Noticing causal properties of objects from sequence statistics

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Questions

Many properties of objects are not physical features: for example, *turns on the light*, *protects from rain*, and *enables communication* are essential to concepts like *light switch*, *umbrella*, and *telephone*. How could we acquire such property concepts, bottom-up, from experience?

Even naive learners are adept at inferring structure from raw streams of events without top-down guidance (e.g., Hunt & Aslin, 2001; Saffran et al., 1996; Turk-Browne, Jungé, & Scholl, 2005). Can this kind of mechanism serve as a basis for building non-physical object properties?

1. Participants in such learning scenarios don't typically have explicit access to this knowledge. Can they gain explicit access?

2. Causal induction paradigms (e.g Cheng 1997) warn subjects they will be making causal judgments and about which target event. Can causality emerge as a property even when you're not looking for it?

3. If statistical structure among events informs concept formation, then might different kinds of statistics lead to different conceptual inferences?

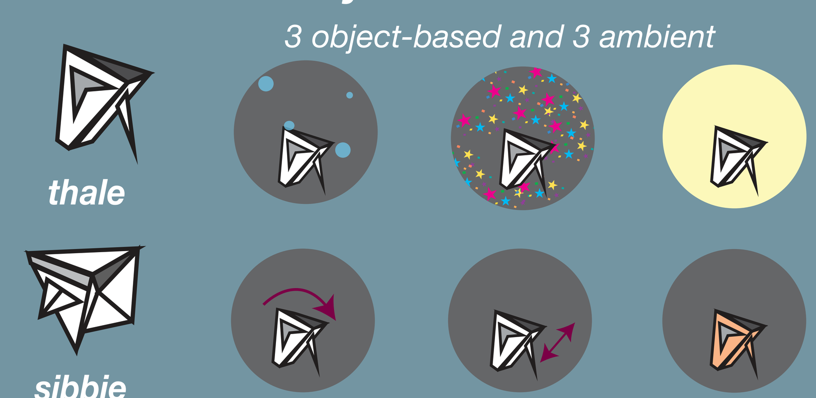
4. If statistics are assigned as properties of objects, they should enable category formation in both supervised and unsupervised contexts (Gopnik & Sobel 2000; Nazzi & Gopnik 2003; Kemp et al 2010). When these properties refer to the structure of events, they should be highly tolerant to sensory details of the objects and events, because they are based on higher-order relations rather than the sensory details. Can novel categories be built purely on the basis of causal direction to an ambient event? Can these categories generalize across the nature of the specific events involved?

Exp. 1 *statistical property learning*

Objects differ in terms of two types of statistics: identity of the rare event, and direction of contingency between two other events.

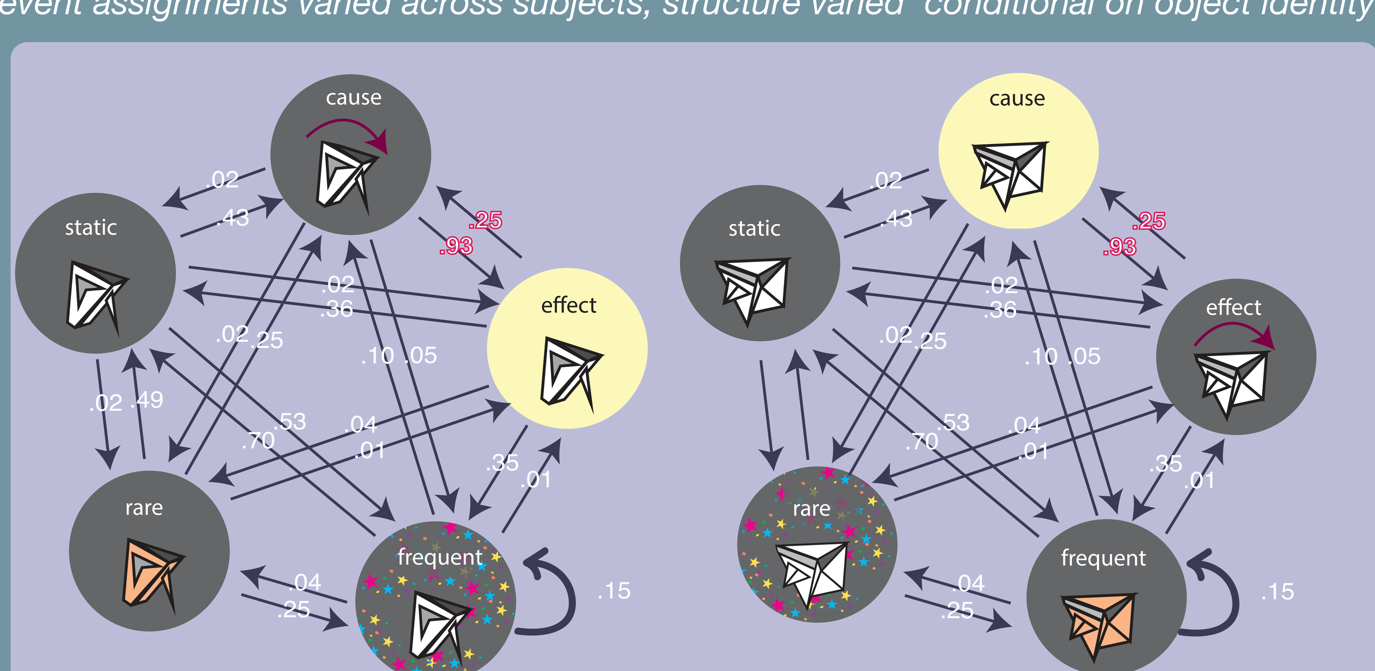
stimuli: objects & events

3 object-based and 3 ambient



conditions: transition probabilities

event assignments varied across subjects; structure varied conditional on object identity



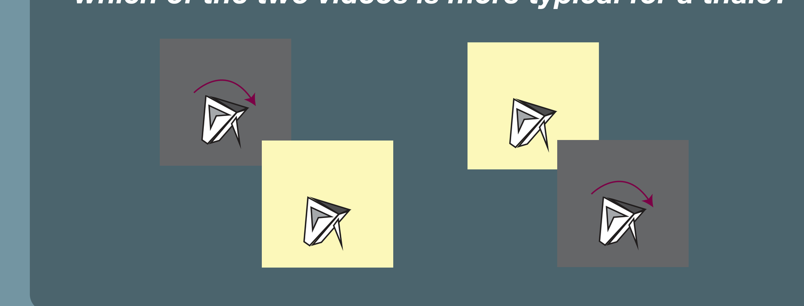
sequence presentation

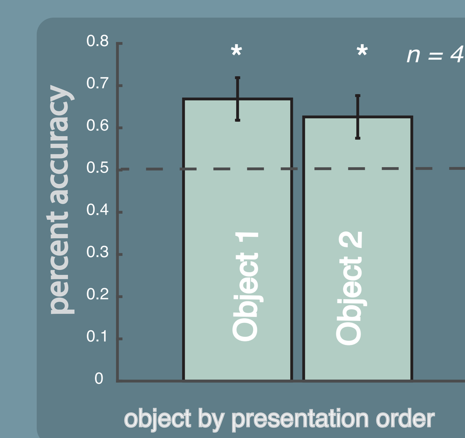
250 trials/object; subjects told to pay close attention and try to predict what will happen next (press a key when something unexpected occurs). Attention checks required subjects to identify the rare event.

familiarity forced choice test

strong transitions compared to weaker transitions to test discrimination of relative contingency strength

which of the two videos is more typical for a thale?





Correlation between objects: r(45) = -0.01

Mean percent accuracy = 0.65 with t(46) = 4.19, p < 0.0001

sentence acceptability test

tests explicit access and conceptual interpretation

ordered: effect to cause

After thales tilt, the light tends to flash

1 *definitely false* – 2 – 3 *unsure* – 4 – 5 *definitely true*

ordered: cause to effect

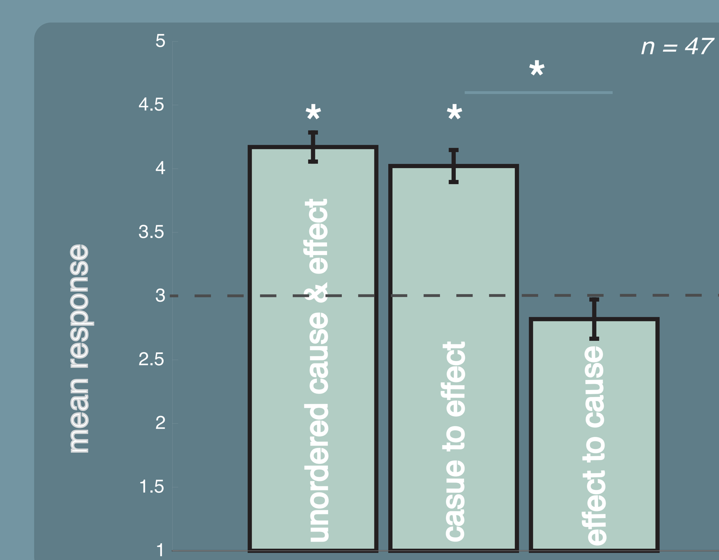
After the light flashes, thales tend to tilt.

1 *definitely false* – 2 – 3 *unsure* – 4 – 5 *definitely true*

unordered: cause & effect

Light flashing around thales and their tilting are strongly related.

1 *definitely false* – 2 – 3 *unsure* – 4 – 5 *definitely true*



1. Subjects can identify which events are contingent on each other from a continuous stream of events with minimal instruction.
2. They can bind different contingency structures to distinct objects.
3. These represenations are explicitly available.
4. And they are naturally directional (ie., structured).

causal acceptability

effect to cause

only in subjects who were accurate on non-causal questions (n =25)

Thales tilting causes the light to flash.

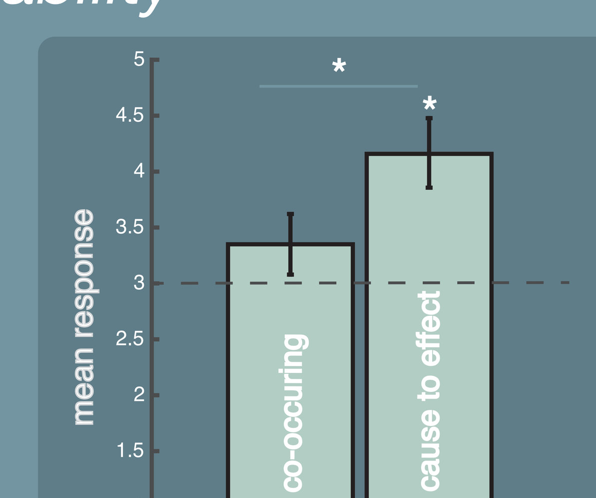
1 *definitely false* – 2 – 3 *unsure* – 4 – 5 *definitely true*

co-occurring (frequent)

only for object where frequent event was ambient, and for subjects who were accurate on non-causal contingency and frequency judgments (n = 20)

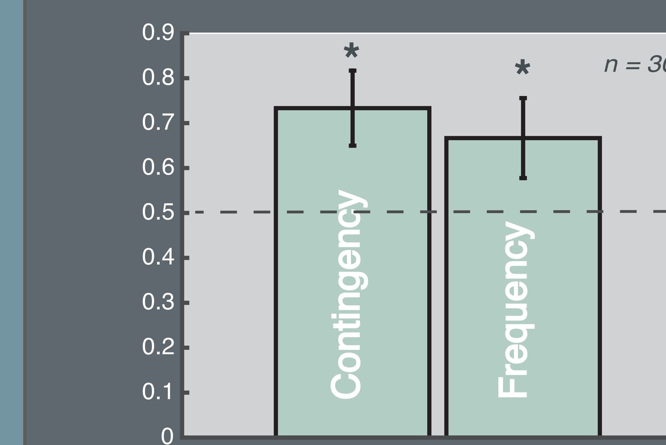
Thales cause confetti to appear.

1 *definitely false* – 2 – 3 *unsure* – 4 – 5 *definitely true*



5. Subjects accept causal interpretations of these contingencies
6. They conceptually distinguish object-event co-occurrence vs. object-dependent contingency structure.

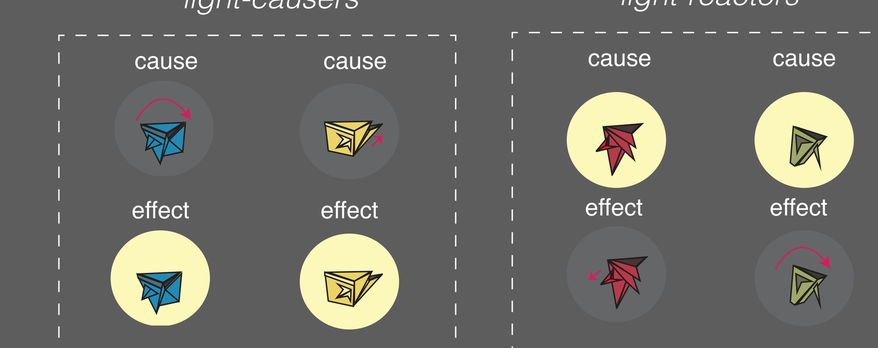
Exp. 2 *supervised category membership judgments*



7. Subjects can classify a novel exemplar based on common causal direction to the same event under supervised (labeled) conditions.

Exp. 3 *unsupervised category induction*

object-dependent structure



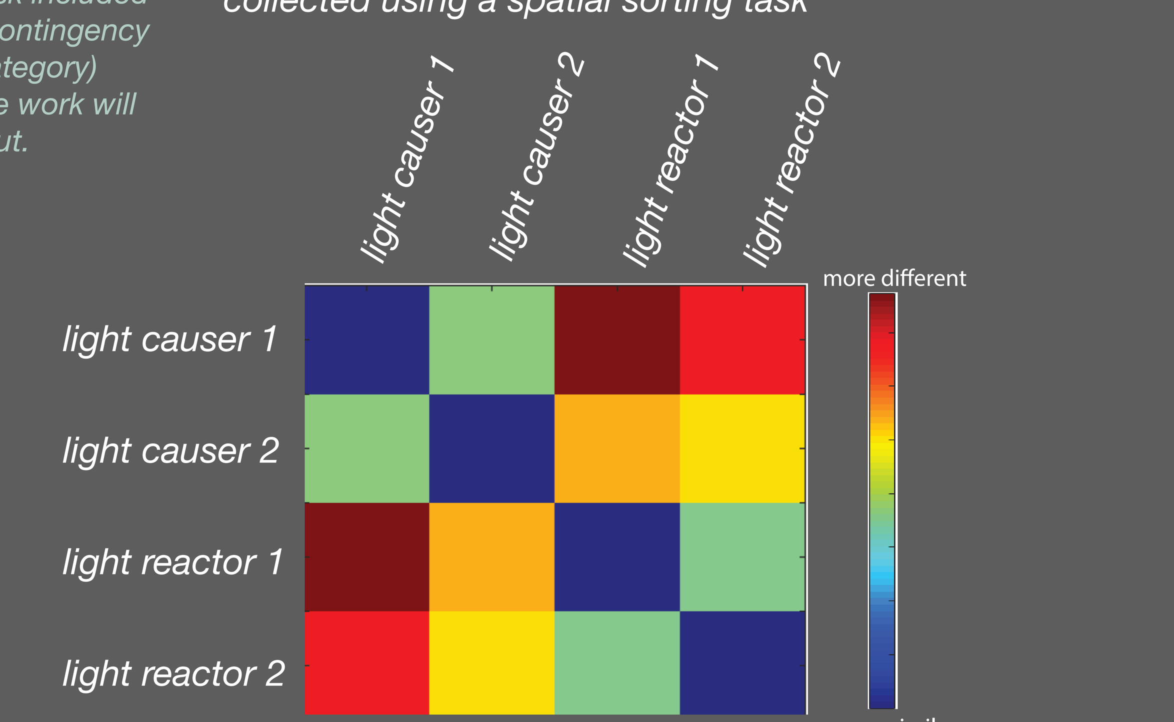
shape to condition assignments counterbalanced

object stimuli

similarity judgments

collected using a spatial sorting task

caveat: this task included feedback on contingency (though not category) learning; future work will test this without.



within vs. between category distance: $t(10) = -5.23$, $p = 0.0001$

8. Subjects group objects by purely statistical properties.

9. They generalize over both object shape and the nature of the causal/effect event.

Conclusions

Human adults can acquire object categories based purely on statistical properties in a bottom-up manner from sensory streams, and gain explicit access to this knowledge. These categories can generalize over the nature of the individual events. We are currently tracing the neural mechanisms that allow such representations to be computed.

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