and avoid infected conspecifics on the basis of olfactory cues associated with the altered chemical composition of infected feces (*2*). Thus, whereas prey “fear” predators, parasite avoidance is more akin to disgust—an innate aversion to cues associated with parasites (*1*). As with predator avoidance, parasite avoidance incurs costs such as altered social interactions, reduced reproductive opportunities, diminished foraging, and increased energy expenditure (*4*). To predict when parasite avoidance is most likely to occur and understand its consequences, it must be integrated into the same trade-off framework that is widely applied to predator avoidance.

Beyond its direct effects on hosts, parasite avoidance has cascading effects at a range of scales and in various systems (*5*). Ants and their parasitoids provide a useful model system for studying the cascading effects of parasite avoidance on herbivory. Azteca ants experimentally exposed to parasitoid flies dramatically reduce their activity levels to avoid infection. This reduces the ants’ ability to attack their herbivorous prey, the coffee berry borer, and allows the latter to consume more coffee berries (*6*). Such ecological impacts of parasite avoidance are not limited to top-down effects on vegetation; they also alter mutualism, competition, and predation.

Like the predator-induced landscape of fear, a parasite-induced landscape of disgust (see the figure) has far-reaching consequences for population dynamics, species interactions, and ecosystem structure. However, whereas direct effects of predators are naturally restricted to prey species (*7*), a parasite-induced landscape of disgust extends to all animals, including very large species and top predators that are typically immune to predation (*8*). For example, a recent synthesis by Moleón *et al.* showed that carnivores avoid foraging on other carnivore carcasses and rarely engage in cannibalism (*9*). Feeding on conspecifics increases disease transmission, and forgoing this food resource reduces exposure to shared parasites (*10*). At a landscape level, this avoidance behavior dramatically alters the amount of carcass material that is available in an ecosystem, with important downstream effects. For instance, carcasses not consumed by mammalian scavengers may support more diverse and abundant arthropod communities (*9*). Furthermore, when carcasses decompose, their nutrient inputs increase plant growth (*11*). Like the ecosystem-level impacts of predator avoidance, the ecosystem-level impacts of parasite avoidance are likely to be substantial.

Parasite and predator avoidance can exert opposing pressures on host and prey species. For example, tadpoles increase their activity levels to protect themselves from trematode infection, but this increases their susceptibility to visual predators (*12*). The tadpoles fear and avoid both predators and parasites, but do not perceive these threats as equal. When experimentally forced to choose between predation and parasitism risk, tadpoles opt for infection (*13*). This makes sense because predation has a larger short-term fitness effect than does parasitism, and the optimal behavior avoids the greatest immediate threat.

However, parasite and predator avoidance are not always mutually exclusive. For instance, avoiding predator feces protects prey against both predators and their parasites (*14*), and, when animals group together, they dilute their risk of attack by both predators and some parasites (for example, ticks, botflies) (*15*). Although predator avoidance has received more attention, parasite avoidance also has strong effects on foraging, movement, and social interactions (*1*).

Parasite avoidance is likely to have important consequences. For example, grazing animals such as cows, sheep, and horses avoid fecal contaminated forage (*4*), and changing livestock practices to recognize the needs and capabilities of animals to avoid parasites will reduce the cost associated with avoidable livestock diseases. Furthermore, conservation planning and projections may benefit from knowledge of how shrinking and fragmented habitat limits the ability of animals to avoid risky sites and conspecifics. As populations of large predators continue to decline, parasite avoidance may become a relatively stronger driver of ecological processes. Integrating parasites into the ecology of fear is thus crucial to understanding the general ecological and evolutionary effects of parasites on ecosystems and predicting how ecosystems are likely to respond to the rapidly changing environments of the Anthropocene. ■

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PSYCHOLOGY

Logic in babies

12-month-olds spontaneously reason using process of elimination

By **Justin Halberda**

The success of science rests on our human ability to reason logically. But where does this ability come from? Is it an inherent attribute of mind that even a young child might possess, or is it a hard-won accomplishment mastered later in life? On page 1263 of this issue, Cesana-Arlotti *et al.* (*1*) reveal that one essential form of logical inference, process of elimination, is within the toolkit of 12-month-old infants. This reveals the earliest known foundations of our human ability to reason logically. The race to document the range of early logical abilities shared by infants, adults, and nonhuman animals, and to determine how these foundational abilities empower our broader capacities to reason, has begun.

Every scientific method requires a supporting logic. For Francis Bacon (*2*), this was unfettered empirical observation followed by induction (reasoning from many cases to form a general principle). Karl Popper (*3*) stressed the importance of hypothesis testing and the ability to refute hypotheses found to be false (science as an extended instance of process of elimination). And Thomas Kuhn (*4*) highlighted the dramatic changes that occur during scientific revolutions, in which wholly new models of phenomena are created through model building and abduction (sometimes called “inference to the best explanation”). Examples of such revolutions are the Copernican Revolution (*5*) producing the heliocentric model of the solar system, and the Einsteinian Revolution of special relativity in which space and time become one (*6*). In each of these cases (induction, hypothesis testing, abduction), the work of science is supported by an underlying logic. No logic, no science.

Where does our human faculty to reason logically come from? At the end of the previous century, Susan Carey suggested that such logic might be deep in our developmental roots: A young child might reason using intuitive theories, models, and abduc-

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An infant at play is also an infant reasoning logically.

PHOTO: OKSANA KUZMINA/SHUTTERSTOCK.COM

tion, much like a professional scientist (*7*). Other developmental psychologists pushed this further and suggested that even infants might be understood to be little scientists drawing inferences in the cradle about objects and causes (*8*). But suggestions like these are frequently met with incredulity (*9*): After all, it often feels like logical reasoning is effortful, conscious, and even linguistically based (*10*). These characteristics, if accurate, would seem to preclude the possibility that preverbal infants could engage in any such process.

Cesana-Arlotti *et al.* asked whether prelinguistic 12- and 19-month-old infants would spontaneously reason using process of elimination. This is a form of inference also known as disjunctive syllogism or modus tollendo ponens—it is any argument of the form: A or B, not A, therefore B. Cesana-Arlotti *et al.* relied on one of the few behaviors babies voluntarily engage in—looking at whatever they find most interesting (*11*). They measured infants' looking at computerized vignettes in which two different objects (A and B) were shown being hidden behind a wall. Infants watched as a cup scooped one of the objects from behind the wall, and then came to rest next to the wall—critically, only the topmost edge of the contained object could be seen peeking out of the cup, such that infants could not tell for sure whether the object was A or B. At this moment, infants could have formed a disjunctive thought—for example, "either the object in the cup is object A or it is object B." Next, this ambiguity was resolved: The wall dropped to reveal that object A was behind the wall, but the contents of the cup remained hidden. This is the moment of potential elimination, and an opportunity for infants to draw a key inference—"because object A is not in the cup, object B must be in the cup." Finally, infants' expectations for the cup's contents were tested: Either the expected object (object B) or, surprisingly, another object A emerged from the cup. Infants looked longer at the surprising outcome—an indication that their expectations were violated and a hint that they were seeking further information to resolve the conflict (*12*).

Potentially even more exciting, infants also showed signs of making the necessary inferences along the way—for example, upon seeing which of the two objects was behind the wall, but before the cup's contents were revealed, infants' pupils dilated and they tended to shift their fixation to the cup (consistent with them inferring which object must be inside). This pattern suggests that infants used the information they had seen to reason through a disjunctive syllogism (A or B, not A, therefore B). There were also additional versions of these vignettes that manipulated the precise sequence of hiding and revealing, which allowed the authors to determine what specifically the infants were remembering and expecting during each moment.

The careful crafting of stimuli and clever analyses of infants' spontaneous looking behavior by Cesana-Arlotti *et al.* show us that infants have the capacity to reason by process of elimination. By contrast, whereas nonhuman animals such as dogs facing similar situations of ambiguity may ultimately form the right conclusion, they appear to arrive at this hunch using an associative rather than logical process (*13*). Unwinding the similarities and differences among infant, child, adult, and animal reasoning abilities is an important task for the future, as is determining why, despite being deployed by infants, reasoning feels effortful and why humans often "go with our gut" and rely on heuristics and biases rather than logical inference (*14*).

A new field, studying the foundations of logical abilities, is emerging. As with other successes of developmental psychology in recent decades [as in work on the psychology of number, language, and theory of mind (*15*)], this new field will make use of behavior and brain studies with infants, children, and adults; studies of nonhuman animal abilities; studies of the correlations between reasoning and other abilities; and training studies to determine where we all begin and how maturation and experience build upon these foundations. It is a thrilling time for us as scientists—using logical reasoning to understand how we reason logically. ■

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