minimize their subsequent physical contact with plants by touching them less frequently than the other object categories. Additionally, infants are especially reluctant to touch the thorny parts of plants, as they touch the thorns of plants least often compared to any other parts of the novel and familiar artifacts. These results are consistent with the findings from Chapter 1 (Włodarczyk et al., 2018), The pattern of results is very similar across the trial block with social information and those after the social information has been presented, however infants touch objects in the after social information block slightly more often.

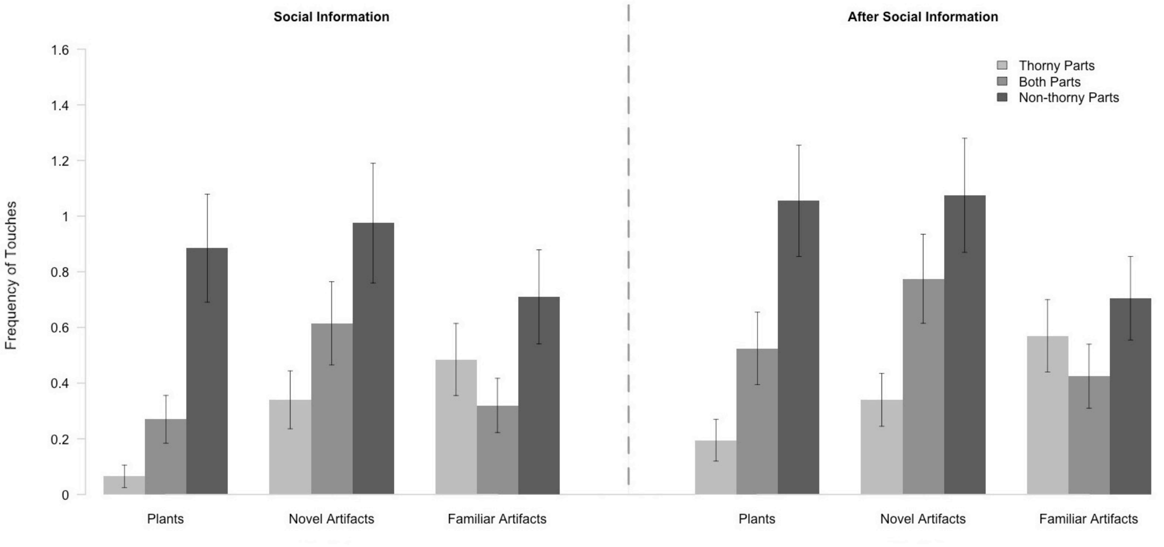


Figure 8. Back-transformed touch frequency to specific parts of the objects (thorny objects only) in the Social Information block and the After Social Information block. Error bars depict standard errors.

3.3.1 Descriptive comparison of touch frequency findings from Chapter 2 and Chapter 1

To preliminarily explore how infants' frequency of touching plants was influenced by the presence of additional social information, we once again juxtaposed the current results with findings presented in Chapter 1 (Włodarczyk et al., 2018) using the same scale (see *Figure 7*).

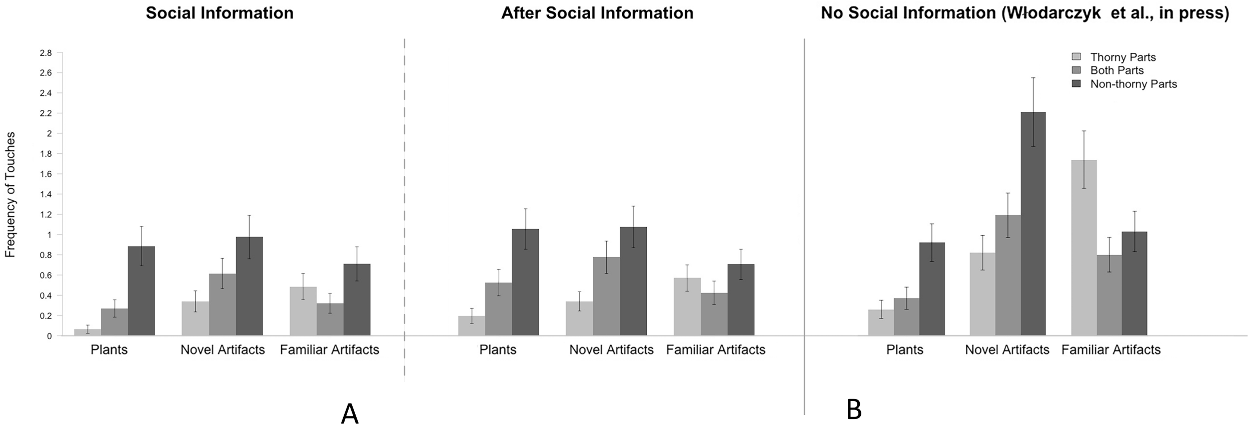


Figure 9. Back-transformed touch frequency to specific parts of the objects (thorny objects only) in the Social Information block and the After Social Information block in the current study (Panel A.) and Chapter 1 in which no social information was presented in the (Panel B). Error bars depict standard errors.

As in the first touch duration descriptive comparisons of Chapter 1 and Chapter 2, when additional social information about the objects is presented, infants' responses to plants seem to be largely unchanged, with one exception: infants appear to touch the thorns on plants less often. In contrast, the additional social information seems to decrease the number of touches infants make to the two artifact types compared to Chapter 1.

3.4. Questionnaire analyses

Following the procedure used in Chapter 1 (Włodarczyk et al, 2018) we conducted correlational analyses of the questionnaire data in order to assess whether infants' prior experiences influenced their responses to our stimulus objects. We looked at infants' prior experience with plants generally, thorny plants specifically, and the familiar artifacts used in the study. We also assessed parents' experience and knowledge about plants, as well as an infant temperament (IBQ-R; Gartstein & Rothbart, 2003) in relation to infants' responses separately in the Social Information and After Social Information trial blocks.

All correlations are reported in Tables S1 – S15 in Supplementary Section 1. As in the Chapter 1 results, the questionnaire measures revealed that most of the previous infants' experiences were not systematically related to infants' touching behavior for plants. Most of the few significant correlations which held after the correction for multiple comparisons, showed significant relationships between the questionnaire measures and infants' responses to artifacts (see Table X).

Interestingly, there were no significant correlations for the questionnaire assessing infants' prior experience with plants generally. However, the results of the questionnaire assessing infants' prior experience with thorny plants indicated that infants whose parents more often encouraged them to touch thorny plants exhibited shorter first touch durations to non-thorny plants (r = -.39, p = .005). Further, the results of the questionnaire assessing parents' own knowledge about plants showed that infants whose parents reported knowing more about the names and characteristics of plants took longer to touch non-thorny plants (r = .39, p = .005).

Finally, the results of the temperament questionnaire (IBQ-R; Gartstein & Rothbart, 2003) showed a significant correlation between infants' score on the Duration of Orientation subscale and infants' first touch duration for thorny plants (r = -.38, p = .007), as well as a significant correlation between infants' score on the Approach subscale and frequency to touch non-thorny parts of plants (r = -.49, p = .003).

4. Discussion

The results of the present study showed that even when presented with additional social information—an adult touching and reacting to an object—,8- to 18-month-old infants remain reluctant to reach for plants compared to other object types, replicating previous findings (Chapter 1, Włodarczyk et al., 2018; Elsner & Wertz, 2019; Wertz & Wynn, 2014a). Infants were also more reluctant to reach for thorny objects compared to non-thorny ones when the objects were accompanied by those social cues, particularly when the thorny objects were presented first. Additionally, infants were more reluctant to reach for the stimulus objects immediately after seeing an adult touching the objects compared to when similar-looking objects were subsequently presented without social cues.

Infants' subsequent manual exploration of the stimulus objects also showed evidence of avoiding plants and thorny objects. Infants spent less time in contact with plants and touched them less frequently than non-plant objects, when provided with social information from an adult. Infants also spent less time in contact with thorny objects compared to non-thorny objects overall. Consistent with the touch latency results, infants spent more time touching the stimulus objects, and touched them more frequently, after seeing an adult touch similar-looking objects in the first trial block.

Taken together, the current findings show that the plant-specific behavioral avoidance strategy (Chapter 1, Włodarczyk et al., 2018; Elsner & Wertz, 2019; Wertz & Wynn, 2014a) is preserved across our measures of initial reaching and subsequent manual exploration, both when additional social information about the objects is presented and continuing after this presentation.

Surprisingly, and contrary to our predictions, infants' behavior toward both plants and non-plant objects did not differ across positive and negative social information conditions. However, our preliminary, qualitative comparisons with the findings from Chapter 1 (Włodarczyk et al., 2018) in which no social information was presented suggest that the experimenter repeatedly touching the objects alone does have an effect on infants' behavior toward the objects. It appears that such social information lessens infants' reluctance to touch all of the object types, even though infants are still overall relatively more reluctant to touch plants. Additionally, it seems that infants' subsequent manual exploration of plants is largely unchanged when the social information is provided, yet infants appear to touch thorns on plants less frequently in the social information condition. Social information seems to decrease infants' subsequent exploration of non-thorny novel artifacts and the thorny parts of familiar objects. These preliminary comparisons suggest that a behavioral avoidance strategy minimizing infants' exposure to plant threats operates both with and without the presence of additional social information from an adult.

4.1. Connections with the existing literature

The findings presented here complement previous studies showing that infants learn socially about the threat-relevant elements of their environment (e.g., Barrett & Broesh, 2012; Broesh, Barrett, & Henrich, 2014; DeLoache & LoBue, 2009; LoBue, Rakison, & DeLoache, 2010). Consistent with previous studies showing that the regulation of infants' behavior is more pronounced in the trials after and not with social information presentations (Gunnar & Stone, 1984; Hornik et al., 1987), infants in the current study were less reluctant to touch and less likely to minimize their contact with all the objects in the trials following the social information presentation. This suggests that infants treated the additional social information from an adult as a signal that these objects are safe to touch and that this information transfers to infants’ later encounters with similar-looking objects.

Our findings are also consistent with previous studies showing that infants’ exploration of objects is influenced overall by social information provided by adults (for review see Feinman, 1992; Mumme et al., 1996; Walden & Ogan, 1988). As the preliminary, qualitative comparisons between Chapter 1 (Włodarczyk et al., 2018) and Chapter 2 suggest, social information modulates infants’ behavior toward plants and non-plant objects. However, the current results diverge from the previous findings of social referencing studies (e.g., De Rosnay et al., 2006; Hertenstein & Campos, 2004; Rapee, 2001, 2007), as infants' behavior toward the stimulus objects did not vary with the different emotional signals displayed by the experimenter. Contrary to our initial predictions, infants did not exhibit more pronounced avoidance behavior when presented with negative emotional expressions compared to positive emotional expressions, neither toward plants in general nor toward threatening elements of plants is particular. The reason for such behavior is not clear at this point.

One possibility is in line with the proposal of Repacholi (2009) and Patzwald et al., (2018) suggesting that when presented with an action performed on the object accompanied by emotional expression, infants understand the affect as a response to the respective action and not to the object itself. Consequently, infants’ imitative behavior is appropriately regulated by different emotional signals displayed by the models, yet infants’ exploratory behavior toward the object does not depend on the emotional display. In our study, we were focused on infants’ appraisal of the objects and we did not measure the imitation of the presented action, so future studies are necessary to investigate this possibility. Additionally, in our procedure the experimenter’s emotional expressions in the negative condition were confounded with her touching behavior. That is, despite showing pain suggesting being hurt after touching each object, the experimenter kept touching the objects. This might have inadvertently presented mixed information to infants, especially in a situation where parent did nothing to prevent the child from approaching or finally touching the harmful object. Thus, infants might not actually have perceived the objects in the negative condition as threatening based on the experimenter's affect, but instead focused on the repeated touching of similar-looking objects.

Another possibility for why infants did not use the emotional cues appropriately is that they could evaluate the meaning of the presented object categories as threatening or non-threatening themselves. Therefore, there would have been no necessity to cope with an ambiguous situation—the kind of situation in which social referencing primarily operates (cf. Gunnar & Stone, 1984). Infants' default strategy is to treat plants as threat-relevant without any input from adults (Chapter 1; Włodarczyk et al., 2018; Elsner & Wertz, 2019; Wertz & Wynn, 2014a), so relying on the others' emotional interpretations to form their own understanding of the objects may be potentially redundant. However, this does not seem likely to be the case because, in the current study, infants' responses to all of the stimulus objects, and the plants in particular, seemed to be modulated by additional social information in the form of the experimenter's touching behavior (cf. the current results with those of Chapter 1). This modulation occurs even though infants disregard the accompanying positive or negative reaction to that touch. Learning about plant threats seems to be a complex process in which different types of social information (an action performed on the object vs. an emotional expression) play different roles in building a child's understanding of threat. More studies are necessary to understand the role of particular aspects of social information in infants' learning about plants and other objects, which has begun to be uncovered here and in previous studies (Elsner & Wertz, 2019; Wertz & Wynn, 2014b).

Finally, the underlying reason why infants did not treat the positive versus negative reactions of the experimenter differently may be related to the procedure used in our study. The emotional expressions presented during the experiment were minimal regarding the time and content of presentation, and the negative and positive expressions were very closely matched. In previous studies that found differences in infants' responses to positive versus negative social information, the emotional display was usually longer (e.g., it consisted of a whole phrase such as, "Oh, how, delightful!") and was repeated several times during one object exposure (e.g., Hertenstein & Campos, 2004; Mumme, Fernald, & Herrera, 1996; Walden & Organ, 1988). In contrast, in the current study the experimenter presented a very short vocal cue "*Ow!*" or "*Wow!*" only once for every presented object. Therefore, infants in our study may have had difficulties in recognizing differences between the two opposite presentations. More research will be necessary to more directly address this possibility.

4.2. The role of infants' previous experiences

Our parent questionnaire measures revealed that infants' previous experiences with plants or the other familiar presented stimulus objects were not systematically related to their reaching behavior for plants. Importantly, similar to the previous studies demonstrating infants' reluctance to touch plants (Elsner & Wertz, 2019; Wertz & Wynn, 2014a), infants' prior experience of being prohibited from touching plants by their parents was not related to their touch behavior toward plants. However, we found that the more parents knew about plants (their names and characteristics), the longer the infants took to touch non-thorny plants. This is in line with the previous findings showing that infants who saw their parents caring for plants more often had longer touch latencies for benign-looking plants (Wertz & Wynn, 2014a), and exhibited even more social looking for plants compared to the other object types (Elsner & Wertz, 2019). In conjunction with the previous findings, the current questionnaire data suggest that infants are responsive to some aspects of social information, however more research will have to be conducted to explore these different aspects in more detail.

4.3. Limitations and future directions

The design of the current study has several limitations. As discussed above, infants may have been unable to distinguish the negative and positive emotional expressions. Therefore, future studies could use longer and more distinct kinds of valence presentation. This longer procedure has already been used in the social referencing literature (e.g., Mumme, Fernald, & Herrera, 1996) and may facilitate infants' recognition of the differences between the two types of emotional valence presentations.

Additionally, as mentioned above, the way the social information was conveyed by the experimenter in our study might have been confounded with the emotional expression presentation. The way of moving forward with this problem could be to look further at our own data and run a first trial analysis. By looking at each infant's response to only the first presented object, we could exclude the influence of the experimenter's repetitive touching behavior. Further, if we find that infants react differently to positive and negative emotion in the first trial, future investigations could use non-repetitive emotional information presentations.

Finally, as the question of which visual features infants use to distinguish plants from the other types of objects still requires empirical examination, it is possible that infants' selective avoidance strategy also applies to other types of entities that of which we are not yet aware. Future studies investigating the processes that infants use to categorize plants can explore this open question.

4.4. Conclusions

The current findings show that infants' behavioral avoidance strategy toward plant threats is preserved, even with the addition of social information and continues after that social information has been presented. Infants' responses to both plants and non-plant objects seems to be influenced by the social signal of an adult touching the object, yet the valence of the adult's emotional reaction to that touch seems to be ignored. Our results suggest that understanding of the complexity of infants learning about the world and its threats requires taking into account both the type of object that infants learn about and the different aspects of social information provided.

References

Bahrick, L. E. (1994). The development of infants' sensitivity to arbitrary intermodal relations. *Ecological Psychology*, *6*(2), 111-123.

Baldwin, D. A., & Moses, L. J. (1996). The ontogeny of social information gathering. *Child Development*, *67*(5), 1915-1939.

Baltazar, N. C., Shutts, K., & Kinzler, K. D. (2012). Children show heightened memory for threatening social actions. Journal of Experimental Child Psychology, 112(1), 102-110.

Barrett, H.C., & Broesch, J. (2012). Prepared social learning about dangerous animals in children. *Evolution and Human Behavior*, 33, 499-508.

Boyd, R., & Richerson, P. J. (1985; 1988). Culture and the evolutionary process. University of Chicago Press.

Broesch, J., Barrett, H. C., & Henrich, J. (2014). Adaptive content biases in learning about animals across the life course. *Human Nature*, *25*(2), 181-199.

Carpenter, M., Nagell, K., Tomasello, M., Butterworth, G., & Moore, C. (1998). Social cognition, joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development*, i-174.

Campos, J. J. (1983). The importance of affective communication in social referencing: A commentary on Feinman. *Merrill-Palmer Quarterly*, 29, 83-87.

Campos, J. J., & Stenberg, C. (1981). Perception, appraisal, and emotion: The onset of social referencing. *Infant Social Cognition: Empirical and Theoretical Considerations*, *273*, 314.

Camras, L. A., & Sachs, V. B. (1991). Social referencing and caretaker expressive behavior in a day care setting. *Infant Behavior and Development*,14, 27-36.

Csibra, G., & Gergely, G. (2006). Social learning and social cognition: The case for pedagogy. *Processes of change in brain and cognitive development. Attention and performance XXI*, *21*, 249-274.

DeLoache, J. S., & LoBue, V. (2009). The narrow fellow in the grass: Human infants associate snakes and fear. *Developmental Science*, 12, 201–207.

De Rosnay, M., Cooper, P. J., Tsigaras, N., & Murray, L. (2006). Transmission of social anxiety from mother to infant: An experimental study using a social referencing paradigm. *Behaviour Research and Therapy*, *44*(8), 1165-1175.

Dubi, K., Rapee, R. M., Emerton, J. L., & Schniering, C. A. (2008). Maternal modeling and the acquisition of fear and avoidance in toddlers: Influence of stimulus preparedness and child temperament. *Journal of Abnormal Child Psychology*, *36*(4), 499-512.

Elsner, B. (2007). Infants' imitation of goal-directed actions: The role of movements and action effects. *Acta Psychologica*, *124*(1), 44-59.

Elsner, C. & Wertz, A.E. (2019). The seeds of social learning: Infants exhibit more social referencing for plants than other types. *Cognition*

Farroni, T., Johnson, M. H., Menon, E., Zulian, L., Faraguna, D., & Csibra, G. (2005). Newborns' preference for face-relevant stimuli: Effects of contrast polarity. *Proceedings of the National Academy of Sciences*, *102*(47), 17245-17250.

Feldman, M. W., Aoki, K., & Kumm, J. (1996). Individual versus social learning: evolutionary analysis in a fluctuating environment. *Anthropological Science*, *104*(3), 209-231.

Fernald, A. (1993). Approval and disapproval: Infant responsiveness to vocal affect in Familiar and unfamiliar languages. *Child Development*, *64*(3), 657-674.

Feinman, S. (1982). Social referencing in infancy. *Merrill-Palmer Quarterly (1982-)*, 445-470.

Feinman, S. (1992). In the broad valley. In *Social referencing and the social construction of reality in infancy* (pp. 3-13). Springer, Boston, MA.

Feinman, S., & Lewis, M. (1983). Social referencing at ten months: A second-order effect on infants' responses to strangers. *Child Development*, 878-887.

Feinman, S., & Roberts, D. (1986). The effect of social referencing on 12-month-olds' responses to a stranger's attempts to “make friends”. *Infant Behavior and Development*, *9*, 119.

Flom, R., & Johnson, S. (2011). The effects of adults' affective expression and direction of visual gaze on 12-month-olds' visual preferences for an object following a 5-minute, 1-day, or 1-month delay. *British Journal of Developmental Psychology*, *29*(1), 64-85.

Frith, C. D., & Frith, U. (2012). Mechanisms of social cognition. Annual Review of Psychology, 63, 287-313.

Gerull, F. C., & Rapee, R. M. (2002). Mother knows best: effects of maternal modelling on the acquisition of fear and avoidance behaviour in toddlers. *Behaviour Research and Therapy*, *40*(3), 279-287.

Gunnar, M. R., & Stone, C. (1984). The effects of positive maternal affect on infant response to pleasant, ambiguous, and fear-provoking toys. *Child Development*, 1231-1236.

Hagen, E. H., Sullivan, R. J., Schmidt, R., Morris, G., Kempter, R., & Hammerstein, P. (2009). Ecology and neurobiology of toxin avoidance and the paradox of drug reward. *Neuroscience*, *160*(1), 69-84.

Hardy, K. (2008). Prehistoric string theory. How twisted fibers helped to shape the world. *Antiquity*, *82*(316), 271-280.

Harris, D. R., & Hillman, G. C. (Eds.). (2014). *Foraging and farming: The evolution of plant exploitation* (Vol. 31). Routledge.

Henry, A. G., Brooks, A. S., & Piperno, D. R. (2014). Plant foods and the dietary ecology of Neanderthals and early modern humans. *Journal of Human Evolution*, *69*, 44-54.

Hewlett, B. S., Fouts, H. N., Boyette, A. H., & Hewlett, B. L. (2011). Social learning among

Congo Basin hunter–gatherers. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *366*(1567), 1168-1178.

Hertenstein, M. J., & Campos, J. J. (2004). The retention effects of an adult's emotional displays on infant behavior. *Child Development*, *75*(2), 595-613.

Hoehl, S., & Pauen, S. (2017). Do infants associate spiders and snakes with fearful facial expressions? *Evolution and Human Behavior*, *38*(3), 404-413.

Hornik, R., Risenhoover, N., & Gunnar, M. (1987). The effects of maternal positive, neutral, and negative affective communications on infant responses to new toys. *Child Development*, 937-944.

Hu, S. (2007). Akaike information criterion. Center for Research in Scientific Computation, 93.

Johnson, M. H. & Morton, J. (1991). Biology and Cognitive Development: The Case of Face Recognition. Oxford: Blackwell.

Kendal, R. L., Boogert, N. J., Rendell, L., Laland, K. N., Webster, M., & Jones, P. L. (2018). Social Learning Strategies: Bridge-Building between Fields. *Trends in Cognitive Sciences*.

Kim, G., & Kwak, K. (2011). Uncertainty matters: impact of stimulus ambiguity on infant social referencing. *Infant and Child Development*, *20*(5), 449-463.

Kingsbury J.M. (1983). The evolutionary and ecological significance of plant toxins. In:

Keeler RF, Tu AT, editors. *Handbook of natural toxins: Plant and fungal toxins*. Vol. 1. New York, NY: Marcel Dekker, Inc; pp. 675–706.

Kinzler, K. D., & Shutts, K. (2008). Memory for ‘‘mean’’ over ‘‘nice’’: The influence of threat on children’s face memory. *Cognition*, 107, 775–783.

Klinnert, M. D., Emde, R. N., Butterfield, P., & Gampos, J. J. (1986). Social referencing: The infant's use of emotional signals from a friendly adult with mother present. *Developmental Psychology,* 22, 427-432.

Laland, K. N. (2004). Social learning strategies. *Animal Learning & Behavior*, 32(1), 4-14.

Lee, R. B. (1993). The Dobe Ju/'hoansi (2nd edition). Fort Worth, TX: Harcourt Brace College Publishers.

LoBue, V., Rakison, D. H., & DeLoache, J. S. (2010). Threat Perception Across the Life Span Evidence for Multiple Converging Pathways. *Current Directions in Psychological Science,* 19(6), 375-379.

Meltzoff, A. N. (1988). Infant imitation after a 1-week delay: Long-term memory for novel acts and multiple stimuli. *Developmental Psychology*, 24, 470-476.

Moore, C. & Dunham, P. J. (1995). Joint Attention. Its Origins and Role in Development. illsdale, NJ: Lawrence Erlbaum.

Morgan, T. J. H., Rendell, L. E., Ehn, M., Hoppitt, W., & Laland, K. N. (2012). The evolutionary basis of human social learning. *Proc. R. Soc. B*, *279*(1729), 653-662.

Mumme, D. L., Fernald, A., & Herrera, C. (1996). Infants' responses to facial and vocal emotional signals in a social referencing paradigm. *Child development*, *67*(6), 3219-3237.

Palo, R. T., & Robbins, C. T. (1991). *Plant defenses against mammalian herbivory*. CRC Press.

Patzwald, C., Curley, C. A., Hauf, P., & Elsner, B. (2018). Differential effects of others' emotional cues on 18-month-olds' preferential reproduction of observed actions. *Infant Behavior and Development*, *51*, 60-70.

Peters, C. R., O'Brien, E. M., Boaz, N. T., Conroy, G. C., Godfrey, L. R., Kawanaka, K., ... & Smith, E. O. (1981). The early hominid plant-food niche: insights from an analysis of plant exploitation by Homo, Pan, and Papio in eastern and southern Africa [and Comments and Reply]. *Current Anthropology*, *22*(2), 127-140.

Pietraszewski, D., Wertz, A. E., Bryant, G. A., & Wynn, K. (2017). Three-month-old human infants use vocal cues of body size. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1856), 20170656.

Repacholi, B. M. (2009). Linking actions and emotions: Evidence from 15-and 18-month-old infants. *British Journal of Developmental Psychology*, *27*(3), 649-667.

Serrano, J. M., Iglesias, J., & Loeches, A. (1992). Visual discrimination and recognition of facial expressions of anger, fear, and surprise in 4-to 6-month-old infants. *Developmental Psychobiology: The Journal of the International Society for Developmental Psychobiology*, *25*(6), 411-425.

Scherer, K. R. (1986). Vocal affect expression: A review and a model for future research. *Psychological Bulletin*, 99, 143-16.

Schmitow, C., & Stenberg, G. (2013). Social referencing in 10-month-old infants. *European Journal of Developmental Psychology*, *10*(5), 533-545.

Sorce, J. F., Emde, R. N., Campos, J. J., & Klinnert, M. D. (1985). Maternal emotional signaling: Its effect on the visual cliff behavior of 1-year-olds. *Developmental Psychology*, *21*(1), 195.

Ungar, P. S., & Sponheimer, M. (2011). The diets of early hominins. *Science, 334*(6053), 190-193.

Walden, T. A., & Ogan, T. A. (1988). The development of social referencing. *Child Development*, 1230-1240.

Wertz, A.E. & Moya, C. (2019). Pathways to cognitive design. *Behavioral Processes*. https://doi.org/10.1016/j.beproc.2018.05.013

Wertz, A.E., & Wynn, K. (2014a). Thyme to touch: Infants possess strategies that protect them from dangers posed by plants. *Cognition, 130,* 44-49.

Wertz, A.E., & Wynn., K. (2014b). Selective social learning of plant edibility in 6- and 18-

month-old infants. *Psychological Science, 24,* 874-882.

Włodarczyk, A., Elsner, C., Schmitterer, A., & Wertz, A.E. (2018). Every rose has its thorn: Infants' responses to pointed shapes in naturalistic contexts. *Evolution & Human Behavior.* https://doi.org/10.1016/j.evolhumbehav.2018.06.001

Supplementary Information

1. Questionnaire analyses

Tables S2-S15 include all the correlations we ran for Latency, First Touch Duration, and Touch Frequency.

Table S1. Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last several months and in the last summer months (6 questionnaire items; corrected alpha level 0.0083) and the latency for the thorny and non-thorny objects in Social Information and After Social Information blocks.

		Plants				Novel Artifacts				Familiar Artifacts			
		Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	How often…	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Indoor & Outdoor plants	Infant interacts with plants	.18	.18	.06	.10	.25	.02	.02	.00	.13	.02	.03	.27
	Parents point out/name plants	.20	.06	.00	.09	.34	.02	.02	.16	.05	.05	.08	.26
	Infant sees parents caring for plants	.10	.04	.10	.22	.14	.05	.03	.03	.01	.10	.13	.26
	Infant eats from plants	.16	.27	.09	.23	.03	.31	.04	.00	.36	.34	.24	.38 * p = .007
	Infant tries to touch plants	.14	.11	.07	.10	.22	.02	.02	.11	.10	.04	.06	.24
	Parents stop infant from touching plants	.18	.13	.01	.13	.24	.04	.03	.00	.16	.18	.02	.02

Table S2. Summary of the correlations between infant's experiences with the thorny plants in the last several months and in the last summer months (5 questionnaire items; corrected alpha level 0.01) and the latency for the thorny and non-thorny objects in Social Information and After Social Information blocks.

	Latency											
	Plants				Novel Artifacts				Familiar Artifacts			
	Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Infant tries to touch thorny plants	-.11	.02	.14	.10	-.12	-.06	-.04	-.19	-.07	-.01	.07	.06
Parents stop infant from touching thorny plants	.03	.11	-.02	-.00	.07	.08	-.12	-.06	-.03	.19	.11	-.01
Parents encourage to touch thorny plants	.16	.10	.29	.12	.20	.24	.24	.16	.36	.37 * *p* = .008	.36	.15
Parents point out/name thorny plants	.05	.16	.23	.14	.10	.13	.20	-.07	.14	.27	.32	.16
Infant sees parents caring for thorny plants	.28	.16	.20	.09	.16	.18	-.06	-.26	.26	.32	-.03	.09

Table S3. Summary of the correlations between parent experience and knowledge about plants (6 questionnaire items; corrected alpha level 0.0083) and the latency for the thorny and non-thorny objects in Social Information and After Social Information blocks.

	Latency											
	Plants				Novel Artifacts				Familiar Artifacts			
	Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Free time spent with plants	.12	.16	.26	.28	.02	.21	.25	.13	.30	.23	.18	.42 ** *p* = .003
Professional time spent with plants	.12	-.09	.03	-.10	.10	-.02	-.07	-.14	.14	.08	.09	-.10
Knowledge about plants	-.08	.05	-.07	.08	-.00	-.08	-.04	-.02	-.18	.08	-.11	.08
Knowledge about names and properties of plants	-.07	.16	.39 ** *p* = .005	.11	.02	.07	.37 ** *p* = .008	.12	.08	.09	.18	.22
Knowledge about the dangerous properties of plants	-.05	.05	.08	-.06	-.04	.03	-.06	-.09	-.02	.27	.00	-.09
Knowledge about plant growth	.09	.06	.22	.03	-.06	-.06	.04	-.25	.11	.21	.10	.28

Table S4. Summary of the correlations between infant's experiences with the familiar objects used in the study (24 questionnaire items; corrected alpha level 0.0021) and the latency for the thorny and the non-thorny objects in Social Information and After Social Information blocks.

	Latency											
	Plants				Novel Artifacts				Familiar Artifacts			
	Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Infant sees parent interacting with shovel	-.04	.05	-.03	.15	-.07	-.02	-.11	-.13	-.09	-.05	-.09	.04
Infant sees parent interacting with rake	-.10	-.01	-.02	.06	.04	-.03	-.17	-.11	-.11	-.16	-.02	-.09
Infant sees parent interacting with hairbrush	.05	-.10	.06	-.02	-.11	-.10	.02	-.06	.10	.21	.03	-.05
Infant sees parent interacting with mirror	.13	.07	.21	.04	.08	.35	.16	.07	.36	.48** *p* =	.18	.17
Infant sees parent interacting with kitchen knife	.17	-.09	.00	-.13	.04	.03	-.04	-.15	.21	.20	.18	.02
Infant sees parent interacting with cutting knife	-.06	-.28	-.15	-.07	-.06	-.12	-.20	-.20	-.06	-.00	-.07	-.13
Infant sees parent interacting with toy key	.09	-.06	.01	.08	.16	.10	.05	.16	.17	.20	.02	-.01
Infant sees parent interacting with door key	.17	.02	.11	.12	.14	.18	.13	.28	.14	.20	.28	.13
Infant interacts with shovel	.02	-.05	-.10	.16	.04	-.03	-.12	-.08	-.02	.05	-.01	.13
Infant interacts with rake	-.06	-.16	-.19	.01	.10	-.03	-.29	-.15	-.07	-.02	-.20	-.09
Infant interacts with hairbrush	-.09	.02	.08	-.06	-.17	-.12	.04	-.01	-.15	.18	.09	.04
Infant interacts with mirror	.07	.09	.16	.10	-.05	.35	.21	.15	.29	.43 ** *p* = .002	.20	.21
Infant interacts with kitchen knife	-.04	.32	.18	-.10	-.04	.32	.13	-.04	.25	.28	.27	.25
Infant interacts with cutting knife	-.18	.18	.14	.09	-.13	.12	.00	-.18	.07	-.08	.00	.19
Infant interacts with toy key	.19	.00	.00	.12	.20	.16	-.08	-.02	.22	.20	-.12	-.04
Infant interacts with door key	-.04	.08	.01	.05	-.16	.02	.03	.09	-.08	-.12	.10	.19
Parents stop infant from touching shovel	-.04	-.13	-.44* *p* = .001	-.04	-.18	-.05	-.36	.01	-.00	-.14	-.14	-.08
Parents stop infant from touching rake	-.12	-.16	-.34	-.07	-.09	-.12	-.32	-.00	-.09	-.18	-.25	-.18
Parents stop infant from touching hairbrush	-.12	-.00	-.14	-.05	-.27	-.12	-.03	.04	-.26	-.22	-.07	-.04
Parents stop infant from touching mirror	.02	.09	-.07	.15	.03	.12	.02	.17	.02	.03	.05	.02
Parents stop infant from touching kitchen knife	-.04	-.03	.14	-.10	.02	.06	.10	.10	.01	.06	.29	-.05
Parents stop infant from touching cutting knife	-.20	-.13	.14	-.09	-.06	.07	.07	.05	-.01	.13	.19	-.14
Parents stop infant from touching key	-.15	-.01	-.06	-.03	-.12	-.16	-.08	-.05	-.12	-.21	.20	-.11
Parents stop infant from touching door key	-.09	.07	.05	.05	-.01	.13	-.02	.14	-.13	-.10	.09	-.14

Table S5. Summary of the correlations between infants' temperament (5 questionnaire items; corrected alpha level 0.01) and the latency for the thorny and non-thorny objects in Social Information and After Social Information blocks.

	Latency											
	Plants				Novel Artifacts				Familiar Artifacts			
	Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Activity Level	.03	.05	.09	.10	-.06	-.14	.17	.02	-.06	.02	.08	.10
Fear	.23	.24	.24	.27	.20	.14	.15	.05	.39 ** p = .006	.15	.27	.12
Duration of Orientation	.12	-.07	.01	.04	-.04	.22	.11	.10	.39 ** p = .006	.28	.34	.35
Perceptual Sensitivity	.01	.10	.02	.11	.09	-.08	-.20	-.15	-.13	-.16	-.17	-.23
Approach	.02	.03	-.04	-.08	-.09	.02	-.06	-.19	-.12	-.12	-.29	-.21

Table S6. Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last several months and in the last summer months (6 questionnaire items; corrected alpha level 0.0083) and the first touch duration for the thorny and non-thorny objects in Social Information and After Social Information blocks.

		Duration											
		Plants				Novel Artifacts				Familiar Artifacts			
		Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	How often…	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Indoor & Outdoor plants	Infant interacts with plants	-.11	-.13	-.07	-.04	.10	-.11	.01	-.15	.31	.04	.10	-.08
	Parents point out/name plants	-.10	-.14	-.09	-.06	.10	-.09	-.18	-.09	.29	-.10	.02	-.09
	Infant sees parents caring for plants	-.09	-.01	-.17	-.17	.10	-.12	-.14	-.18	.09	-.06	-.16	-.20
	Infant eats from plants	-.33	-.27	-.16	-.13	-.04	-.28	-.24	-.18	-.05	-.16	-.11	-.25
	Infant tries to touch plants	-.12	-.02	-.07	-.03	.06	-.13	.02	-.18	.18	.04	.04	-.09
	Parents stop infant from touching plants	.10	.01	-.00	-.13	.15	-.04	-.16	.01	.25	.11	.13	-.19

Table S7. Summary of the correlations between infant's experiences with the thorny plants in the last several months and in the last summer months (5 questionnaire items; corrected alpha level 0.01) and the first touch duration for the thorny and non-thorny objects in Social Information and After Social Information blocks.

	Duration											
	Plants				Novel Artifacts				Familiar Artifacts			
	Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Infant tries to touch thorny plants	.00	-.09	-.20	.00	.16	.01	-.08	-.12	.03	.06	-.05	-.12
Parents stop infant from touching thorny plants	-.12	-.26	-.12	-.12	-.04	-.23	-.20	-.22	-.05	-.16	-.12	-.03
Parents encourage to touch thorny plants	-.27	-.05	-.39 ** *p* = .005	-.01	-.04	-.23	-.45 ** *p* = .001	-.29	-.16	-.15	-.36 ** *p* = .01	-.27
Parents point out/name thorny plants	-.21	-.27	-.40	-.14	-.15	-.27	-.45 ** *p* = .003	-.03	-.04	-.35	-.17	-.08
Infant sees parents caring for thorny plants	-.38 ** *p* = .007	-.13	.15	-.04	-.24	-.13	-.08	.09	-.19	-.29	.04	.12

Table S8. Summary of the correlations between parent experience and knowledge about plants (6 questionnaire items; corrected alpha level 0.0083) and the first touch duration for the thorny and non-thorny objects in Social Information and After Social Information blocks.

	Duration											
	Plants				Novel Artifacts				Familiar Artifacts			
	Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Free time spent with plants	-.18	-.03	-.06	-.19	-.04	-.04	-.13	-.26	.05	-.07	-.15	-.14
Professional time spent with plants	.15	.05	-.06	.08	.08	.11	.08	.08	.02	-.05	.09	.04
Knowledge about plants	.21	-.14	-.05	.03	.18	-.05	.02	.04	.33	-.14	.01	.06
Knowledge about names and properties of plants	-.07	-.25	-.11	-.14	.00	-.26	-.32	-.01	-.00	-.26	-.11	-.10
Knowledge about the dangerous properties of plants	-.17	-.13	-.08	.06	-.03	-.16	-.14	-.08	-.26	-.18	-.09	-.02
Knowledge about plant growth	-.18	-.05	-.18	-.12	.11	.03	.02	-.12	.00	.07	-.11	-.18

Table S8. Summary of the correlations between infant's experiences with the familiar objects used in the study (24 questionnaire items; corrected alpha level 0.0021) and the first touch duration for the thorny and the non-thorny objects in Social Information and After Social Information blocks.

	Duration											
	Plants				Novel Artifacts				Familiar Artifacts			
	Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Infant sees parent interacting with shovel	.02	-.14	.07	-.07	.08	-.06	-.12	.02	.15	-.02	.12	-.02
Infant sees parent interacting with rake	-.06	-.10	.07	-.07	-.03	-.03	-.07	.12	.02	.02	.23	.04
Infant sees parent interacting with hairbrush	-.09	.14	.09	.09	.06	.13	.02	-.00	-.02	.02	-.06	.01
Infant sees parent interacting with mirror	-.13	-.08	-.16	-.14	-.10	-.19	-.18	-.06	-.26	-.31	-.14	-.30
Infant sees parent interacting with kitchen knife	-.25	-.08	-.12	-.07	-.12	-.04	-.10	.07	-.10	-.12	-.12	-.08
Infant sees parent interacting with cutting knife	.01	.22	.07	-.03	.06	.16	-.04	.06	.00	.06	-.01	-.01
Infant sees parent interacting with toy key	-.09	.09	-.03	.06	-.23	-.10	-.06	-.21	-.28	-.15	-.17	-.18
Infant sees parent interacting with door key	-.22	-.09	-.06	-.12	-.11	-.21	-.14	-.07	.04	-.13	-.15	-.12
Infant interacts with shovel	.01	.05	.00	-.12	-.03	.01	-.15	-.12	.13	.08	-.06	-.28
Infant interacts with rake	-.04	.06	.03	-.05	-.10	.02	-.15	-.01	-.06	.09	.11	-.09
Infant interacts with hairbrush	.02	-.06	.02	.26	.15	.07	.04	.02	.18	.08	.04	.10
Infant interacts with mirror	-.14	-.07	-.13	-.19	-.02	-.26	-.20	-.12	-.19	-.26	-.16	-.26
Infant interacts with kitchen knife	-.30	-.27	-.27	.01	-.07	-.33	-.17	-.10	.02	-.23	-.02	-.08
Infant interacts with cutting knife	-.16	-.09	-.32	-.14	-.10	.03	-.15	.04	.08	.10	.09	-.16
Infant interacts with toy key	-.05	-.02	-.06	.08	-.10	-.10	.05	-.21	-.19	-.20	-.09	-.24
Infant interacts with door key	-.16	.03	-.08	-.03	.04	.04	.01	-.20	.13	.21	-.02	-.18
Parents stop infant from touching shovel	.15	.14	.06	.14	.04	.13	.14	.13	.07	.14	.12	.09
Parents stop infant from touching rake	.19	.12	.07	.14	.03	.13	.12	.09	.02	.18	.13	.11
Parents stop infant from touching hairbrush	.17	-.03	-.00	-.00	.26	.02	-.04	-.06	.24	.15	.04	-.04
Parents stop infant from touching mirror	.12	-.16	-.23	-.16	.10	-.21	-.32	-.22	.10	.01	-.10	-.20
Parents stop infant from touching kitchen knife	-.28	.13	-.03	-.03	-.22	-.17	-.02	.02	-.12	-.10	-.15	.10
Parents stop infant from touching cutting knife	-.13	.14	.04	.06	-.07	-.10	-.06	.10	-.16	-.09	-.07	.17
Parents stop infant from touching key	.15	.04	.04	.06	.04	.10	.08	.07	-.04	.14	.09	.05
Parents stop infant from touching door key	-.14	-.15	-.09	-.04	-.04	-.25	-.11	-.12	.08	-.21	-.13	-.06

Table S9. Summary of the correlations between infants' temperament (5 questionnaire items; corrected alpha level 0.01) and the first touch duration for the thorny and non-thorny objects in Social Information and After Social Information blocks.

	Duration											
	Plants				Novel Artifacts				Familiar Artifacts			
	Thorny		Non-thorny		Thorny		Non-thorny		Thorny		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Activity Level	-.02	-.05	-.02	-.22	.10	-.20	-.13	-.23	.01	-.07	-.32	-.14
Fear	-.30	-.22	-.20	.24	-.17	-.21	-.20	-.09	-.19	-.09	-.32	-.17
Duration of Orientation	-.38 ** *p* = 007	-.10	-.09	-.10	-.14	-.12	-.19	-.04	-.19	-.17	-.19	-.11
Perceptual Sensitivity	-.14	-.07	.04	.12	-.11	.03	.06	.05	-.09	.04	.17	.06
Approach	.17	.10	.35	.25	.10	-.01	.10	.16	.02	-.07	.29	.21

Table S10. Summary of the correlations between infant's experiences with the indoor and outdoor plants in the last several months and in the last summer months (6 questionnaire items; corrected alpha level 0.0083) and the touch frequency to specific parts of the thorny objects in Social Information and After Social Information blocks.

		Touch Frequency																	
		Plants						Novel Artifacts						Familiar Artifacts					
		Thorny		Both		Non-thorny		Thorny		Both		Non-thorny		Thorny		Both		Non-thorny	
	How often…	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Indoor & Outdoor plants	Infant interacts with plants	.64	-.43	-.02	-.08	.13	-.22	.02	-.12	.07	-.11	.15	-.07	-.15	-.18	-.22	-.17	-.02	-.02
	Parents point out/name plants	.66	-.22	.01	-.20	-.08	.05	-.06	-.09	-.02	-.16	-.01	-.25	-.27	-.09	-.43	.01	.14	.01
	Infant sees parents caring for plants	.92	-.01	-.13	-.32	-.08	-.02	-.05	-.29	-.11	.07	-.05	-.22	-.01	-.32	-.08	-.00	-.01	.15
	Infant eats from plants	.63	.02	.01	-.09	-.18	-.03	.24	-.03	-.36	-.11	-.26	-.23	.04	-.14	-.13	-.02	.37	-.12
	Infant tries to touch plants	.61	-.47	.09	-.11	.10	-.20	.04	.21	.12	-.07	.21	.07	-.14	-.11	-.07	-.16	.12	-.03
	Parents stop infant from touching plants	-.23	.09	-.21	-.32	.18	-.17	.14	.12	-.18	.08	.37	-.13	-.27	-.00	.33	.09	.24	-.14

Table S11. Summary of the correlations between infant's experiences with the thorny plants in the last several months and in the last summer months (5 questionnaire items; corrected alpha level 0.01) and the touch frequency to specific parts of the thorny objects in Social Information and After Social Information blocks.

	Touch Frequency																	
	Plants						Novel Artifacts						Familiar Artifacts					
	Thorny		Both		Non-thorny		Thorny		Both		Non-thorny		Thorny		Both		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Infant tries to touch thorny plants	1.00 ** $p<0.001$	-.16	.44	.03	-.20	-.04	-.14	-.18	-.33	-.25	-.31	-.10	-.15	.12	-.20	.14	.20	.08
Parents stop infant from touching thorny plants	.61	-.20	.16	-.20	-.04	-.08	.02	-.23	-.17	-.13	-.13	.06	.15	.09	-.06	.04	.20	.12
Parents encourage to touch thorny plants	.41	.12	.13	-.28	-.27	.17	-.23	-.01	-.30	-.30	-.46 ** $p = .005$	-.22	.08	.16	-.02	.12	.18	.10
Parents point out/name thorny plants	.98	-.08	.17	-.30	.12	-.04	-.13	-.25	-.13	-.17	-.41	-.08	-.09	.04	-.08	.30	.08	.08
Infant sees parents caring for thorny plants	.52	.06	.02	-.12	-.25	.07	-.13	-.03	-.26	-.29	-.51 ** $p = .005$	.09	.13	-.44	.14	.21	-.05	-.14

Table 12. Summary of the correlations between parent experience and knowledge about plants (6 questionnaire items; corrected alpha level 0.0083) and the touch frequency to specific parts of the thorny objects in Social Information and After Social Information blocks.

	Touch Frequency																	
	Plants						Novel Artifacts						Familiar Artifacts					
	Thorny		Both		Non-thorny		Thorny		Both		Non-thorny		Thorny		Both		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Free time spent with plants	.87	.28	.04	.01	.05	.05	-.14	-.06	-.17	-.29	-.20	-.22	-.13	-.25	-.16	-.01	-.00	-.04
Professional time spent with plants	.b	.60	.b	-.17	-.25	.25	-.20	-.17	.12	-.00	.14	-.06	.04	.02	.b	-.10	.01	-.16
Knowledge about plants	.61	.30	-.52	-.21	-.03	.21	-.13	-.09	.20	-.31	-.09	-.04	.01	-.02	.04	-.08	.11	-.06
Knowledge about names and properties of plants	.41	-.09	.06	-.34	.06	.08	.00	-.22	.10	-.08	-.15	-.24	-.11	.01	-.33	.06	.06	.19
Knowledge about the dangerous properties of plants	.17	-.12	.06	-.14	.18	-.16	.05	.17	.24	-.07	.06	.06	.21	-.05	-.14	.02	.12	.01
Knowledge about plant growth	.67	.37	.31	.02	-.13	-.02	-.12	-.09	-.13	-.17	-.25	-.05	-.15	-.28	-.04	.08	.19	.05

Table 13. Summary of the correlations between infant's experiences with the familiar objects used in the study (24 questionnaire items; corrected alpha level 0.0021) and the touch frequency to specific parts of the thorny objects in Social Information and After Social Information blocks.

	Touch Frequency																	
	Plants						Novel Artifacts						Familiar Artifacts					
	Thorny		Both		Non-thorny		Thorny		Both		Non-thorny		Thorny		Both		Non-thorny	
	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info	Social Info	After Social Info
Infant sees parent interacting with shovel	.84	-.07	.08	-.17	-.03	-.11	-.02	-.15	-.14	.02	-.12	.12	.17	-.16	-.11	.16	.14	.02
Infant sees parent interacting with rake	.72	-.02	.11	-.18	-.04	-.17	.28	.04	-.19	-.03	-.09	.04	-.11	.05	-.02	.27	.09	.02
Infant sees parent interacting with hairbrush	.41	-.06	.09	-.03	-.21	-.15	.12	.01	-.14	.09	-.14	-.10	.34	.15	-.09	-.24	-.01	-.11
Infant sees parent interacting with mirror	.33	.24	.35	.00	-.36	-.09	-.40	-.19	.08	-.11	-.20	-.29	-.10	-.19	.18	-.08	.10	.09
Infant sees parent interacting with kitchen knife	.61	.c	.19	.06	-.15	.15	-.01	.01	-.17	.06	-.21	.04	.09	.01	.23	.10	.10	-.24
Infant sees parent interacting with cutting knife	.61	.23	.11	.03	-.04	.26	-.24	-.10	-.34	.16	-.29	-.00	.05	.04	.17	.17	-.07	-.16
Infant sees parent interacting with toy key	.61	.10	.11	.07	-.10	.12	.10	.24	.32	-.02	.16	.17	.28	.05	-.21	-.02	.17	.05
Infant sees parent interacting with door key	.c	-.32	.24	.24	.11	.12	.20	.17	-.47	.17	-.20	-.12	.08	-.04	-.01	.08	-.17	.08
Infant interacts with shovel	.80	-.19	.18	-.01	-.17	-.10	-.17	-.14	-.06	.10	-.30	.14	.08	-.33	.21	.27	.03	.01
Infant interacts with rake	.84	-.16	.15	.01	-.25	-.13	-.26	-.04	-.08	-.15	-.30	.12	-.15	-.11	.15	.32	.08	.05
Infant interacts with hairbrush	.61	-.64 ** *p* = .005	-.03	.10	-.27	-.06	.20	-.37	-.26	-.14	-.36	-.10	.19	-.15	.10	-.11	.08	.15
Infant interacts with mirror	.27	-.14	.41	.21	-.08	-.19	.03	.14	.05	-.17	-.41	-.20	-.21	.01	.00	.04	.23	-.03
Infant interacts with kitchen knife	.00	-.27	.10	-.14	-.11	.08	.17	.03	-.34	-.18	-.23	.06	.07	-.18	-.14	.12	.22	.08
Infant interacts with cutting knife	.17	-.18	.11	-.15	-.23	.22	-.09	.20	-.34	-.26	-.29	-.04	-.27	.04	-.16	.20	-.13	-.06
Infant interacts with toy key	.64	.40	.10	.11	-.27	.25	.06	.12	.32	-.00	.13	.14	.52	-.19	-.22	.15	.09	.00
Infant interacts with door key	-.33	-.48	.38	.00	.16	-.01	.20	.26	-.32	.17	.04	.14	.11	-.17	-.22	-.02	-.09	.15
Parents stop infant from touching shovel	.c	.c	-.25	-.02	-.13	-.16	.11	.15	.15	.16	.17	.05	.08	.04	-.17	-.18	.03	-.16
Parents stop infant from touching rake	.c	.c	-.24	-.08	-.11	-.25	-.20	.c	.29	.04	.12	.04	-.12	.03	-.16	-.14	.03	-.22
Parents stop infant from touching hairbrush	-1.000 ** *p* < 0.001	-.06	-.05	-.15	.19	.08	.36	.36	.07	.29	.52 ** *p* = .001	.06	.12	.34	-.34	-.30	-.04	-.04
Parents stop infant from touching mirror	.41	.18	-.10	-.26	-.13	-.22	.17	-.01	.26	-.12	.24	-.06	-.02	-.05	-.20	-.23	.05	.01
Parents stop infant from touching kitchen knife	.22	-.33	.16	-.03	.15	-.19	.32	.36	-.23	.07	.01	.27	.02	.02	.03	-.18	.14	.12
Parents stop infant from touching cutting knife	.41	-.33	.16	-.10	.13	-.10	-.16	.12	-.42	-.08	-.15	.04	-.27	.12	.00	.11	.06	.02
Parents stop infant from touching key	.c	.c	-.17	-.17	-.06	-.25	.c	-.17	.39	-.00	.18	.05	.38	.02	-.12	-.10	.13	-16
Parents stop infant from touching door key	-.17	-03	-.39	-.17	.22	.02	.13	.30	-.04	.18	.29	-.23	.14	.28	-.24	.15	.30	-.06

Table 14. Summary of the correlations between infants' temperament (5 questionnaire items; corrected alpha level 0.01) and the touch frequency to specific parts of the thorny objects in Social Information and After Social Information blocks.

	Touch Frequency																	
	Plants						Novel Artifacts						Familiar Artifacts					
	Thorny		Both		Non-thorny		Thorny		Both		Non-thorny		Thorny		Both		Non-thorny	
Activity Level	-.63	.03	-.29	-.25	.26	.30	.24	.57 ** *p* = .003	-.10	.20	.16	.13	-.04	.29	-.14	-.08	.06	-.04
Fear	.62	.27	-.04	-.07	-.00	-.03	.16	.43	-.18	-.06	-.22	-.05	-.06	.18	-.09	-.02	.12	-.22
Duration of Orientation	-.10	.43	.19	.11	.06	.14	.05	.30	-.26	-.01	-.23	-.03	.10	.13	-.14	.08	.03	-.14
Perceptual Sensitivity	.16	.09	-.30	-.28	-.19	-.01	.17	.11	-.17	-.20	.19	.01	.31	-.04	.19	.17	-.01	-.18
Approach	.39	-.27	-.25	-.07	-.48 ** *p* = .003	.02	.40	.20	-.19	-.15	-.13	.03	-.09	.03	-.01	.15	.25	.01

Chapter 3. Infants’ visual attention patterns for pointed shapes in a plant context

1. Introduction

Numerous studies show that human attention is biased toward ancestrally recurrent threatening stimuli, such as dangerous animals or violent conspecifics (LoBue & Rakison, 2013; Öhman & Mineka, 2001; Öhman, Flynkt, & Esteves, 2001). Since the appearance of the genus *Homo* about 1.9 million years ago humans have been experiencing dangerous encounters which shaped their cognition and behavior (Wood & Collard, 1999). Successfully negotiating such encounters depended on an array of cognitive mechanisms and skills, one of which was selective sensitivity of the perceptual system (Barrett, 2005). Facilitated attentional response to danger has been crucial for survival as it enabled quick assessment of potential sources of harm in the environment, followed by appropriate self-protective actions. Accordingly, studies using a number of various visual attention tasks consistently show that threat is preferentially processed at the early stages of perception (Koster, et al., 2004; MacLeod, Mathews, & Tata, 1986; MacNamara et al., 2013; Posner, 1980).

1.1. Components of attentional bias to threat in adults and young children

Experimental tasks assessing attentional bias to threat use mainly visual threat analogs, such as pictures depicting angry humans or wild animals in the position of attacking the viewer. For comparison, non-threatening stimuli is used, such as neutral facial expressions or pets. Based on the results from these visual attention tasks, two components of the threat bias have been reported: attentional capture and holding. Threatening stimuli capture attention when individuals are particularly quick to locate or orient toward the threat-relevant pictures in comparison to the non-threatening ones. Attention holding occurs when individuals have difficulty disengaging from the threatening stimuli. Both attentional components have been shown in adults and young children. For example, LoBue & DeLoache (2008) using a visual detection task, found that preschool children and adults detected snakes more rapidly than flowers, frogs or caterpillars. This attention capture effect has been reported by many other researchers presenting participants with pictures of snakes or spiders along side a variety of benign control stimuli (e.g., Flykt, 2005, 2006; Hayakawa, Kawai, & Masataka, 2011; Lipp, 2006). Adults and young children also locate threatening social stimuli, such as angry faces, faster than non-threatening happy, neutral, and sad faces (Calvo, Avero, & Lundqvist, 2006; Esteves, 1999; LoBue, 2009; Lundquist & Öhman, 2005; Schubo, Gendolla, Meinecke, & Abele, 2006). The process of attention holding has been shown in studies where threatening stimuli were presented as distracters in a search task. For instance, individuals detect happy faces slower when angry faces are used as distracters (Horstmann, Scharlau, & Ansorge, 2006) and they are slower to find images of cats or rabbits when snakes and spiders are presented as distracters (Forbes, Purkis, & Lipp, 2011; Lip & Waters, 2007).

However, some studies show a reversed attentional pattern, namely an avoidance of threatening stimuli. This type of response is often reported in studies using long presentation times and free-viewing conditions (Hunnius et al., 2011). For instance, Becker et al. (2009) found that participants passively viewing displays consisting of one emotional face among three neutral faces were actively avoiding looking at angry and fearful faces compared to the other emotional displays.

1.2. Attentional capture and holding by threat in infancy

Ancestrally recurrent threatening stimuli are privileged in attention very early in development (for a review, see LoBue & Rakison, 2013). Studies with young infants show evidence that threat captures attention already within the first year of life. More specifically, 8- to 14-month-old infants orient more quickly toward snakes compared to flowers and toward angry faces compared to happy ones when presented with pairs of stimulus images side by side (LoBue & DeLoache, 2010). Moreover, 5-month-olds look longer in a preferential looking paradigm at schematic spider images than at scrambled versions of these stimuli (Rakison & Derringer, 2008). The holding of attention to threatening stimuli has also been found in infancy. In particular, infants take significantly longer to disengage their attention from centrally presented threat-relevant faces compared to happy or neutral ones to allocate their attention to a peripheral target (Nakagawa & Sukigara, 2012; Peltola et al., 2009). These results show that the capture and holding of attention by threatening stimuli is present as early as the first year of life.

Nonetheless, the reverse attentional pattern is also noted in the infancy literature. Infants as young as 4 months show avoidant looking pattern while visually scanning threatening facial expressions with reduced dwell times and fewer fixations distributed over the entire stimulus (Hunnius et al., 2011).

1.3. The role of low-level shape features in biased responses to threat

Some researchers suggest that the underlying mechanism of attentional bias to threat may be related to the low-level perceptual features that frequently occur in threatening stimuli (Becker, Horstmann, & Remington, 2011; Horstmann, 2009; Horstmann, Borgstedt, & Heumann, 2006; LoBue, 2013; LoBue, Rakison, & DeLoache, 2010). There is some evidence that specific geometric shapes, such as the ‘‘V’’ shaped brow attribute of angry faces or curvilinearity typical of snakes are sufficient to evoke attention capture (Larson, Aronoff, & Stearns, 2007; LoBue & DeLoache, 2011; LoBue & Larson, 2010). There are also studies showing that adults prefer curved contours over sharp angles (Bar & Neta, 2006; Silvia & Barona, 2009), and even newborn infants preferentially fixate on curved contours compared to sharp-angled ones (Fantz & Miranda, 1975) and it is hypothesized by some authors that pointed forms convey information about threat (Bar & Neta, 2006).

1.4.Infants' responses to plant threats

Despite many existing studies on infants' biases to ancestrally recurrent threatening stimuli, such as dangerous animals or threatening facial expressions, little is known about infants' attentional reactions to ancestrally recurrent dangers in broader naturalistic contexts.

Recent behavioral studies are providing growing evidence that infants are sensitive to plant dangers (Elsner & Wertz, 2019; Wertz & Wynn, 2014; Włodarczyk et al., 2018). For example, Włodarczyk et al. (2018; i.e., Chapter 1 of this dissertation) showed that 8- to 18-month-old infants exhibit both an initial reluctance to touch and minimized subsequent physical contact with plants compared to other object types. Further, there were no differences in infants' touch latencies or touch durations for plants with and without thorns, suggesting that infants treat all plants as potentially dangerous whether or not they possess visible indicators of threat. However, infants did show sensitivity to visible plant threats during the later phases of object exploration: they touched the thorny parts of plants less frequently than either the thorny or non-thorny parts of any of the other object types. Notably, evidence for a similar reluctance to touch plants has also recently been found in children from an environment with intensive exposure to plants: Shuar children from the Amazon region in Ecuador (Wertz, Erut, Smith, Elsner, & Barrett, in prep).

As Chapter 2 demonstrates, infants continue to show evidence of a behavioral avoidance strategy toward plants when additional social cues are present. In that study, the stimuli were presented to infants by an experimenter who first touched the stimulus object and then reacted with pain or with delight signaled with a facial expression (negative vs. positive) and a vocalization ("*Ow!*" vs. "*Wow!*"). Surprisingly, infants did not respond differently to the plants or other stimulus objects in the negative and positive social information conditions. Instead, they only seemed to react to the fact that experimenter physically touched the objects. In comparison to the results without any social information (Chapter 1; Włodarczyk et al., 2018), infants' reluctance to touch all of the stimulus objects was reduced. This reduction appeared to be particularly strong for the plants, even though infants nevertheless still exhibited a relative avoidance for plants than the other stimulus objects tested.

1.5. The current experiment

The underlying mechanism mediating these selective behavioral responses to plants is still unclear. Given the hypothesized threat-relevance of pointed shapes (e.g., Bar & Neta, 2006) and the preferences for curvilinear forms present already after birth (Fantz & Miranda, 1975), we may expect that different low-level shape features are playing a role in facilitating avoidance responses to thorns on plants. Thus far, our behavioral results show that infants treat novel and familiar artifacts with and without thorns differently (duration of first touch), but treat thorny and non-thorny plants the same (Chapter 1; Włodarczyk et al., 2018). Nevertheless, comparing across categories, infants touch thorns on plants even less than thorns on the other objects (Chapter 1; Włodarczyk et al., 2018; Chapter 2). Therefore, here we are focusing on the differences within an object category between pointed and non-pointed shapes, to investigate whether there is evidence of low-level perceptual mechanism underlying infants' selective behavioral responses. In particular, we test whether the presence of pointy-shaped elements (e.g., thorns) influence infants' visual attention, and whether any such effect would differ depending on the context in which the thorns are presented (i.e., on plants vs. other object types).

To investigate these questions, we used a dot-probe paradigm. It is a well-established task measuring attentional bias to threat (defined as attention capture and holding) in adults and children (MacLeod, Mathews, & Tata, 1986; Lipp & Derakshan, 2005; Roy, Dennis, & Warner, 2015). The task is designed to measure how strongly attention is captured and held by threat-relevant stimuli. Participants are shown a pair of pictures for a short time at two different positions along the midline of a screen. One of the pictures is threatening, the other one is neutral. After the offset of these stimuli, a dot probe appears on the screen in the previous position of one of the stimuli. Adults or children are asked to press one of two keys as quickly and as accurately as possible to indicate whether the probe occurred in the position of the left or right picture.

The task consists of congruent trials where the dot appears at the location of the threatening stimulus and incongruent trials where the dot appears on the opposite side of the threatening stimulus. The allocation of attention is measured by the time needed to respond to the dot probe. It is reasoned that responding to the probe will be faster when attention is already shifted to the spatial location where the probe appears. By examining the difference in participants' gaze latencies to fixate at the probe appearing either at the congruent or incongruent trials we infer the pattern of expected attentional bias to the threatening cues. If participants are faster to respond when they are presented with congruent trials versus incongruent trials, it is inferred that participants' attention is drawn toward and held by the threat-relevant stimuli. The opposite pattern indicates an avoidance of threat.

The task has been recently adapted for use with infants for the first time by LoBue and colleagues (LoBue et al., 2016). In this age-appropriate version the behavioral reaction time (RT) responses have been replaced by the use of eye-tracking technology to assess the location and duration of infants' visual attention. LoBue and colleagues (2016) in two experiments investigated the developmental differences in 4- to 24-month-old infants' attention to social (i.e., angry faces) and non-social (i.e., snakes) animate threats. The authors measured infants' latency to first fixate the probe and infants' overall attention to threatening stimuli before the onset of the probe (i.e., dwell time to each stimulus and the number of first fixations). The results of the study using social stimuli did not show evidence for an attentional bias toward angry faces. However, the findings of the study using animal stimuli showed that infants were faster to fixate probes that appeared in place of threating animals. That is, infants fixated snakes first compared to frogs, and also fixated more often on snakes first compared to frogs. These effects provided further evidence for a perceptual bias for the ancestrally recurrent threat of snakes in infancy.

Here, in order to test whether infants possess an attentional bias toward the visually threatening elements of plants, we adapted LoBue and colleagues' modified dot-probe paradigm to assess 8- to 10-month-old infants' attentional patterns for objects with pointed versus round elements. The objects belonged to three categories: plants, novel artifacts, and familiar artifacts. In the current study, infants were presented with pairs of objects. The object pairs were always of the same category type. One of the objects included visually-threating pointy-shaped elements (e.g., thorns), and the other included size- and location-matched round elements. The object pairs were then followed by a probe appearing at a location either congruent or incongruent with the prior location of the stimulus with visually-threating elements. Because our stimuli were perceptually more complex than the stimuli presented by LoBue and colleagues, we lengthened the stimuli presentation time compared to their study. Additionally, we presented infants with negative social information—a negative vocalization—during the introductory phase of our study. We assessed two convergent measures of infants' initial attention to threating stimuli: latency to first fixation and overall looking time.

If infants' attention is biased toward thorny objects, we would expect infants to have shorter latencies to fixate the probe in the congruent trials than in the incongruent trials. Given the existing behavioral results showing infants' avoidance strategy towards plants compared to other objects, we may also expect to observe the strongest effect of thorns on plants. Another possibility, given our longer stimulus presentation times (see e.g., Becker & Detweiler-Bedell, 2009), is that infants would exhibit the reversed attentional pattern. That is, infants may avoid fixating on pointed forms, especially in the context of plants. Finally, there may be no attentional bias toward our relatively complex and inanimate threatening stimuli.

2. Methods

2.1. Participants

Fifteen 8- to 10-month-old infants (8 female; Mean Age = 9.07 months; Range = 8.08 – 10.06) participated in the study. This age group was selected based on the prior research showing both enhanced visual detection of ancestrally relevant threatening stimuli (LoBue & DeLoache, 2010; LoBue et al., 2016) and sensitivity to plant threats (Elsner & Wertz, 2019; Wertz & Wynn, 2014a; Włodarczyk et al., 2018) by 8 months of age. Infants were recruited from the participants' database of the Max Planck Institute for Human Development in Berlin, Germany and tested in the Institute's BabyLab. All infants were healthy and born full term, without vision correction. Five more infants were tested but excluded from the analyses because of fussiness (N=3), mistake in recruiting (N=1), and procedure error (N=1). The study was approved by the Ethics Committee of the Max Planck Institute for Human Development and all parents gave written consent for their child's participation. Each family was compensated with 10 Euros and a paper certificate of participation with their child's name.

2.2. Stimuli

The picture stimuli were 24 color images of four different types of plants, novel artifacts and familiar artifacts (see *Figure 1*) presented on a white background. There were two versions of each object type: one with thorny or pointed elements and one with size- and location-matched rounded elements. The amount of visual information presented in 2D across object types and their elements was kept approximately similar. The stimulus images were designed by the authors and rendered by the IT support of the Max Planck Institute for Human Development in Berlin, using 3ds MAX® modeling and rendering software (Version: Autodesk 3ds Max 2016).

The image stimuli were modelled on the objects used in the previous investigations of infants' behavioral responses to plants (Włodarczyk et al., 2018; Włodarczyk, Rioux, & Wertz, under review). However, as infants' responses to plants in two-dimensional space are not well studied yet, and infants have difficulties processing 2D stimuli compared to 3D (e.g., Barr, 2010, 2013; Barr & Hayne, 1999), the number of elements on each object was minimized in the current study compared to the earlier 3-D presentations. Additionally, the plants were presented as growing directly from the soil, instead of being arranged in plastic pots as they were for the previous behavioral studies.

The plants used in our stimulus set were comprised of a stem protruding from a pile of soil, and six leaves with four different shapes: oval, hastate, heart-shaped and orbicular (see Fig 1). Ten thorns or rounded elements protruded from the stems of each plant in the same locations. The novel artifacts were designed to closely match the visual complexity of the plants. They had exactly the same individual elements, but these elements were given different colors and arranged in different configurations that are not typical for naturally-occurring forms.

The stimulus elements that comprised the plants and novel artifacts had the following dimensions: There were ten pointy-shaped, cactus-like thorns on the plants and the novel artifacts: six small-sized ones (approximately 1.5 cm long and 3 mm wide at the base), one medium-sized (approximately 3 cm long and 3 mm wide at the base) and three large-sized (approximately 4 cm long and 4 mm wide at the base). Consequently, there were also ten rounded elements on the equivalent versions of the plants and the novel artifacts: six small-sized ones (approximately 6 mm in diameter), one medium-sized (approximately 8 mm in diameter) and three big-sized (approximately 1.2 mm in diameter). The familiar artifacts consisted of two parts: a bottom part where the object is usually held and a top part with distinguishable pointy or rounded elements (see *Fig 1*). The familiar artifacts in the set were a door key and a toy key, a kitchen knife and a butter knife, a toy rake and shovel, and a hairbrush and a hand mirror. The probe was 10 cm in diameter.

The stimulus image set was divided into four subsets, each containing a different kind of plant, novel artifact, and familiar artifact pair (see *Fig 1*). Each infant was shown only one stimulus subset during the experiment. This presentation of subsets to each infant was intended to facilitate the recognition of particular items as belonging to the same category, and generalization of those items as belonging to the same object types during the course of the experiment. The plants and novel artifacts within particular subsets had identical leaf shape. The green color of the familiar artifacts within a particular subset matched the color of the plants in that subset.

In Subset A. (see Fig 1., column A), the plants and novel artifacts were 23 cm wide and their height ranged from 27 to 28 cm. The keys were 28 cm long. They had a green and grey bow 11 cm in diameter as well as a 17 cm long grey blade. The blade of the door key had eight 1.5 cm long pointy cuts. The toy key had eight rounded elements 1 cm in diameter instead.

In Subset B. (see Fig 1., column B), the plants and the novel artifacts ranged from 18.5 to 20.5 cm in width and from 27 to 31.5 cm in height. The knives were each 31.5-cm long. They had green, 11.5 cm long handles and 20 cm long grey blades. The kitchen knife had a pointy-shaped blade that was 6 cm long at its base. The butter knife had and oval-shaped 2.5 cm wide blade.

In Subset C. (see Fig 1., column C), the plants and the novel artifacts were 23 cm wide and their height ranged from 27 to 29 cm. The toy rake and shovel were 29 cm long and had 13 cm long green handles. At the top of the rake were three 16 cm long grey tines. The top of the shovel was a 16 cm long and 13 cm wide rounded grey blade.

In Subset D. (see Fig 1., column D), the plants and the novel artifacts ranged from 18.5 to 20.5 cm in width and from 27 to 29 cm in height. The hairbrush and the hand mirror were light brown and 29 cm long. They each had 13 cm long handles. The top of the hairbrush was 6 cm wide and 16 cm long and comprised of 1 cm long, pointy-shaped bristles set in a dark-colored pad. The top of the hand mirror had the same size as the top of the hairbrush but instead of the pad with pointy elements it had a light grey rectangle as the reflecting surface of the mirror.

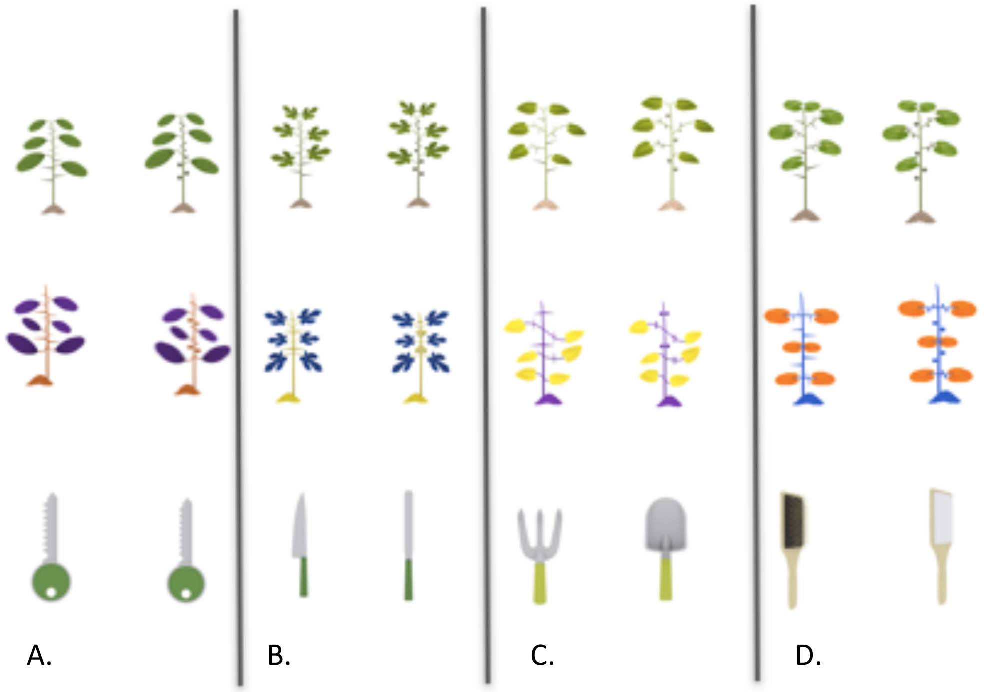


Fig.1. Stimulus set used in the study. The three object types were plants (top row), novel artifacts (middle row), and familiar artifacts (bottom row) with thorny and rounded elements divided into the four subsets of image pairs used in the study are depicted in columns A – D.

2.3. Design & Procedure

The task consisted of two parts: an introduction phase and a test phase (see *Figure 2*). Each trial in both phases of the experiment began with a central gaze-contingent attention getter, a yellow duck, which was presented until the infant fixated their gaze on it. In each trial of the introduction and test phase, the stimulus pictures were presented side by side in same-object-type pairs. In each pair, one object had thorny or pointy elements and the other had round elements. The presentation times for these image pairs were longer than in the previous infant dot probe study (LoBue et al., 2016), to ensure that infants would have enough time to process the more complex, non-social stimuli we presented.

The introduction phase consisted of 6 randomly sequenced trials. Each object type pair (plant pairs, novel artifact pairs, and familiar artifact pairs) appeared twice for 4000 ms. The location of the thorny object (left or right side of the pair) was counterbalanced across the trials. An additional vocal cue "OW!" signaling threat was presented 1000 ms after the appearance of the images. The vocalization incorporated acoustic properties that convey emotional displeasure (Scherer, 1986). It was spoken rapidly with a tense voice that was sharp and slightly high in pitch. It sounded as if the person had just been physically injured. The same vocalization was used in the behavioral study described in Chapter 2. The goals of the introduction phase were: (1) to introduce infants to the stimuli, and (2) given the previous findings showing that negative vocal information is selectively associated with stimuli representing ancestral danger in 8- and 16-month-old infants (DeLoache & LoBue, 2009), to indicate to infants that at least one of the objects in the pair was dangerous.

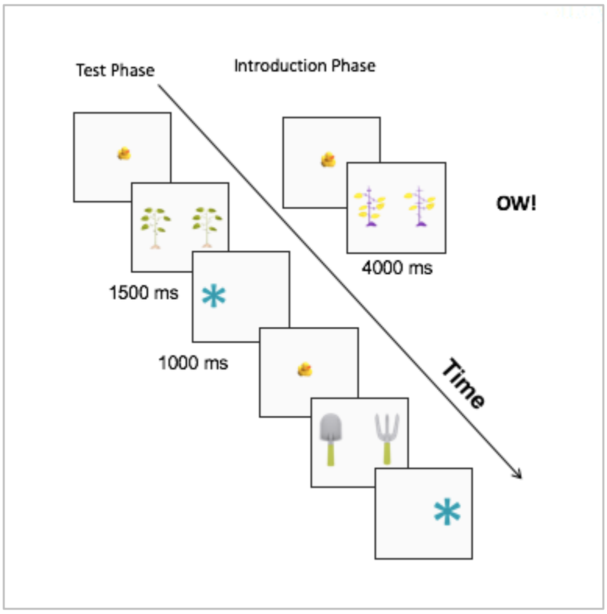


Fig.2. Diagram of the experimental procedure depicting the stimulus presentation during the introduction phase and test phase.

During the second part of the experiment, the test phase, infants were presented with the same image pairs from the introduction phase, but without the additional vocal cue, for 1500 ms. After the stimulus pair offset, the probe—a blue asterisk on a white background—appeared on either the left or right side of the screen for 1000 ms. The asterisk appeared either on the same side of the screen where the object with pointy-shaped elements had been presented (congruent trials) or on the side where the object with rounded elements had been presented (incongruent trials). Twelve trials with all possible combinations of image pairs (i.e., pointy shape on the left or right side) and asterisk positions (i.e., on the left or right side) were presented in one block. Additionally, for 3 trials per block, infants were presented with two objects with rounded elements (neutral trials) side by side. Following the literature (LoBue et al., 2016; Mogg, Philippot, & Bradley, 2004) the neutral trials were treated as fillers, which impeded infants' expectation of encountering threatening stimuli in every trial. As such, these trials were not analyzed.

The trial presentation order within a block was randomized across participants. Four blocks, each containing 15 trials, were shown in total, resulting in a maximum of 66 randomized trials (6 in introduction phase and 60 in the test phase) per experimental session. In order to focus infants' attention for longer periods during the experiment, a short attention getting video was presented on the screen every seventh trial, which consisted of colorful abstract shapes randomly moving on the screen with cheerful music playing in the background.

2.4. Apparatus and eye tracking procedure

Infants' gaze behavior was collected using an EyeLink 1000 Plus (SR Research Ltd., 2013-2015) eye-tracking system installed on a host PC with a 32bit operating system Intel® Core™ Duo processor with 2.80GHz and 2Gb RAM. The EyeLink 1000 Plus High-speed camera recorded the reflection of an infrared light source on the infants' cornea relative to the pupil from one eye in remote mode, without head stabilization. A small sticker with a high-contrast pattern was placed on infants' forehead to aid the eye tracker in keeping the infant's position. The camera was situated approximately 60 cm in front the infant participant. The average accuracy of this device is in the range of 0.25°-0.5° and its precision (as measured by RMS) is <.05 visual angle. Gaze information was assessed using a sampling rate of 500 Hz. The experimental stimuli were presented on a video screen approximately 140 cm from the participants' eyes on a Samsung UE50H6470SS monitor (50" display, of which 80 cm by 63 cm relating to 1280 by 1024-pixel resolution were used for presentation) using Experiment Builder (the SR Research eye-tracking presentation software).

Before the study began, the infant's parent was given detailed information about the experimental procedure including a general description of the eye tracking measures and a description of the particular presentation that the infant would be shown. Parents were also reminded that they are free to end their infant's session at any time. Parents were asked to sit quietly during the experiment with their eyes closed so as not to direct their infants' attention. Parents were given the opportunity to ask any questions about the study and then signed the participation consent form. Then the sticker was placed on the infant's forehead and the parent and infant were led to the dimly lit testing room where the infant sat on the parent's lap facing the display monitor. The eye-tracker settings (corneal reflection and contrast sensitivity) were adjusted according to the infant's eye and sitting position while a welcome animation film was shown. The testing procedure began with a 5-point calibration using an animated black and white octagonal figure, followed by the introduction trials and test trials of the experiment. Testing continued until all trials had been presented, or the infants could not maintain attention any longer. The entire experimental presentation lasted approximately 5 minutes.

3. Results

3.1. Data preparation

Given the exploratory nature of the study, all trials were included in the analysis, unless an infant's entire session was excluded from the sample due to fussiness. Gaze behavior was defined as a fixation when it was not recognized as a saccade; a velocity based algorithm with the velocity of 30° per second was used to detect a saccade. The exploratory character of the study also influenced the decision to include fixations that were shorter than 50ms in the analysis.

The extraction of data for further analysis was based on gaze data within specific areas of interest (AOIs) and periods of interest (POIs). The AOIs and POIs were defined by means of Experiment Builder (the SR Research eye-tracking presentation software) in order to exclude points of gaze that most likely were not related to the parts of the experiment we were interested in, or did not represent infants' attention to specific target. The AOIs covered the entire surface of the stimulus objects pair and a surrounding rectangular space (approximately 30 x 40 cm on the display screen) as well as the entire surface of the probe and a surrounding rectangular space (approximately 30 x 35 cm on the display screen). The size of the AOIs were large enough to include the infants' gaze that was directed toward the stimulus images but misplaced due to inaccurate measurement. There were three POIs defined in the experiment: (1) a period covering the presentation of a stimulus pair in the introduction phase lasting 4000 ms, (2) a period covering the presentation of a stimulus pair presented in the test phase lasting 1500 ms, and (3) a period covering the presentation of the probe lasting 1000 ms.

3.2. Dependent measures & statistical analyses

Data from the predefined AOIs and POIs were exported using the EyeLink Data Viewer software package (SR Research Ltd., 2013 - 2015).

In line with the dot probe literature (MacLeod, Mathews, & Tata, 1986; LoBue et al., 2016), our main dependent variable was the latency to fixate the probe during the test phase. This was defined as the time it took infants to orient their visual attention to the probe once it appeared on the screen in the location of one of the previously presented stimulus objects (congruent vs. incongruent trials). The prediction was that infants would be faster to detect the probe when it appeared in the place of a visually-detectable threat-relevant object, in this case the objects with pointed parts (i.e., the congruent trials). We also assessed a second measure of initial attention convergent to the latency to fixate the probe: the latency to fixate each of the stimulus objects presented in the image pairs. We used this measure in order to assess the time it took infants to orient to the stimuli with pointed versus rounded elements. Finally, we assessed the dwell time to each stimulus object to assess the overall time infants spent looking at the different object types. This measure of sustained attention was also used by LoBue et al. (2016). Both the latency to fixate the stimulus objects and the dwell time to each stimulus object were assessed in the introduction phase as well as in the test phase.

The gaze data was exported and then analyzed using SPSS v22 (Chicago, IL, USA). Repeated measures ANOVAs were used to analyze the gaze DVs in the introduction and test phases.

3.3. Latency to fixate the probe

To assess whether infants were faster to detect the probe when it appeared in the location of stimulus objects with pointed elements compared to the objects with rounded elements, we analyzed the latency to fixate the probe in congruent (i.e., probe appears in the location of the thorny object) and incongruent (i.e., probe appears in the location of the rounded object) trials across three different object types (see *Table 1* for descriptive statistics).

A two-way repeated measures ANOVA on the within-subjects factors of Congruence (congruent vs. incongruent) and Object Type (plant, novel artifact, familiar artifact) showed that there was no significant effect of Congruence ($F(1,13) = 0.35$, $p = 0.56$) nor Object Type ($F(2,26) = 1.15$, $p = 0.33$; see *Fig 3*). There was also no significant Congruence × Object Type interaction ($F(2,26) = 0.06$, $p = 0.94$). This analysis showed no evidence of the predicted faster detection of the probe when it appeared in the previous location of thorny objects. Our results also showed that infants did not fixate the probe differently across the three object types.

Table 1. Descriptive statistics for latency to fixate the probe

	Latency	
	Congruent Trials (Probe in the location of Thorny Objects)	Incongruent Trials (Probe in the location of Round Objects)
Plants	287 (42)	282 (61)
Novel Artifacts	256 (50)	228 (55)
Familiar Artifacts	352 (56)	307 (60)

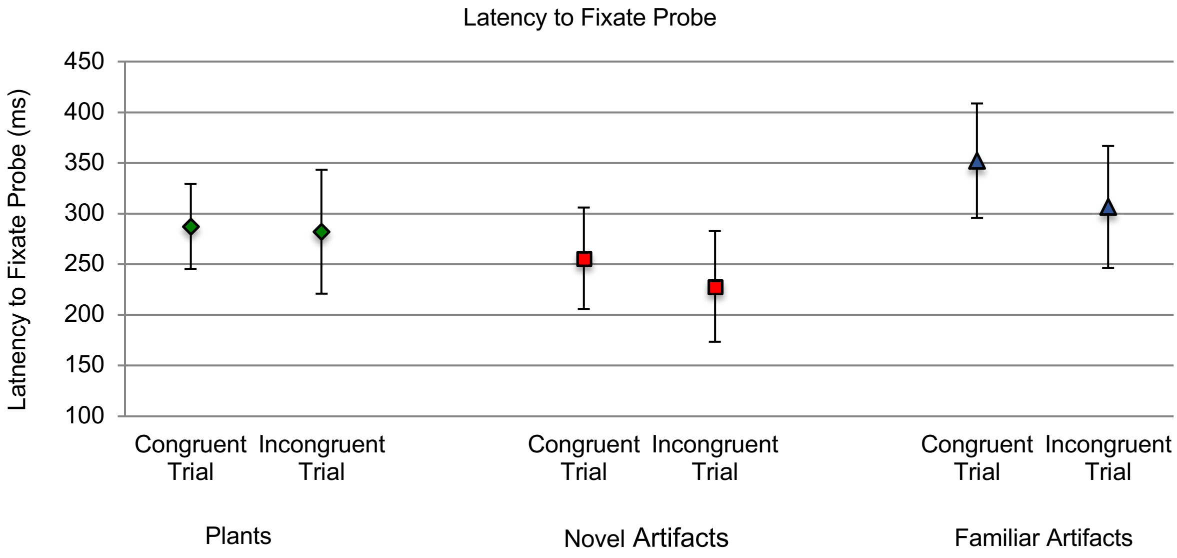


Fig 3. Mean latency until infants' first fixation on the probe for the different object types. Error bars represent standard errors.

3.4. Introduction phase: Latency to fixate the stimulus objects and dwell time

In order to assess further infants' initial orienting to different types of stimuli when they were presented with a negative vocalization signaling danger, we analyzed the effects of

Thorniness and Object Type on the latency to fixate the stimulus objects in the introduction phase (see *Table 2* for descriptive statistics).

We ran a two-way repeated measures ANOVA on the time infants took to fixate the stimulus objects with Thorniness (objects with pointed element vs. objects with rounded elements) and Object Type (plants, novel artifacts, familiar artifacts) as within-subject factors. The results showed no main effect of Thorniness ($F(1,13) = 0.03$, $p = 0.85$) and no main effect of Object Type ($F(2,26) = 2.29$, $p = 0.12$; see *Fig 4*). There was a significant Thorniness × Object Type interaction ($F(2,26) = 5.65$, $p < 0.05$, $\eta_p^2 = 0.30$). However, the individual Bonferroni-corrected pairwise comparisons (cut-off p-value = 0.017) within each object type (i.e., thorny plants vs. rounded plants, thorny novel artifacts vs. rounded novel artifacts, and thorny familiar artifacts vs. rounded familiar artifacts) were not significant

Although none of the comparisons reached statistical significance, the raw latency means were in the direction of infants orienting quicker to plants compared to both novel and familiar artifacts. They also showed that infants fixated their gaze quicker on plants with rounded elements compared to the plants with pointed elements. The pattern for the fixations on the familiar artifacts was reversed.

Table 2. Descriptive statistics for latency to first fixate the stimulus objects and dwell time in the introduction phase

	Latency		Dwell Time	
	Thorny Objects	Round Objects	Thorny Objects	Round Objects
Plants	911 (107)	595 (90)	1316 (141)	1625 (104)

Novel Artifacts	976 (147)	886 (135)	1251 (116)	1602 (150)
Familiar Artifacts	706 (80)	1171 (124)	1637 (202)	1032 (138)

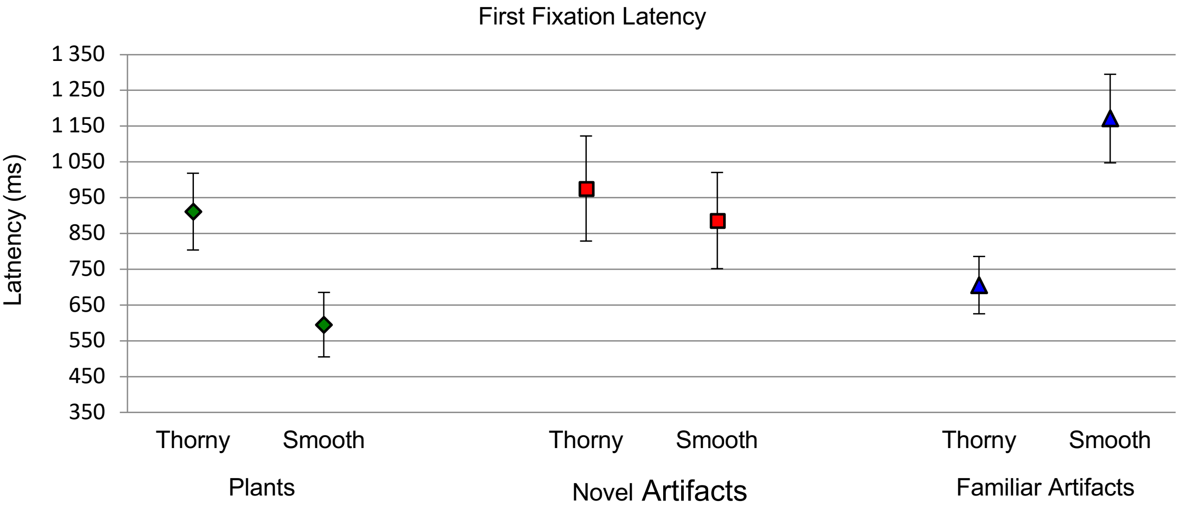


Fig 4. Mean latency until the first fixation on the stimulus objects for the different object types in the introduction phase. Error bars represent standard errors.

Next, in order to examine whether infants showed differential patterns of sustained attention for objects with pointed versus rounded elements across different object types when the objects were presented with negative vocalization signaling danger, we analyzed the effects of Thorniness and Object Type on the dwell time to each stimulus in the introduction phase (see *Table 2* for descriptive statistics).

A repeated measures ANOVA with Thorniness (objects with pointy element vs. objects with round elements) and Object Type (plants, novel artifacts, familiar artifacts) as within-subject factors showed that there was no main effect of Thorniness (*F*(1,14) = 0.02, $p = 0.89$) and no main effect of Object Type (*F*(2,28) = 0.88, $p = 0.42$; see *Fig 5*). As in the latency results above, we found a significant Thorniness x Object Type interaction (*F*(2,28) = 6.65, $p < 0.05$, $\eta_p^2 = 0.32$). However, also as before, the Bonferroni-corrected individual pairwise comparisons (cut-off *p*-value = 0.017) within each object type (i.e., thorny plants vs. rounded plants, thorny novel artifacts vs. rounded novel artifacts, and thorny familiar artifacts vs. rounded familiar artifacts) were not significant.

The raw dwell time means were in the direction of infants spending more time looking at familiar objects with thorny elements compared to familiar objects with rounded elements, but this difference did not reach the statistical significance.

Taken together, these results do not provide any convincing evidence that infants' attention is captured and held by the objects with pointed elements in the presence of an additional vocal cue signaling threat. We also did not find evidence that infants employ different attentional patterns for plants compared to the other object types.

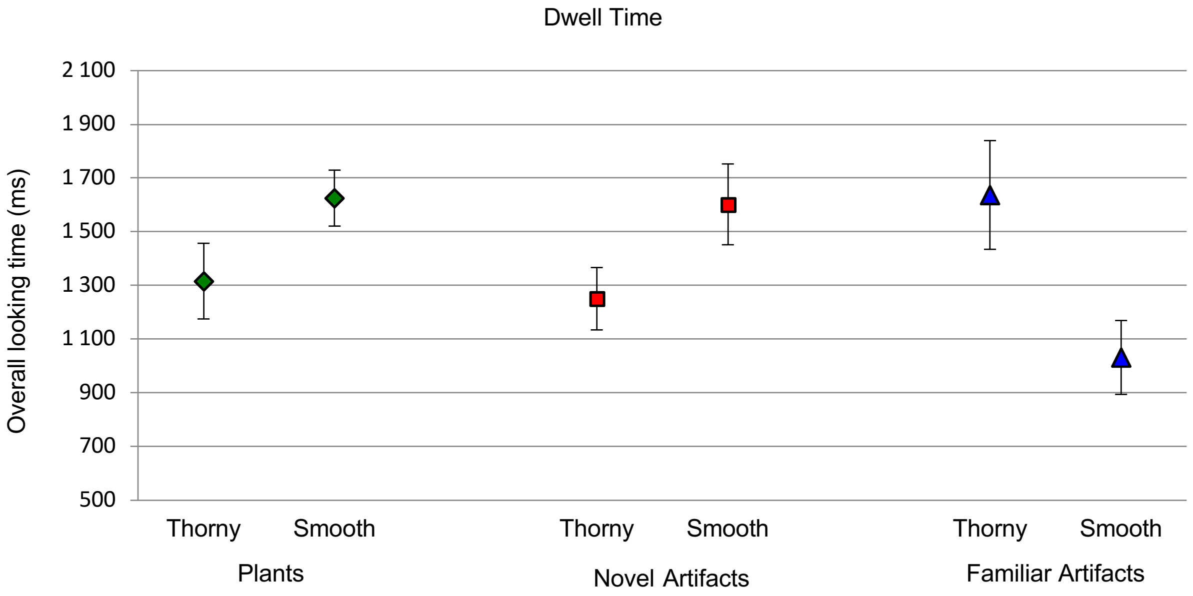


Fig 5. Mean overall looking time for the stimulus objects of different object types in the introduction phase. Error bars represent standard errors.

3.5. Test phase: Latency to fixate the stimulus objects and dwell time

Next, in order to assess infants' attentional patterns further, we analyzed the effects of Thorniness and Object Type on the latency to fixate the stimulus objects and dwell time to the different stimuli in the test phase of the experiment (see *Table 3* for descriptive statistics).

First, we ran a two-way repeated measures ANOVA on the time infants took to fixate the stimulus objects with Thorniness (objects with pointed element vs. objects with round elements) and Object Type (plants, novel artifacts, familiar artifacts) as within-subject factors. The results showed no main effect of Thorniness ($F(1,13) = 1.97$, $p = 0.18$) and no main effect of Object Type ($F(2,26) = 1.13$, $p = 0.34$; see *Fig 6*). There was a trend toward a significant Thorniness × Object Type interaction ($F(2,26) = 3.31$, $p = 0.052$, $\eta_p^2 = 0.20$). However, follow-up comparisons within each object type (i.e., thorny plants vs. rounded plants, thorny novel artifacts vs. rounded novel artifacts, and thorny familiar artifacts vs. rounded familiar artifacts) showed no significant differences (Bonferroni-corrected *p*-value = 0.017).

As in the introduction trials, the raw latency means in the test trials were in the direction of infants fixating their gaze quicker on plants with rounded elements compared to the plants with pointed elements, but this difference did not reach statistical significance.

Table 3. Descriptive statistics for latency to first fixate the objects and the dwell time in the test phase

	Latency		Dwell Time	
	Thorny Objects	Round Objects	Thorny Objects	Round Objects
Plants	658 (35)	506 (49)	366 (27)	436 (35)
Novel Artifacts	518 (46)	597 (57)	424 (29)	378 (38)
Familiar Artifacts	575 (52)	490 (59)	390 (64)	316 (35)

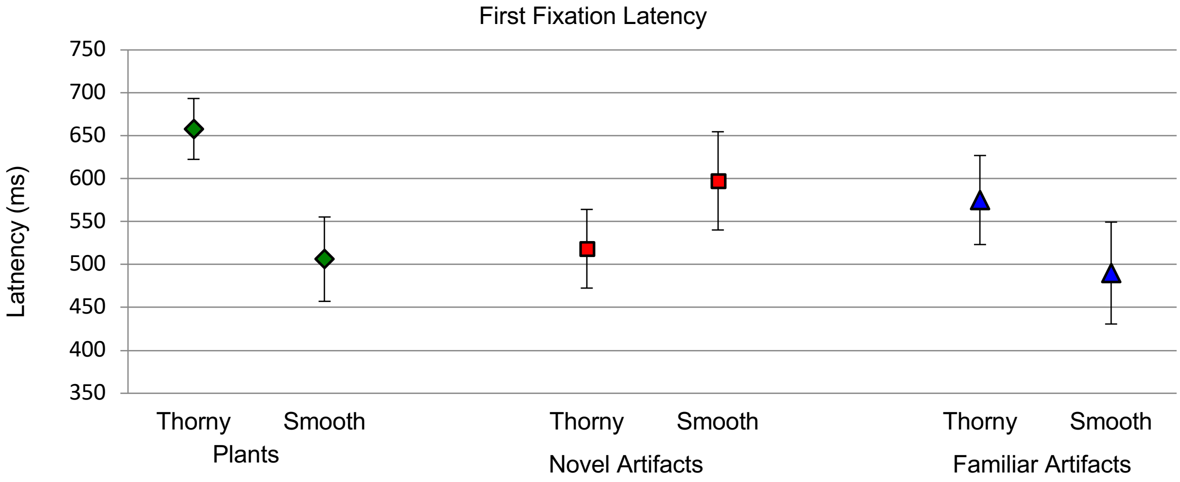


Fig 6. Mean latency until the first fixation on the stimulus objects for the different object types in the test phase. Error bars represent standard errors.

Finally, we conducted a repeated measures ANOVA on the dwell time during the test trials for the different stimulus objects with Thorniness (objects with pointy element vs. objects with round elements) and Object Type (plants, novel artifacts, familiar artifacts) as within-subject factors. We found no significant main effect of Thorniness ($F(1,14) = 0.30$, $p = 0.60$) and no significant main effect of Object Type ($F(2,28) = 2.5$, $p = 0.10$; see *Fig 7*). There was also no significant Thorniness × Object Type interaction ($F(2,28) = 1.25$, $p = 0.30$).

Taken together, our results show that infants' attention was not captured and held by the objects with pointed parts in the test phase of the experiment. There was also no evidence that infants employ different attentional patterns for plants compared to other object types.

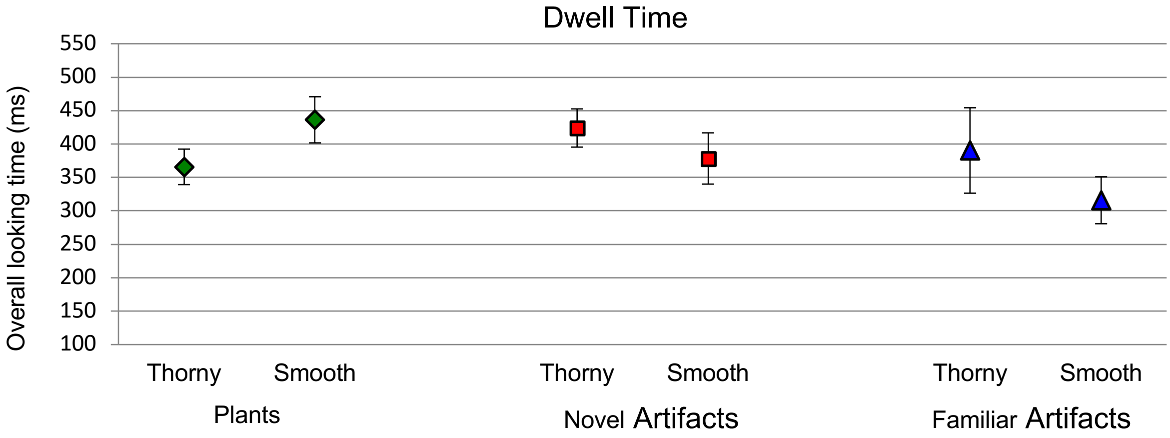


Fig 7. Mean overall looking time for the stimulus objects of different object types in the test phase. Error bars represent standard errors.

4. Discussion

The findings presented here did not provide evidence for an attentional bias toward pointed shapes compared to round ones in infancy. Further, there was no clear evidence for attentional differences across three different object types: plants, novel artifacts, and familiar artifacts. In contrast to previous results showing an attentional bias to threatening entities in infants (LoBue, at al., 2016), infants in this experiment exhibited no differences in how quickly they fixated the probe in the congruent and incongruent trials across any of the object types. The findings of the current study are inconsistent with the existing literature showing that infants' visual attention is captured and held by dangerous stimuli within the first year of life (e.g., Hunnius et al., 2011; LoBue & DeLoache, 2010; Nakagawa & Sukigara, 2012; Peltola et al., 2009; Rakison & Derringer, 2008). Additionally, these results seem not to be aligned with the previous results showing infants' behavioral avoidance of plants compared to non-plant objects (Elsner & Wertz, 2019; Wertz & Wynn, 2014; Włodarczyk et al., 2018).

There are many possible explanations for the current null effects. One possibility is that there simply is no attentional bias toward inanimate threats, such as plants, or pointed shapes more generally. This was, to our knowledge, the first attempt to examine whether infants exhibit a visual attentional bias for pointed versus round shapes in the plant context, and only the second attempt to conduct a study with infants using a modified version of the dot probe task. In the previous study where significant effects of attentional biases to threat were found (LoBue et al, 2016), only images of animate threats were presented to infants (e.g., snakes, faces). This is also the case in previous studies using other visual attention paradigms (for a review, see LoBue, 2013). In contrast, all of the images we presented in the current experiment depicted inanimate entities: plants, novel artifacts and familiar artifacts.

Plants and other inanimate objects with potentially injurious pointed shapes are environmental hazards that have to be avoided just like animate threats. However, the problems posed by avoiding animate hazards differ in important ways from the problems posed by plants and other inanimate threats. As the authors of the *animate monitoring hypothesis* argue, animals (human and non-human) are a time-sensitive category (New, Cosmides, & Tooby, 2007). Animate threats modify their status far more often than inanimate elements of the landscape like plants, artifacts, or features of the terrain. Humans and other animals can change their minds within seconds, which leads to rapid modifications of their behavior, trajectory, or location. In contrast, plants and other animate entities cannot move, so they cannot seek out and attack others. Therefore, they do not require using complicated mechanisms involved in understanding agency, from self-propelled motion and gaze direction detection to theory of mind mechanisms for reasoning about the internal mental states that drive behavior (Barrett, 2005).

Without the risk of being attacked, the timeframe of the decision to react to inanimate objects in a particular way (e.g., move away from them or change trajectory and take a different path) depends solely on the individual confronted with the dangerous entity, not the dangerous entity itself. Thus, limiting the costs inflicted by plants and pointed inanimate objects may not require the same attentional strategy compared to the strategies used against dangerous animate predators or conspecifics. This proposal is consistent with the fact that several of the studies providing evidence for an attentional bias toward threating animals used plants and flowers as their neutral control stimuli (e.g., LoBue & DeLoache, 2010).

Further, the set of features that infants use to recognize an object as a plant is still unclear. This identification process may be particularly challenging when the stimulus objects are presented in two-dimensional (2D) space as in the current experiment. Previous studies have shown that infants and young children have difficulties processing stimuli when they are presented in 2D versus in 3D space (Barr, 2010, 2013; Barr & Hayne, 1999; Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009; Zack, Gerhardstein, Meltzoff, & Barr, 2013). For example, research on infants' imitative learning showed that the ability of 12-, 15-, and 18-month-olds to use information presented in 2D (television) is worse than the ability to use the same information presented live (Barr & Hayne, 1999). Additionally, infants at this age were shown to struggle to transfer learned information between 2D (touchscreen) and 3D stimuli (Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009; Zack, Gerhardstein, Meltzoff, & Barr, 2013). Future work can address this problem by empirically comparing infants' responses to plants compared to non-plant objects in 2D and 3D displays. In addition, our stimuli were not photos of real plants, but rendered animations of cartoon-like pictures. We chose this presentation in the interest of matching our stimuli precisely across the different categories. However, this kind of presentation may have further impeded the recognition of our stimuli as plants or other objects by our young infants. Relatedly, our stimulus images of the plants and novel artifacts in particular were matched so closely that infants potentially may not have distinguished them as different categories.

It is also possible that the null-results in the current studies are related to a failure of the dot-probe task procedure we employed. The dot-probe task has only been used once before with infants, and because of our more visually-complex stimuli, we lengthened the presentation times relative to this study during the trials. Therefore, it would be informative to match the stimulus pair presentation to previous study (LoBue et al., 2016) in order to provide better conditions for observing a dot-probe effect. In fact, the current data showed that, before the probe appeared during the test trials, infants managed to switch their gaze between the two objects in the stimulus pair at least once, which suggests that the time of the image pairs display may have been too long to assess attentional capture.

Finally, it is possible that the threatening social signal we presented in this study—the negative vocalization—was not sufficient to cue infants' attention toward the threat-relevant objects in the presented stimulus pair. Previous studies suggest that infants readily seek out and use social information about plants to guide their behavior (Elsner & Wertz, 2019; Wertz & Wynn, 2014b; Chapter 2). In particular, they seem to be sensitive to information about plant edibility (Wertz & Wynn, 2014b) and whether an adult physically touches an object (Chapter 2). However, infants do not appear to treat plants and other inanimate objects differently based on positive versus negative vocal cues (Chapter 2). It is therefore possible that, in the current study, a similar-sounding negative vocal cue was not enough to signal to infants that a danger was present in our stimuli. In the future, we could use longer and more pronounced negative vocal cues and social signals of danger to ensure that infants are alerted to the presence of threat-relevant objects.

Conclusion

Although we found no evidence for attentional biases toward plant threats or sharp-looking pointed forms, the current investigation broadens the literature on infants' responses to ancestrally-recurrent threats by attempting to shed light on possible attentional mechanisms underlying the behavioral avoidance strategy used by infants to mitigate harm from plants. As the first attempt to examine an attentional bias to plant threats, the study reveals interesting avenues for future work.

References

Barr, R. (2010). Transfer of learning between 2D and 3D sources during infancy: Informing theory and practice. *Developmental review*, 30(2), 128-154.

Barr, R. (2013). Memory constraints on infant learning from picture books, television, and touchscreens. *Child Development Perspectives*, 7(4), 205-210.

Barr, R., & Hayne, H. (1999). Developmental changes in imitation from television during infancy. *Child Development*, 70(5), 1067-1081.

Bar, M., & Neta, M. (2006). Humans prefer curved visual objects. *Psychological Science*, *17*(8), 645-648.

Barrett, H. C. (2005). Adaptations to predators and prey. *The Handbook of Evolutionary Psychology*, 200-223.

Becker, M. W., & Detweiler-Bedell, B. (2009). Short article: Early detection and avoidance of threatening faces during passive viewing. *Quarterly Journal of Experimental Psychology*, 62(7), 1257-1264.

Becker, S. I., Horstmann, G., & Remington, R. W. (2011). Perceptual grouping, not emotion, accounts for search asymmetries with schematic faces. *Journal of Experimental Psychology: Human Perception and Performance*, *37*(6), 1739.

Calvo, M. G., Avero, P., & Lundqvist, D. (2006). Facilitated detection of angry faces: Initial orienting and processing efficiency. *Cognition and Emotion*, 20(6), 785-811.

DeLoache, J. S., & LoBue, V. (2009). The narrow fellow in the grass: Human infants associate snakes and fear. *Developmental Science*, *12*(1), 201-207.

Elsner, C. & Wertz, A.E. (2019). The seeds of social learning: Infants exhibit more social referencing for plants than other types. *Cognition*

Esteves, F. (1999). Attentional bias to emotional facial expressions. *European Review of Applied Psychology/Revue Européenne de Psychologie Appliquée.*

Fantz, R. L., & Miranda, S. B. (1975). Newborn infant attention to form of contour. *Child Development*, 224-228.

Flykt, A. (2005). Visual search with biological threat stimuli: Accuracy, reactions times, and heart rate changes. *Emotion*, 5, 349–353.

Flykt, A. (2006). Preparedness for action: Responding to the snake in the grass. *The American Journal of Psychology*, 119, 29–43.

Forbes, S. J., Purkis, H. M., & Lipp, O. V. (2011). Better safe than sorry: Simplistic fear-relevant stimuli capture attention. *Cognition & Emotion*, *25*(5), 794-804.

Hayakawa, S., Kawai, N., & Masataka, N. (2011). The influence of color on snake detection in visual search in human children. *Scientific Reports*, 1, 1–4.

Horstmann, G. (2009). Visual search for schematic affective faces: Stability and variability of search slopes with different instances. *Cognition and Emotion*, *23*(2), 355-379.

Horstmann, G., Borgstedt, K., & Heumann, M. (2006). Flanker effects with faces may depend on perceptual as well as emotional differences. *Emotion*, *6*(1), 28.

Horstmann, G., Scharlau, I., & Ansorge, U. (2006). More efficient rejection of happy than of angry face distractors in visual search. *Psychonomic Bulletin & Review*, *13*(6), 1067-1073.

Hunnius, S., de Wit, T. C., Vrins, S., & von Hofsten, C. (2011). Facing threat: Infants' and adults' visual scanning of faces with neutral, happy, sad, angry, and fearful emotional expressions. *Cognition and Emotion*, 25(2), 193-205.

Koster, E. H., Crombez, G., Verschuere, B., & De Houwer, J. (2004). Selective attention to threat in the dot probe paradigm: Differentiating vigilance and difficulty to disengage. *Behaviour Research and Therapy*, 42(10), 1183-1192.

Larson, C. L., Aronoff, J., & Stearns, J. J. (2007). The shape of threat: Simple geometric forms evoke rapid and sustained capture of attention. *Emotion*, *7*(3), 526.

Lipp, O. V. (2006). Of snakes and flowers: Does preferential detection of pictures of fear relevant animals in visual search reflect on fear-relevance? *Emotion,* 6, 296–308.

Lipp, O. V., & Derakshan, N. (2005). Attentional bias to pictures of fear-relevant animals in a dot probe task. *Emotion*, 5, 365–369.

Lipp, O. V., & Waters, A. M. (2007). When danger lurks in the background: Attentiona capture by animal fear-relevant distractors is specific and selectively enhanced by animal fear. *Emotion*, *7*(1), 192.

LoBue, V. (2009). More than just another face in the crowd: Superior detection of threatening facial expressions in children and adults. *Developmental Science*, 12(2), 305-313

LoBue, V. (2010a). What's so scary about needles and knives? Examining the role of experience in threat detection. *Cognition & Emotion*, 24, 80–87.

LoBue, V. (2010b). And along came a spider: Superior detection of spiders in children and adults. *Journal of Experimental Child Psychology*, 107, 59–66.

LoBue, V. (2013). What are we so afraid of? How early attention shapes our most common fears. *Child Development Perspectives*, 7(1), 38-42.

LoBue, V., & DeLoache, J. S. (2008). Detecting the snake in the grass: Attention to fear-relevant stimuli by adults and young children. *Psychological Science*, *19*(3), 284-289.

LoBue, V., & DeLoache, J. S. (2010). Superior detection of threat-relevant stimuli in infancy. *Developmental Science*, 13(1), 221-228.

Lobue, V., & Deloache, J. S. (2011). What's so special about slithering serpents? Children and adults rapidly detect snakes based on their simple features. *Visual Cognition*, *19*(1), 129-143.

LoBue, V., & Larson, C. L. (2010). What makes an angry face look so… angry? Examining visual attention to the shape of threat in children and adults. *Visual Cognition*, *18*(8), 1165-1178.

LoBue, V., Rakison, D. H., & DeLoache, J. S. (2010). Threat Perception Across the Life Span: Evidence for Multiple Converging Pathways. *Current Directions in Psychological Science, 19*(6), 375-379.

LoBue, V., & Rakison, D. H. (2013). What we fear most: A developmental advantage for threat-relevant stimuli. *Developmental Review*, *33*(4), 285-303.

LoBue, V., Buss, K. A., Taber-Thomas, B. C., & Pérez-Edgar, K. (2016). Developmental differences in infants' attention to social and nonsocial threats. *Infancy*, *22*(3), 403-415.

Lundqvist, D., & Öhman, A. (2005). Caught by the evil eye. *Emotion and Consciousness*, 97-122.

MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology*, 95, 15–20.

MacNamara, A., Kappenman, E. S., Black, S. R., Bress, J. N., & Hajcak, G. (2013). Integrating behavioral and electrocortical measures of attentional bias toward threat. *Handbook of self-regulatory processes in development: New directions and international perspectives*, 215-242.

Mogg K, Bradley BP, Miles F, Dixon R. Time course of attentional bias for threat scenes: Testing the vigilance-avoidance hypothesis. *Cognition and Emotion*. 2004;18(5):689–700.

Nakagawa, A., & Sukigara, M. (2012). Difficulty in disengaging from threat and temperamental negative affectivity in early life: A longitudinal study of infants aged 12–36 months. *Behavioral and Brain Functions*, *8*(1), 40.

New, J., Cosmides, L., & Tooby, J. (2007). Category-specific attention for animals reflects ancestral priorities, not expertise. *Proceedings of the National Academy of Sciences*, *104*(42), 16598-16603.

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychological Review*, 108, 483–522.

Peltola, M. J., Leppänen, J. M., Vogel-Farley, V. K., Hietanen, J. K., & Nelson, C. A. (2009). Fearful faces but not fearful eyes alone delay attention disengagement in 7-month-old infants. *Emotion*, *9*(4), 560.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*(1), 3-25.

Rakison, D. H., & Derringer, J. (2008). Do infants possess an evolved spider-detection mechanism? *Cognition*, *107*(1), 381-393.

Roy, A. K., Dennis, T. A., & Warner, C. M. (2015). A critical review of attentional threat bias and its role in the treatment of pediatric anxiety disorders. *Journal of Cognitive Psychotherapy*, *29*(3), 171-184.

Scherer, K. R. (1986). Vocal affect expression: A review and a model for future research.

Psychological Bulletin, 99, 143-16

Schubö, A., Gendolla, G. H., Meinecke, C., & Abele, A. E. (2006). Detecting emotional faces and features in a visual search paradigm: Are faces special? *Emotion*, *6*(2), 246.

Schubö, A., Gendolla, G. H., Meinecke, C., & Abele, A. E. (2006). Detecting emotional faces and features in a visual search paradigm: Are faces special? *Emotion*, *6*(2), 246.

Silvia, Paul & M. Barona, Christopher. (2009). Do People Prefer Curved Objects? Angularity, Expertise, and Aesthetic Preference. *Empirical Studies of The Arts*. 27. 25-42. 10.2190/EM.27.1.b.

Wertz, A.E. & Moya, C. (2019). Pathways to cognitive design. *Behavioral Processes*. https://doi.org/10.1016/j.beproc.2018.05.013

Wertz, A.E.**,** Elsner, C., Erut, A.S., Smith, A.M., & Barrett, H.C. (in preparation). Shuar infants' behavioral and social referencing strategies for plants compared to other object types.

Wertz, A. E., & Wynn, K. (2014a). Thyme to touch: Infants possess strategies that protect them from dangers posed by plants. *Cognition*, *130*(1), 44-49.

Wertz, A. E., & Wynn, K. (2014b). Selective social learning of plant edibility in 6-and 18-month-old infants. *Psychological Science*, *25*(4), 874-882.

Włodarczyk, A., Elsner, C., Schmitterer, A., & Wertz, A.E. (2018). Every rose has its thorn:

Infants' responses to pointed shapes in naturalistic contexts. *Evolution & Human Behavior*. https://doi.org/10.1016/j.evolhumbehav.2018.06.001

Włodarczyk, A., Rioux, C., & Wertz, A. E. (under review). Social information reduces infants' avoidance of plants. *Cognitive Development.*

behavioral responses to plants threat.

Wood, B., & Collard, M. (1999). The human genus. Science, 284(5411), 65-71.

Zack, E., Barr, R., Gerhardstein, P., Dickerson, K., & Meltzoff, A. N. (2009). Infant imitation from television using novel touch screen technology. *British Journal of Developmental Psychology*, *27*(1), 13-26.

Zack, E., Gerhardstein, P., Meltzoff, A. N., & Barr, R. (2013). 15-month-olds' transfer of learning between touch screen and real-world displays: language cues and cognitive loads. *Scandinavian Journal of Psychology*, *54*(1), 20-25.

General Discussion

This thesis investigated thus far unexplored aspects of infants' behavioral avoidance strategy toward plants, including infants' responses to visible plant threats (i.e., thorns). The results of the presented set of studies shed some light on the four broad questions raised in the introduction.

The findings of the study in Chapter 1 (Włodarczyk et al., 2018) showed that 8- to 18-month-old infants, in addition to an initial reluctance to touch, exhibit minimized subsequent physical contact with plants compared to other object categories. Notably, infants' touch latencies and touch durations did not differ for plants with and without thorns, indicating that infants treat all plants as potentially dangerous whether or not they possess visible threats. However, infants did show some sensitivity to visible plant threats as they made contact with the thorny parts of plants significantly less often than either the thorny or non-thorny parts of any of the other object types. These results replicate and extend previous findings by demonstrating that the avoidance strategy serves to both prevent potential harm from plants during the initial approach (Elsner & Wertz, 2019; Wertz & Wynn, 2014a) and mitigate injury during infants' subsequent contact with plants.

The results in Chapter 2 (Włodarczyk, Rioux, & Wertz, under review) showed that evidence of infants' behavioral avoidance strategy toward plant threats remains when additional social information is provided. That is, 8- to 18-month-old infants exhibited both delayed approach and minimized subsequent manual exploration of plants compared to other object types, even when social cues were presented. The original intention of the study was to test whether infants react differently to negative and positive social information in the context of plants and other objects. However, and in opposition to our predictions, infants did not respond to the negative and positive social information displays differently for either plants or non-plant objects. Although unexpected, this finding is not unique. Previous studies have also found no regulatory effects of emotional valence on object-directed behavior when an experimenter provides cues of both emotional expression and touch, as we did (Repacholi, 2009; Patzwald et al., 2018). This suggests that social information in the form of making contact with an object can interfere in some way with emotional displays. The preliminary, qualitative comparisons with the findings from Chapter 1 (Włodarczyk et al., 2018) in which no social information was present suggested that infants in Chapter 2 responded to the fact that an adult touched the objects. It appears that this social information lessened infants' reluctance to touch all the object types, even though infants were overall relatively more reluctant to touch plants both immediately after seeing an adult touch and when similar objects were subsequently presented. However, these same comparisons suggest that infants' subsequent manual exploration of plants was largely unchanged when social cues were provided, although infants' frequency to touch thorns on plants seemed to be decreased.

Finally, the results of the eye tracking experiment in Chapter 3 provided no evidence of visual attentional bias for plant threats in 8- 10-month-old infants as a possible underlying low-level attentional mechanism related to the behavioral avoidance strategy. These findings seem to be in opposition to the literature showing a differential allocation of attention toward evolutionarily threatening stimuli early in ontogeny (e.g., LoBue & DeLoache, 2008; LoBue, 2010a; Waters & Lipp, 2008). It is important to point out, however, that previous evidence for threat-specific attention capture and holding in children is based on studies using animate target stimuli (dangerous animals or threatening human faces; for the review LoBue & Rakison, 2013) with many studies using flowers or mushrooms as threat-irrelevant control stimuli (e.g., LoBue & DeLoache, 2010). Attentional biases may not be necessary for responding appropriately to inanimate environmental threats. More empirical work is needed to explore the differences in attentional patterns involved in visual exploration of animate versus inanimate objects.

I. *Infants' responses to artifacts*

Although the main focus of this dissertation was infants' responses to plants, the results also provide some insight into infants' responses to novel and familiar manmade artifacts. Our studies showed that infants are less reluctant to touch man-made objects compared to plants, both when social information was absent (Chapter 1) and present (Chapter 2). This was the case for both novel artifacts, which were visually attractive with their various shapes and bright colors, as well as for familiar artifacts that had rather dull colors and more simplistic forms. These findings suggest that infants treat artifacts as a category that is generally safe to be manually explored.

Nevertheless, infants' responses within the artifact category differed. In line with a large body of literature showing perceptual preference for novelty in infancy (e.g., Fantz, 1958; Thompson, Fagan, & Fulker, 1991), our novel artifacts seemed especially attractive for participants during the early stages of exploration (i.e., infants' initial reach). Infants reached for novel artifacts faster than plants and familiar artifacts, both with and without (Chapter 1) the presence of additional social information about the objects.

Surprisingly, infants' initial reaching behavior did not differ for the thorny novel artifacts compared the non-thorny novel artifacts when the latency to touch any part of the objects was analyzed (Chapter 1). According to the hypothesis that pointed thorns are perceived as threat-relevant (e.g., Bar & Neta, 2006; Munar et al., 2015; Silvia & Barona, 2009), they were expected to evoke a reluctance reaction when presented in the context of unknown, strange looking objects. However, a more detailed, follow-up analysis of the impact of the location of infants' touch during the initial reach showed that thorns did influence infants' behavior toward the novel artifacts. Infants reached for the thorny parts of thorny novel artifacts slower compared to both the non-thorny parts of thorny artifacts and the non-thorny artifacts (Chapter 1; Supplementary Information). Further, infants also showed sensitivity to thorns in the context of novel artifacts during the later stages of object exploration: they stayed in contact with thorny novel artifacts longer, and touched them less often, compared to the non-thorny novel artifacts. However, infants did not avoid thorns in all contexts. In line with studies showing that young children are sensitive to pointed shapes in familiar manmade objects only after having negative experience with them (LoBue, 2010b), infants touched thorny parts of familiar artifacts more often than non-thorny parts of these objects (Chapter 1).

II. Contribution to the existing threat literature

The current work broadens the existing literature on human sensitivity to evolutionarily threatening stimuli early in ontogeny (e.g., Barrett & Broesch, 2012; DeLoache & LoBue, 2009; Rakison & Derringer, 2008). The behavioral avoidance strategy examined in this thesis is likely to provide adequate protection against typical plants threats. By treating all plants as potentially dangerous, infants can protect themselves from both visible (e.g., thorns) and invisible (i.e., toxic chemical compounds) plant defenses that may cause harm. Consistent with Nesse's (2001, 2005) smoke detector analogy for dealing with threat, infants seem to be overresponsive to avoiding all kinds of plants, despite the fact that only some plants actually require defensive responses, because the costs of failing to identify plants that are dangerous may be critically high. Continuing with the logic of error management (e.g., Haselton & Buss, 2000; Haselton & Nettle, 2006; Johnson, Blumstein, Fowler, & Haselton, 2013), being reluctant to touch all plants may not maximize *expected payoffs* (here food), but may reduce the overall individual costs, making such a strategy adaptive in the long term.

Given the fact that plants cannot move on their own and therefore can only impose danger when someone or something approaches and touches them, the kind of delayed approach and minimized subsequent contact with plants exhibited by infants in our studies (Chapter 1 and Chapter 2) is a simple, yet efficient way of negotiating plant threat. Using this relatively easy, and therefore feasible for infants, strategy is consistent with Boyer & Bergstrom's (2011) proposal that children develop age-appropriate responses to threat which are relevant to their current developmental stage.

In addition to sensitivity to the entire category of plants, infants' also exhibit some sensitivity to the visible plant threat of sharp-looking thorns. This is evident during the later phases of object exploration (Chapter 1 and Chapter 2). As injury from the sharp, pointed thorns could have been very costly in evolutionary circumstances without modern sanitation (Gurven, Allen-Arave, Hill, & Hurtado, 2000; Gurven, Stieglitz, Hooper, Gomes, & Kaplan, 2012), it seems that evolved strategies for dealing with plant threats, consistent with other mechanisms for avoiding sharp-angled forms (e.g., Bar & Neta, 2006; Silvia & Barona, 2009), include the propensity to avoid contact with thorns. This suggests that the behavioral avoidance strategy for dealing with plant threats is adjusted to different stages of plant exploration (initial reach and subsequent exploration) and to cope with different types of plant threats (visibly-pointy thorns and unobservable toxins).

In line with the literature showing that infants readily use social information to learn about threatening aspects of their environment (Barrett & Broesch, 2012; Barrett, Peterson, & Frankenhuis, 2016; LoBue, Rakison, & DeLoache, 2010) the findings presented in this thesis suggest that infants regulate their behavior toward plants (and other inanimate entities) based on observing an adult touching the objects. The relative avoidance of plant threats continues to be exhibited when such social cues are present, yet it is reduced in these circumstances. This implies that, as proposed by Wertz & Wynn (2014a, 2014b), plant-specific behavioral strategies include some social learning rules that facilitate safe acquisition of information about plants

Importantly, the findings presented in this thesis uncover interesting differences between infants' reactions to plants as compared to the kinds of animate threats that have explored in the existing literature. Despite the fact that both dangerous animals (including other aggressive human conspecifics) and plants are ancestrally recurrent threats that have shaped multiple levels of human cognition, the structure of human response to these threats seems to be different. This difference is evident in both behavioral and attentional aspects of these responses. When confronted with animate threats, such as dangerous animals, infants and young children exhibit great interest in these stimuli by readily approaching and interacting with them (e.g., LoBue et al, 2013). At the same time, infants' attention is more easily captured by animate threats, such as snakes and spiders (e.g., LoBue & DeLoache, 2008; Rakison & Derringer, 2008), a tendency that remains into adulthood (New et al., 2007). In contrast, inanimate threats, such as plants, evoke an inhibited approach and minimized interaction (Chapters 1 and 2; Elsner & Wertz, 2019; Wertz & Wynn, 2014a; Włodarczyk et al., 2018), even when additional social information from an adult is provided. Further, unlike infants' response to animate threats (citations), there is no evidence of a visual attention bias toward plants threats (Chapter 3). All these findings suggest that the structure of infants' responses to ancestrally-recurrent threats are more variable than has been shown before in the threat literature because infants' defensive reactions appear to be tailored to the different properties of particular kinds of threats.

III. Open questions

The current findings pose some interesting questions that can guide future experimental investigations. First, infants participating in our studies and exhibiting behavioral avoidance toward plant threats were brought up in WEIRD urban environments (Western, Educated, Industrialized, Rich, and Democratic; Henrich et al., 2010). As a consequence, these infants have limited contact with vegetation in their daily life. As Ross and colleagues (2003) point out, urban children's understanding of nature may be highly atypical precisely because plants and animals do not play a significant role in their everyday life. In contrast, children growing up in rural environments or modern small-scale societies have far more interactions with plants (e.g., Crittenden, Conklin-Brittain, Marlowe, Schoeninger, & Wrangham, 2009; Hawkes, O'Connell, & Jones, 1995; Greenwald, Eerkens, & Bartelink, 2016). Additionally, they are surrounded by adults who possess extensive knowledge about the plants around them (e.g., Turner et al., 2011). This raises an important question whether the behavioral avoidance strategy for plants observed in this thesis would hold among these children.

On one hand, being intensively exposed to plants very early in life could lead infants to abandon their reluctance to touch plants. These infants would have many opportunities to gain knowledge about plant properties and therefore not wait for parental cues before making contact with the kinds of plants they encounter in their local environment. This would be consistent with the proposal of Frankenhuis and colleagues (2016) that natural selection designs developmental mechanisms that use individual experience to tailor phenotypes to local conditions. On the other hand, given the huge diversity in plant life and lack of clear morphological features that reliably signal plant threats (e.g., particular leaf shapes or colors) in combination with the relative vulnerability of infants, it may be that the behavioral avoidance strategy for plants would also be found among children living in non-urban environments.

In line with the latter possibility, there is empirical evidence that rural and urban children exhibit similar sensitivity to ancestrally recurrent threats (e.g., Penkunas & Coss, 2013). Additionally, preliminary results of the ongoing cross-cultural project with 8- to 36-month-old children living in an indigenous Amazonian society in Ecuador (Shuar) indicate that non-WEIRD infants and toddlers are indeed reluctant to touch plants compared to other familiar and natural objects (Wertz, Elsner, Erut, Smith, & Barrett, in prep). These preliminary results raise an important methodological question of whether Shuar children recognize the stimulus plants presented to them in pots indoors as the plants they regularly encounter outside It is also still unclear how infants from any society interact with plants in naturalistic settings, although ongoing projects are currently addressing this question (Fantasia & Wertz, in preparation; Wertz, Oña, Fantasia, & Cole, in preparation).

Another open question that can broaden our understanding of responses to plant threats is to investigate how other organisms navigate the threatening features of their environment and plant threats in particular. Specifically, are the plant-specific behavioral strategies we observed in human infants shared by other species? This is an especially interesting issue with regard to species that rely on a variety of plants as food sources, such as nonhuman primates. There is evidence that some nonhuman primate species exploit the medicinal properties of plants to fight pathogens and diseases (Baker, 1996; Huffman, & Vitazkova, 2007), use plants parts as tools for acquiring food, usually by extraction (van Schaik, Deaner, & Merrill; 1999), and use plants in social displays to initiate play or attract a mate (e.g., the leaf clipping display of chimpanzees; McGrew, 1992). Additionally, it has already been shown that some nonhuman primates share some of the facilitated learning mechanisms for threatening stimuli shown in human infants. For instance, macaques readily associate snakes with a fearful vocal stimulus and also with a conspecific's fear response (Cook & Mineka, 1990). All of these findings suggest that nonhuman primates, like human infants, may possess behavioral mechanisms for dealing with plants. However, the possibility remains that the behavioral avoidance mechanism presented in this thesis may be uniquely human. Future studies will be necessary to answer this important question.

IV. Conclusions

Plants are not a kind of threat that we usually consider in modern circumstances because our everyday interactions with plants are infrequent and limited in scope. However, across evolutionary time our ancestors have been extensively exposed to plant threats on daily basis. Recently researchers started to uncover the important but often overlooked cognitive consequences of human interactions with plants: behavioral avoidance strategies and selective social learning mechanisms in human infants.

The work presented in this thesis provides new insights into previously unknown aspects of these recently discovered mechanisms. This thesis shows that infants are sensitive to different types of plant hazards—sharp-looking thorns and poisonous toxins—and that their response is tailored to successfully negotiating these threats. The evidence presented here for selective behavioral responses to plants generally and plants with visible thorny defenses in particular, broadens the existing literature by illustrating the complexity of human responses to threat. The findings contradict the intuitive idea that responses to ancestrally recurrent threats are structured in the same way across different threat categories. Further, they highlight the important role played by both the type of entity that infants are responding to (plants vs. non-plants) and the different aspects of social information provided by others (touch vs. emotional expression) during threat learning in infancy. Finally, this work reveals interesting avenues for future investigations that include comparisons with different cultures and different nonhuman animal species.

References

Baker, M. (1996). Fur rubbing: use of medicinal plants by capuchin monkeys (Cebus capucinus). *American Journal of Primatology*, *38*(3), 263-270.

Bar, M., & Neta, M. (2006). Humans prefer curved visual objects. *Psychological Science*, *17*(8), 645-648.

Barrett, H.C., & Broesch, J. (2012). Prepared social learning about dangerous animals in children. *Evolution and Human Behavior, 33,* 499-508.

Barrett, H. C., Peterson, C. D., & Frankenhuis, W. E. (2016). Mapping the cultural learnability landscape of danger. *Child Development*, 87(3), 770-781.

Boyer, P., & Bergstrom, B. (2011). Threat-detection in child development: An evolutionary perspective. *Neuroscience & Biobehavioral Reviews*, *35*(4), 1034-1041.

Crittenden, A. N., Conklin-Brittain, N. L., Marlowe, F. W., Schoeninger, M. J., Wrangham, R.W. (2009). Foraging strategies and diet composition of Hadza children. *American Journal of Physical Anthropology, 138(S48): 112.*

Cook, M., & Mineka, S. (1990). Selective associations in the observational conditioning of fear in rhesus monkeys. *Journal of Experimental Psychology: Animal Behavior Processes*, *16*(4), 372.

DeLoache, J. S., & LoBue, V. (2009). The narrow fellow in the grass: Human infants associate snakes and fear. *Developmental Science*, *12*(1), 201-207.

Hawkes, K., O'Connell, F., & Jones, N. B. (1995). Hadza children's foraging: juvenile dependency, social arrangements, and mobility among hunter-gatherers. *Current Anthropology*, *36*(4), 688-700.

Fantasia, V., & Wertz, A.E. (in preparation). 18- to 36-month-olds' behavior in a naturalistic garden setting.

Fantz R. 1958. Pattern vision in young infants. *The Psychological Record* 8: 43–47.

Frankenhuis, W. E., Panchanathan, K., & Nettle, D. (2016). Cognition in harsh and unpredictable environments. *Current Opinion in Psychology*, *7*, 76-80.

Greenwald, A. M., Eerkens, J. W., & Bartelink, E. J. (2016). Stable isotope evidence of juvenile foraging in prehistoric Central California. *Journal of Archaeological Science: Reports*, *7*, 146-154.

Gurven, M., Allen-Arave, W., Hill, K., & Hurtado, M. (2000). "It's a wonderful life": signaling generosity among the Ache of Paraguay. *Evolution and Human Behavior*, *21*(4), 263-282.

Gurven, M., Stieglitz, J., Hooper, P. L., Gomes, C., & Kaplan, H. (2012). From the womb to the tomb: the role of transfers in shaping the evolved human life history. *Experimental Gerontology*, *47*(10), 807-813.

Johnson, D. D., Blumstein, D. T., Fowler, J. H., & Haselton, M. G. (2013). The evolution of error: Error management, cognitive constraints, and adaptive decision-making biases. *Trends in Ecology & Evolution*, *28*(8), 474-481.

Haselton, M. G., & Buss, D. M. (2000). Error management theory: a new perspective on biases in cross-sex mind reading. *Journal of Personality and Social Psychology*, *78*(1), 81.

Haselton, M. G., & Nettle, D. (2006). The paranoid optimist: An integrative evolutionary model of cognitive biases. *Personality and Social Psychology Review*, *10*(1), 47-66.

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). Most people are not WEIRD. *Nature*, *466*(7302), 29.

Huffman, M. A., & Vitazkova, S. K. (2007). Primates, plants, and parasites: the evolution of animal self-medication and ethnomedicine. *Ethnopharmacology, e-book* http://www. *eolss. net, Eolss Publishers, Oxford*.

LoBue, V. (2010a). What's so scary about needles and knives? Examining the role of experience in threat detection. *Cognition & Emotion*, 24, 80–87.

LoBue, V. (2010b). And along came a spider: Superior detection of spiders in children and adults. *Journal of Experimental Child Psychology*, 107, 59–66.

LoBue, V., & DeLoache, J. S. (2008). Detecting the snake in the grass: Attention to fear-relevant stimuli by adults and young children. *Psychological Science*, *19*(3), 284-289.

LoBue, V., & DeLoache, J. S. (2010). Superior detection of threat-relevant stimuli in infancy. *Developmental Science*, 13(1), 221-228.

LoBue, V., & Rakison, D. H. (2013). What we fear most: A developmental advantage for threat-relevant stimuli. *Developmental Review*, *33*(4), 285-303.

LoBue, V., Rakison, D. H., & DeLoache, J. S. (2010). Threat perception across the life span: Evidence for multiple converging pathways. *Current Directions in Psychological Science*, *19*(6), 375-379.

LoBue, V., Bloom Pickard, M., Sherman, K., Axford, C., & DeLoache, J. S. (2013). Young children's interest in live animals. *British Journal of Developmental Psychology*, *31*(1), 57-69.

McGrew, W. C., & McGrew, W. C. (1992). *Chimpanzee material culture: implications for human evolution*. Cambridge University Press.

Munar, E., Gómez-Puerto, G., Call, J., & Nadal, M. (2015). Common visual preference for curved contours in humans and great apes. *PLoS One, 10*(11), e0141106.

Nesse, R. M. (2001). The smoke detector principle. *Annals of the New York Academy of Sciences*, *935*(1), 75-85.

Nesse, R. M. (2005). Natural selection and the regulation of defenses: A signal detection analysis of the smoke detector principle. *Evolution and Human Behavior*, *26*(1), 88-105.

New, J., Cosmides, L., & Tooby, J. (2007). Category-specific attention for animals reflects ancestral priorities, not expertise. *Proceedings of the National Academy of Sciences*, *104*(42), 16598-16603.

Patzwald, C., Curley, C. A., Hauf, P., & Elsner, B. (2018). Differential effects of others' emotional cues on 18-month-olds' preferential reproduction of observed actions. *Infant Behavior and Development*, *51*, 60-70.

Penkunas, M. J., & Coss, R. G. (2013). A comparison of rural and urban Indian children's visual detection of threatening and nonthreatening animals. *Developmental Science*, *16*(3), 463-475.

Rakison, D. H., & Derringer, J. (2008). Do infants possess an evolved spider-detection mechanism? *Cognition*, *107*(1), 381-393.

Repacholi, B. M. (2009). Linking actions and emotions: Evidence from 15-and 18-month-old infants. *British Journal of Developmental Psychology*, *27*(3), 649-667.

Ross, N., Medin, D., Coley, J. D., & Atran, S. (2003). Cultural and experiential differences in the development of folkbiological induction. *Cognitive Development*, *18*(1), 25-47.

Silvia, Paul & M. Barona, Christopher. (2009). Do People Prefer Curved Objects? Angularity, Expertise, and Aesthetic Preference. *Empirical Studies of The Arts*. 27. 25-42. 10.2190/EM.27.1.b.

Thompson, L. A., Fagan, J. F., & Fulker, D. W. (1991). Longitudinal prediction of specific cognitive abilities from infant novelty preference. *Child Development*, *62*(3), 530-538.

Turner, N. J., Łuczaj, Ł. J., Migliorini, P., Pieroni, A., Dreon, A. L., Sacchetti, L. E., & Paoletti, M. G. (2011). Edible and tended wild plants, traditional ecological knowledge and agroecology. *Critical Reviews in Plant Sciences*, *30*(1-2), 198-225.

Van Schaik, C. P., Deaner, R. O., & Merrill, M. Y. (1999). The conditions for tool use in primates: implications for the evolution of material culture. *Journal of Human Evolution*, *36*(6), 719-741.

Waters, A. M., & Lipp, O. V. (2008). The influence of animal fear on attentional capture by fear-relevant animal stimuli in children. *Behaviour Research and Therapy*, 46, 114–121.

Wertz, A.E**.,** Elsner, C., Erut, A.S., Smith, A.M., & Barrett, H.C. (in preparation). Shuar infants' behavioral and social referencing strategies for plants compared to other object types.

Wertz, A.E. & Moya, C. (2019). Pathways to cognitive design. *Behavioral Processes*. https://doi.org/10.1016/j.beproc.2018.05.013

Wertz, A.E., Oña, L., Fantasia, V., & Cole, W. (in preparation). Learning in the garden: Young children's social learning about and memory for plant properties over a three year period.

Wertz, A. E., & Wynn, K. (2014a). Thyme to touch: Infants possess strategies that protect them from dangers posed by plants. *Cognition*, *130*(1), 44-49.

Wertz, A. E., & Wynn, K. (2014b). Selective social learning of plant edibility in 6-and 18-

month-old infants. *Psychological Science*, *25*(4), 874-882.

Włodarczyk, A., Elsner, C., Schmitterer, A., & Wertz, A. E. (2018). Every rose has its thorn: Infants' responses to pointed shapes in naturalistic contexts. *Evolution* & Human Behavior. https://doi.org/10.1016/j.evolhumbehav.2018.06.001

Włodarczyk, A., Rioux, C., & Wertz, A. E. (under review). Social information reduces infants' avoidance of plants. *Cognitive Development*.

Abstract (German)

Der Umgang mit Umweltgefahren nimmt evolutionsgeschichtlich eine Schlüsselrolle im täglichen Leben des Menschen ein.

Daraus folgern Evolutionspsychologen, dass die Begegnung mit Gefahren über Millionen von Jahren vermutlich Spuren in der menschlichen Psyche hinterlassen hat (Barrett, 2005, 2015; Cosmides & Tooby, 1997). Übereinstimmend mit diesem Ansatz zeigen Kinder Unterschiede im Umgang mit und beim Lernen über stammesgeschichtlich wiederkehrende Gefahren wie beispielsweise gefährliche Tiere und wütende Gesichtsausdrücke (Barrett & Broesch, 2012; LoBue, 2013).

Jedoch ist nur wenig darüber bekannt, wie Kinder auf wiederkehrende Gefahren im breiteren naturalistischen Kontext reagieren. Obwohl sie harmlos erscheinen mögen, verfügen Pflanzen über eine Vielfalt von verschiedenen Abwehrmechanismen, die für Menschen gefährlich sein können. Dementsprechend zögern Kinder selbst dann, Pflanzen zu berühren, wenn diese harmlos aussehen; eine Verhaltensstrategie, die sie vor möglichen pflanzenspezifischen Gefahren schützt (Wertz & Wynn, 2014a).

In der vorliegenden Dissertation werden mehrere neue Aspekte des Vermeidungsverhaltens in Bezug auf pflanzenspezifische Gefahren einschließlich der Reaktion von Kindern auf sichtbare Gefahren, die von Pflanzen ausgehen (z. B. Dornen), untersucht. Wie die Ergebnisse aus Kapitel 1 verdeutlichen, zeigen Kinder im Alter von 8 bis 18 Monaten im Vergleich zu anderen Objekten sowohl anfängliches Zögern beim Berühren von Pflanzen als auch minimierten nachfolgenden physischen Kontakt mit diesen.

Kinder behandeln alle Pflanzen als potenziell gefährlich, unabhängig davon, ob sie harmlos aussehen oder spitze Dornen aufweisen. Sie behalten ihr Vermeidungsverhalten gegenüber Pflanzen auch dann bei, wenn zusätzlich soziale Hinweise vorhanden sind, wie in Kapitel 2 aufgezeigt wird. Überraschenderweise wird die Reaktion der Kinder auf Pflanzen oder andere Stimuli weder von negativen noch positiven sozialen Informationen beeinflusst. Stattdessen scheinen sie darauf zu reagieren, wenn der Versuchsleiter die Objekte berührt. Die Eyetracker-Studie, die in Kapitel 3 vorgestellt wird, erbrachte keinen Nachweis, dass das Vorhandensein spitzförmiger Elemente einen Einfluss auf die visuelle Aufmerksamkeit 8 bis 10 Monate alter Kinder gegenüber Pflanzen, unbekannten Artefakten und bekannten Gegenständen hat.

Insgesamt legen die Ergebnisse dieser Dissertation nahe, dass es zum Verständnis der Komplexität kindlicher Reaktionen auf Gefahren in der natürlichen Umwelt erforderlich ist, sowohl die Objektart (Pflanzen vs. Gegenstände) als auch verschiedene Aspekte sozialer Informationen durch andere (Berührung vs. Zeigen von Emotionen) miteinzubeziehen.

Eidesstattliche Erklärung

Hiermit versichere ich,

____________________ ____________________

Vorname Name

an Eides statt, dass die vorliegende Arbeit von mir selbstständig und ohne unerlaubte Hilfe Dritter verfasst wurde und ich keine anderen als die angegebenen Quellen und Hilfsmittel verwendet sowie wörtliche und sinngemäße Zitate als solche kenntlich gemacht habe.

Diese Arbeit hat in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegen und wurde bisher nicht veröffentlicht.

____________________ ____________________

Ort, Datum Unterschrift