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Great apes and children infer causal relations from patterns of variation and covariation

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ABSTRACT

We investigated whether nonhuman great apes (N = 23), 2.5-year-old (N = 20), and 3-year-old children (N = 40) infer causal relations from patterns of variation and covariation by adapting the *blicket detector* paradigm for apes. We presented chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*), orangutans (*Pongo abelii*), gorillas (*Gorilla gorilla*), and children (*Homo sapiens*) with a novel reward dispenser, the blicket detector. The detector was activated by inserting specific (yet randomly determined) objects, the so-called *blickets*. Once activated a reward was released, accompanied by lights and a short tone. Participants were shown different patterns of variation and covariation between two different objects and the activation of the detector. When subsequently choosing between one of the two objects to activate the detector on their own all species, except gorillas (who failed the training), took these patterns of correlation into account. In particular, apes and 2.5-year-old children ignored objects whose effect on the detector completely depended on the presence of another object. Follow-up experiments explored whether the apes and children were also able to re-evaluate evidence retrospectively. Only children (3-year-olds in particular) were able to make such retrospective inferences about causal structures from observing the effects of the experimenter's actions. Apes succeeded here only when they observed the effects of their own interventions. Together, this study provides evidence that apes, like young children, accurately infer causal structures from patterns of (co)variation and that they use this information to inform their own interventions.

1. Introduction

A chimpanzee looking up at the canopy suddenly sees a group of colobus monkeys moving in the tree and feels simultaneously a gust of wind followed by a fruit falling to the ground (cf. Tomasello & Call, 1997). Based on this observation, the chimpanzee might learn associations between the presence of monkeys, the gust of wind, and the appearance of the fruit. Detecting such spatio-temporal associations in the environment is an essential step to make causal inferences about the world. However, mere associations even while taking into account important principles such as temporal priority or spatial contiguity are not always sufficient to infer causal structures (Hume, 1748/2000). For instance, based on the above observation alone, it remains ambiguous what caused the fruit to fall down (Seed & Call, 2009). One possibility is that the wind (W) and not the monkeys (M) caused the detachment of the fruit (F) (one-cause model: $W \rightarrow F$). Alternatively, the gust of wind and the moving monkeys might be independent causes of a common effect (two-cause model: $W \rightarrow F \leftarrow M$). Given the evidence, other models such as common cause and causal chain models are viable alternatives too.

Inferring causal structures in the environment based on the perceptual input is known as the *causal inverse problem* (Gopnik et al., 2004). Gopnik and colleagues proposed the differentiation of substantive and formal causal assumptions that might help an organism to solve this problem. On the one hand, substantive assumptions are specific causal principles such as the temporal order of cause and effect, spatial contiguity, and generally any prior knowledge about the world that constrains possible causal structures. On the other hand, formal assumptions provide a general, content-independent tool to infer causality-based patterns of correlation. These formal assumptions help us to distinguish between causal relations and mere correlations that are caused, for instance,

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by an unknown third factor (like an unobserved, common cause of two correlated variables).

Returning to the initial example, to resolve the aforementioned ambiguity between a one-cause model (W → F) and a two-cause model (W → F ← M), there are two options based on these formal causal assumptions: interventions and passive observations taking into account conditional probabilities of the events (Gopnik et al., 2004). First of all, intervening on each of the potential causes (e.g. chasing the monkeys away) while keeping the presence or absence of the other candidate cause constant would lead to different expectations depending on different causal structures. The second option is to observe situations in which only one of two co-occurring events is present. For instance, observing whether the monkeys' presence and the fruit's appearance are correlated depending on the presence of wind will reveal whether there is a relation between monkeys and the fruit's appearance independent of wind (as expected from a two-cause model but not from a one-cause model). The theoretical foundation for this is the causal Markov assumption (Hausman & Woodward, 1999) which states that given all direct causes of a variable are known and kept constant this variable will be independent of all other variables in the causal map except for its effects.

To shed light on infants' ability to learn about novel causal structures, in particular with regard to their ability to discount alternative candidate causes, Gopnik and colleagues (Gopnik & Sobel, 2000; Gopnik, Sobel, Schulz, & Glymour, 2001; Nazzi & Gopnik, 2000) developed a new experimental paradigm. Gopnik et al. (2001) presented 2.5- to 4-year-old children with a new device, the so-called *blicket detector*. This detector lit up and played a tune, if certain objects, the *blickets*, were placed on top of it. Other objects did not activate the blicket detector. Children were told that that blickets would always make the machine go. The task for the children was to identify objects that were "like blickets". The children received then different experimenter-given demonstrations. These demonstrations involved two novel objects but varied depending on the condition. In the one-cause condition, each object was placed on top of the detector by itself. One object (A) activated the detector; the other one (B) did not. Then both objects were placed on top of the detector simultaneously two times in a row and both times the detector was activated. In the two-cause condition, each object was placed on top of the detector by itself three times in a row. Whereas one object (A) activated the detector three times in a row, the other object (B) did not activate the detector the first time but did so the two following times. Thus, in both conditions one object (A) was associated with the activation of the detector in 100% of instances, while the other object (B) only in 67% of cases. However, in the one-cause condition, the effect of object B was conditional on object A. In contrast, in the two-cause condition the effect of object B on the detector was not conditional on A. Therefore, in the one-cause condition only object A could be like a blicket, whereas in the two-cause condition both objects might be regarded as blickets. Children's performance confirmed the hypothesized difference between the two conditions. In the two-cause condition, 3- and 4-year-old children were more likely to say that object B (the 67% object) was a blicket than in the one-cause condition. Moreover, in a forced-choice situation, 2.5-year-olds preferred object A over B in the one-cause condition but not the two-cause condition. Hence, Gopnik et al. (2001) concluded that young children infer novel causal relations by using conditional dependencies to discounting alternative candidate causes.

The extent to which the cognitive abilities of nonhuman great apes, our closest living relatives, might match those of humans is subject to ongoing debate. The relational reinterpretation hypothesis (Penn, Holyoak, & Povinelli, 2008) proposes that the cognitive differences between humans and nonhuman primates originate in the ability for abstract, relational reasoning. According to this view, nonhuman apes are incapable of re-interpreting perceptual input in terms of higher-order structural relations (e.g. reasoning about unobservable mechanisms and physical regularities). Contrary to this hypothesis, other scholars (Seed & Call, 2009) contended that nonhuman apes do have the capacity to encode and process information at an abstract, structural level, and not only at the perceptual level (allowing, for instance, for transferring knowledge between perceptually disparate but functionally equivalent tasks). In line with the latter view, there is some experimental evidence suggesting that great apes, at least in some situations, take unobservable object properties (such as weight and solidity) into account when solving problems (for recent reviews see, Seed & Call, 2009; Seed, Hanus, & Call, 2011).

Apart from this debate on nonhuman animals' ability to reason about unobservable causal mechanisms, a central question in this context is how nonhuman animals (as compared to humans) learn and represent novel causal structures. Penn and Povinelli (2007, p. 110) propose that "nonhuman animals' capacity for flexible goal-directed actions suggests that they explicitly represent the causal relation between their own action and its consequences". At least in the case of their own instrumental actions, nonhuman apes may be able to distinguish between covariation and causation. However, up to this point no study has explicitly addressed this issue, not to mention the question of whether apes are also able to distinguish between causation and covariation solely based on observational evidence (e.g. by observing others' interventions).

Under natural conditions, animals often face situations with multiple covarying events as alluded to in our opening example. In order to make efficient predictions about their environment animals would benefit from differentiating between causation and covariation. Causal discounting, or explaining away, is important to achieve this differentiation. Discounting means that the presence of one cause of an effect reduces the requirement of invoking other causes (Sloman, 2009). In certain situations, cue competition effects known from the associative learning literature can lead to similar outcomes. The nature of the cognitive processes underlying these cue competition or interaction effects is the subject of an ongoing debate (De Houwer, Vandorpe, & Beckers, 2005). Evidence for the involvement of inferential reasoning processes is provided by findings indicating that blocking effects are sensitive to ceiling effects and outcome additivity in rats and humans (Beckers, De Houwer, Pineno, & Miller, 2005; Beckers, Miller, De Houwer, & Urushihara, 2006). Additionally, the extent of training might be informative here. Cue competition effects in nonhuman animals are usually observed only after many exposures to the relevant contingencies (except for some specific contexts such as taste aversion). The demonstration of causal discounting after minimal exposure to the relevant contingencies (like in the blicket detector paradigm) would provide more evidence for the role of reasoning processes.

Compared to the literature on causal mechanisms, very few studies have examined the capacity of nonhuman primates to learn novel causal structures. One such study investigated whether nonhuman great apes (henceforth apes) were sensitive to the temporal order of cause and effect in the context of an object displacement task (Völter & Call, 2014). In this study, great apes needed to locate a yoghurt reward that was hidden under one out of two opaque cups and displaced out of their sight. Crucially, the yogurt baited cup left a yoghurt trail behind it. The apes spontaneously used the trail to locate the baited cup. Moreover, when presented with two perceptually identical trails leading to two different cups the apes ignored the trail that was already present before the cups were displaced and picked the cup at the endpoint of the causally relevant trail. This suggests that apes can integrate temporal information about cause and effect when making causal judgments.