Development 1: Cognition in infancy

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CBMM Summer School
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Development

Two mornings (Thurs: Laura & Tomer; also Josh, Shimon)

The topic is actually narrower:

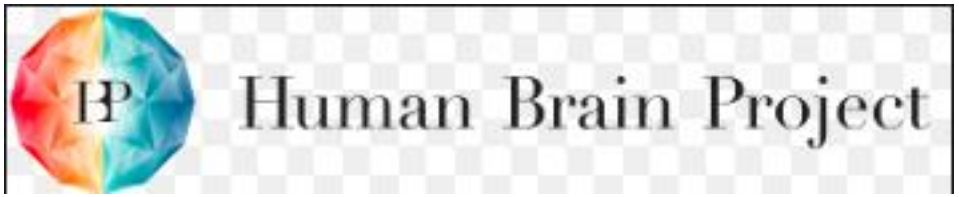
human development

cognitive development

mostly as revealed through behavioral experiments

And my topic is narrower than this: human infants

Why??



Why cognition in human infancy?

Intrinsically fascinating:

From birth to maturity, we go from knowing almost nothing to become the smartest, most knowledgeable entities on the planet. Many of the biggest changes occur early. How do we do it?

Historically, recognized as important for understanding minds and brains & for building smart machines.

Helmholtz

Turing

Hubel/Wiesel

Useful for BMM today:

Studies of human cognitive development can shed light on 3 questions at the heart of the study of intelligence.

One question today, from Josh

How do we get so much from so little?

prior knowledge: compositional, causal explanatory models

but what are these models?

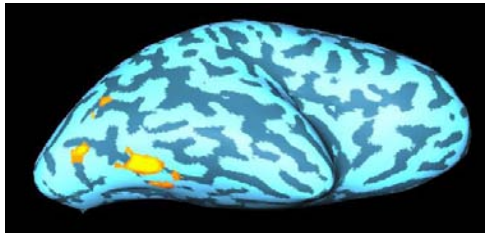
how are they organized?

Can study this in adults (Nancy, Josh, Rebecca)

But in adults, these questions are hard to answer

we know too much

we can connect anything we know to anything else (e.g., analogical reasoning).



Human infants know far less and are less flexible at linking knowledge across domains. But they are in the business of learning about the world, and they seem to do it by developing models.

Studies of infants may shed light on the fundamental cognitive systems that support learning, organize human knowledge and underlie human intelligence.

How can we study what infants know?

They can't talk to us.

They can't do much:

Before 5 months, no reaching
Before 7 months, no locomotion
Before 10-12 months, no pointing, talking....

But infants observe the world and start learning about it from the beginning.
Their observations are systematic and are reflected in simple exploratory behaviors: looking, orienting to sound.
These behaviors can tell us something about what infants perceive and understand.

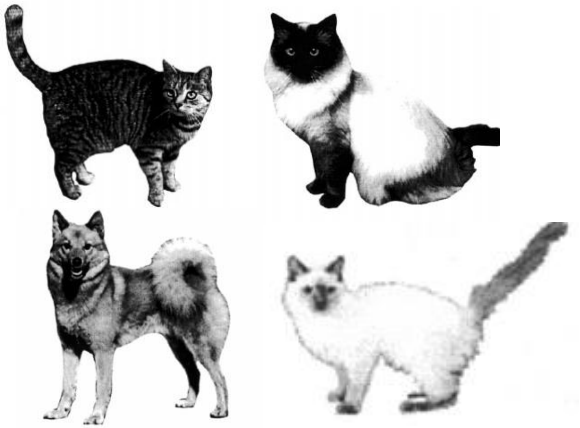
Infants' looking patterns

Infants look at some things more than others (Fantz):

- black/white stripes > gray
- moving > stationary arrays
- sphere > disc

Infants look more at new things (e.g., Quinn)

- ex: 6 pairs of cats → dog > new cat



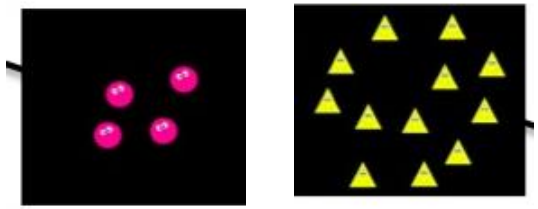
Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.
Source: Quinn, Paul C., Peter D. Eimas, and Michael J. Tarr. "Perceptual categorizationof cat and dog silhouettes by 3-to 4-month-old infants." Journal of experimental child psychology 79, no. 1 (2001): 78-94; doi:10.1006/jecp.2000.2609.

Infants look longer when what they see relates to what they hear (e.g., Izard)

4 vs. 12 syllables:

... « tuuuuu-tuuuuu-tuuuuu-tuuuuu » ...

... «tu-tu-tu-tu-tu-tu-tu-tu-tu-tu-tu-tu» ...



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Source: Coubart, Aurélie, Véronique Izard, Elizabeth S. Spelke, Julie Marie, and Arlette Streri. "Dissociation between small and large numerosities in newborn infants." Developmental science 17, no. 1 (2014): 11-22.

newborn infants

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An unanswered question: what do infants perceive or understand?

(Fantz, 1958; Quinn et al., 1990s; Izard et al., 2009 and since)

Infants' looking patterns

To find out, need systematic experiments connecting infants' performance to that of adults:

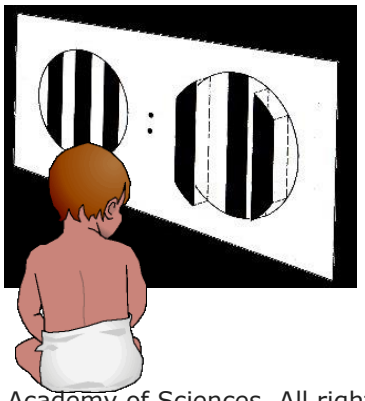
1. sphere vs. disc: perceive 3D objects?

Held's experiments with stereopsis.

2. cats vs. dogs??

Quinn, others: faces....

3. abstract number? Izard's experiments testing for signatures of approx. number



Source: Held, Richard, Eileen Birch, and Jane Gwiazda. "Stereoacuity of human infants." Proceedings of the National Academy of Sciences 77, no. 9 (1980): 5572-5574.

Good news: these questions can be answered.

Bad news: the research is slow. But it's going to get faster.

Lookit: web-based testing of infants (Scott & Schulz)

fNIRS: more specific measures from passive observation (Powell & Saxe)

?new technologies to enhance infants' motor capacities?

And it has already shed some light on infants' knowledge.

What I think this research tells us

Our starting state includes a set of domain-specific cognitive systems:

objects (motions, collisions....)
people as agents (actions, intentions)
people as social partners (interactions, experiences)
number
places
forms } geometry

Each system operates as a whole (internally compositional)
is partially distinct from the others
is limited
is shared by other animals
functions throughout life and supports new, uniquely human concepts and knowledge systems

What I think this research tells us (but won't discuss today)

Humans have a species-unique capacity to combine representations from these systems productively, yielding new concepts

These productive combinations underlie our uniquely human, later-emerging systems of knowledge (and abstract concepts):

object kinds (animals, plants, artifacts)
natural number and Euclidean geometry
persons and mental states (Alia)

Hypothesis: this capacity = natural language (words, productively combinatorial syntax, compositional semantics)
Its words and rules apply across core domains and so give rise to new families of concepts capturing abstract properties of the world.
Language is learned from other people, and so it points children toward the concepts that others consider most worth having.

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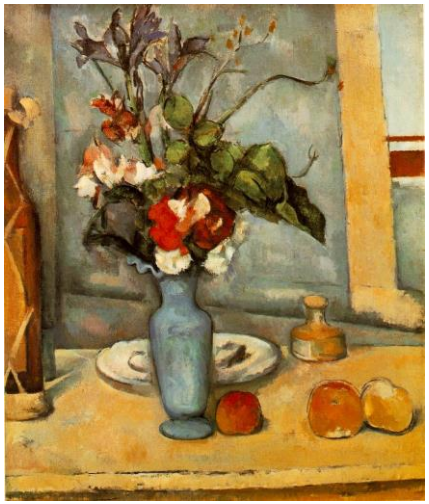
Objects

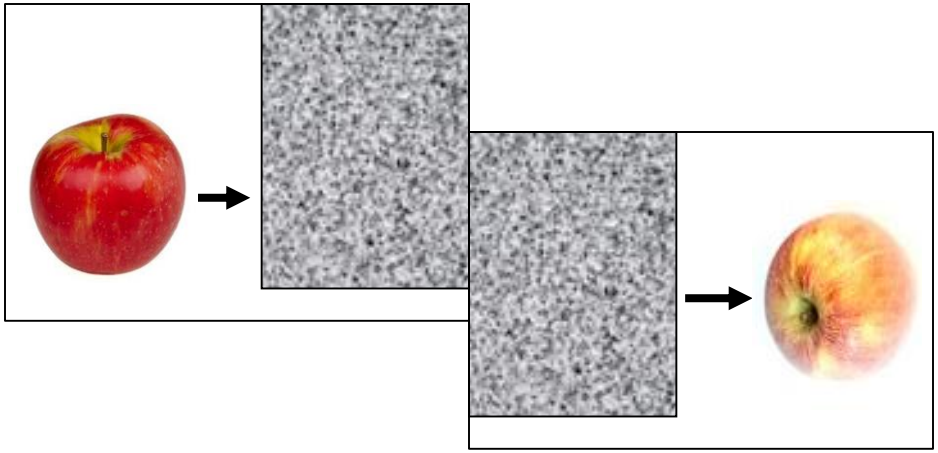
segmentation

completion



This painting by Paul Cezanne is in the public domain.

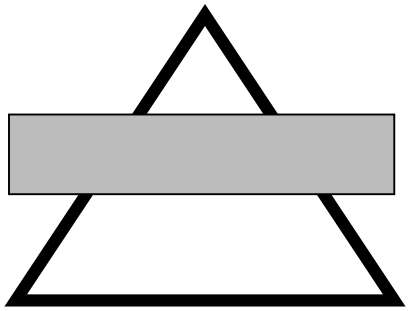
Identity

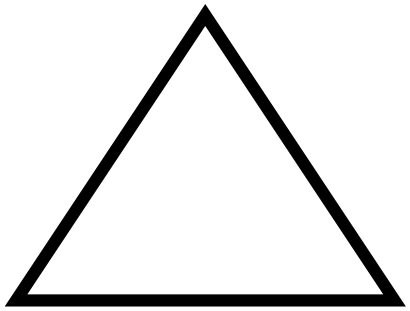


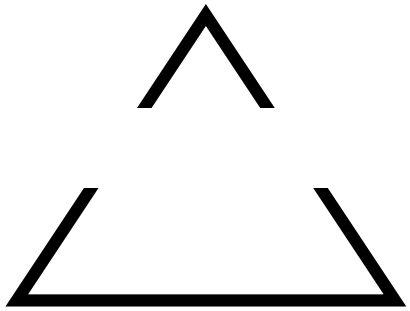
mechanics

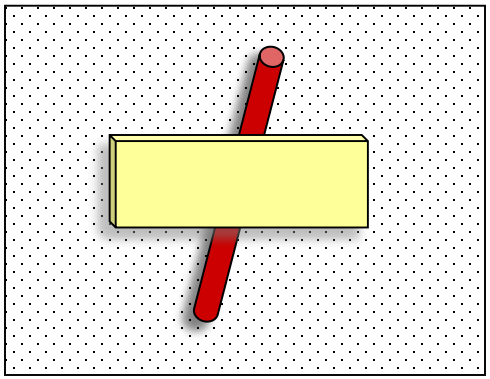
Amodal completion

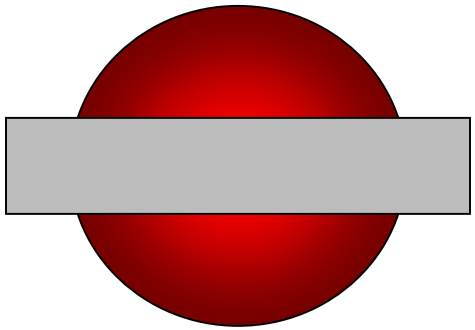
(4 months)







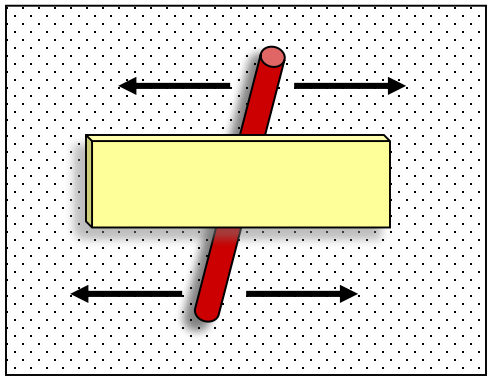




Equal increase in looking at the two test displays

(Kellman & Spelke, Schmidt & Spelke, 80s)

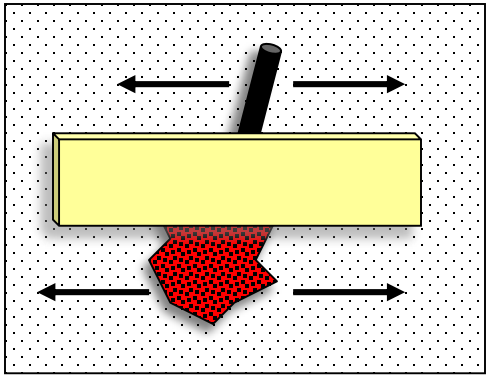
Amodal completion

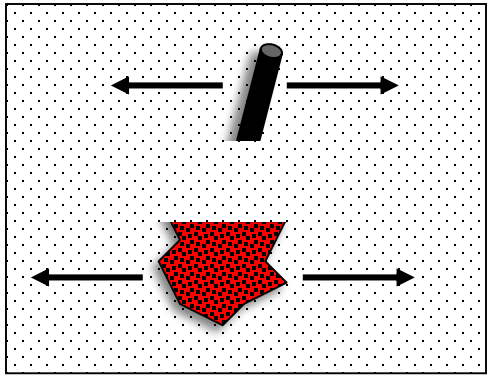


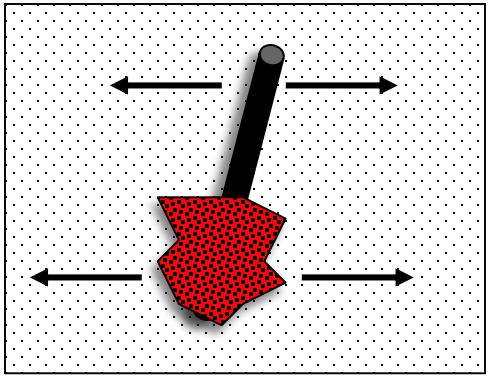
(4 months)

Longer looking at the test display with the gap.

Why motion: calls attention to alignment?





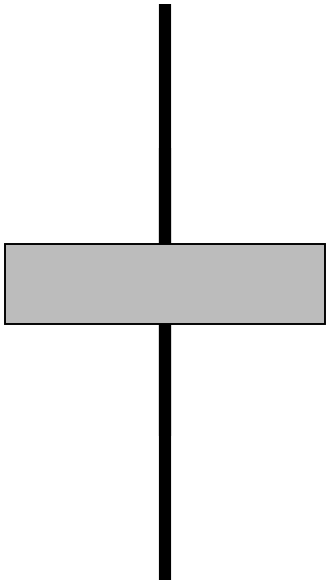


Same pattern, as strong as for the rod.

Common motion: a suspicious coincidence, unless the ends are connected.

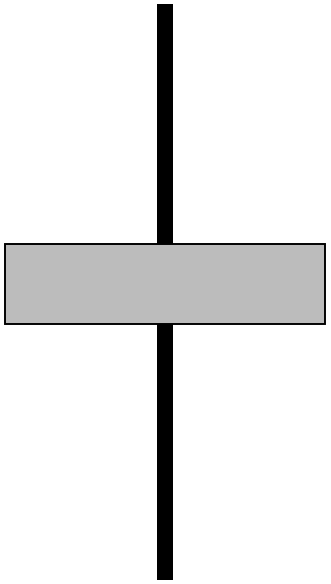
(Kellman & Spelke)

What kind of motion?



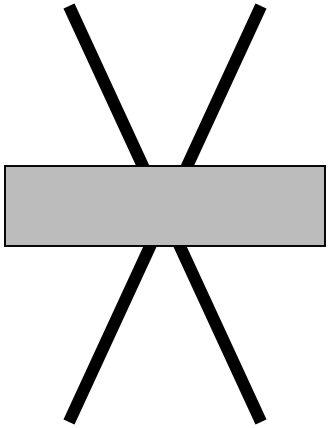
vertical

✓



depth

✓

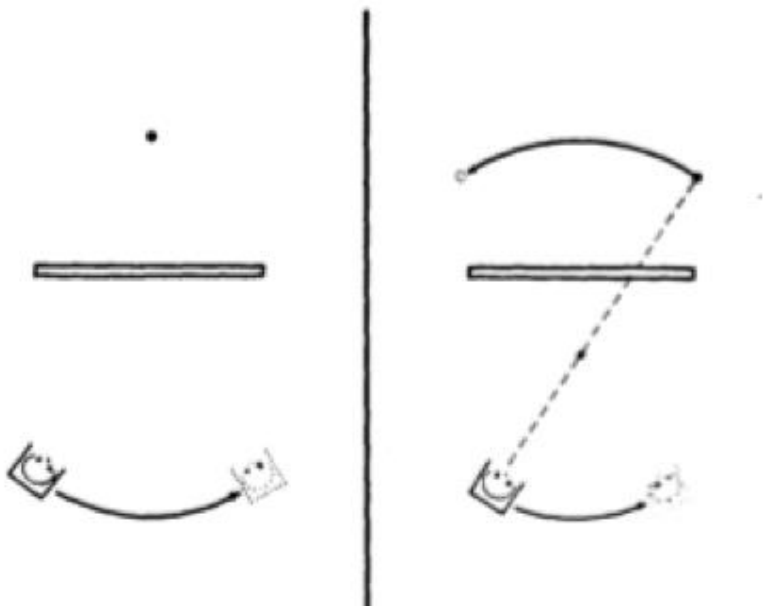


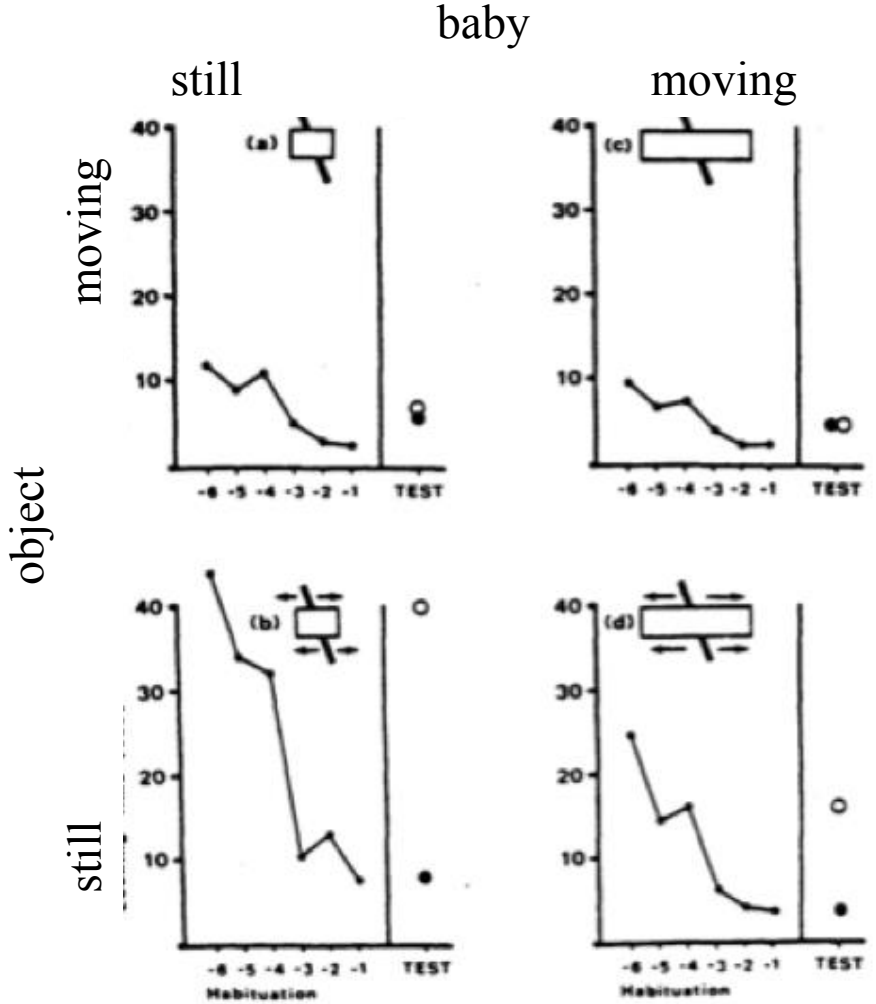
rotation

✗

(Kellman papers)

What kind of motion?

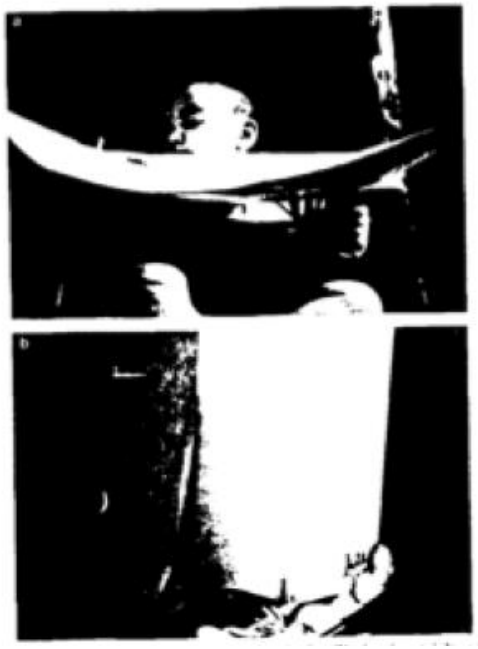




Movement of the object through the scene, with or without displacement of its image in the infant's visual field

(Kellman et al., 80s)

Are these effects found only with vision?



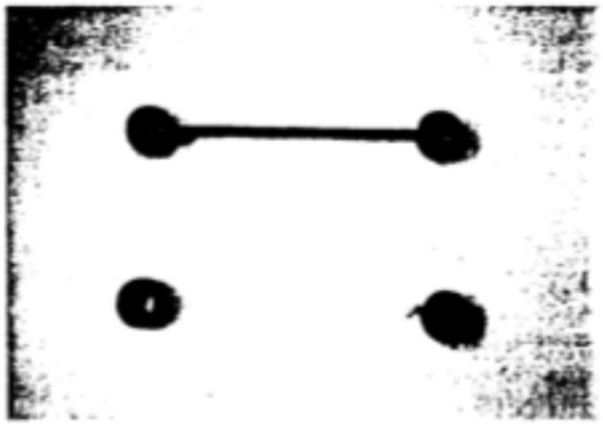


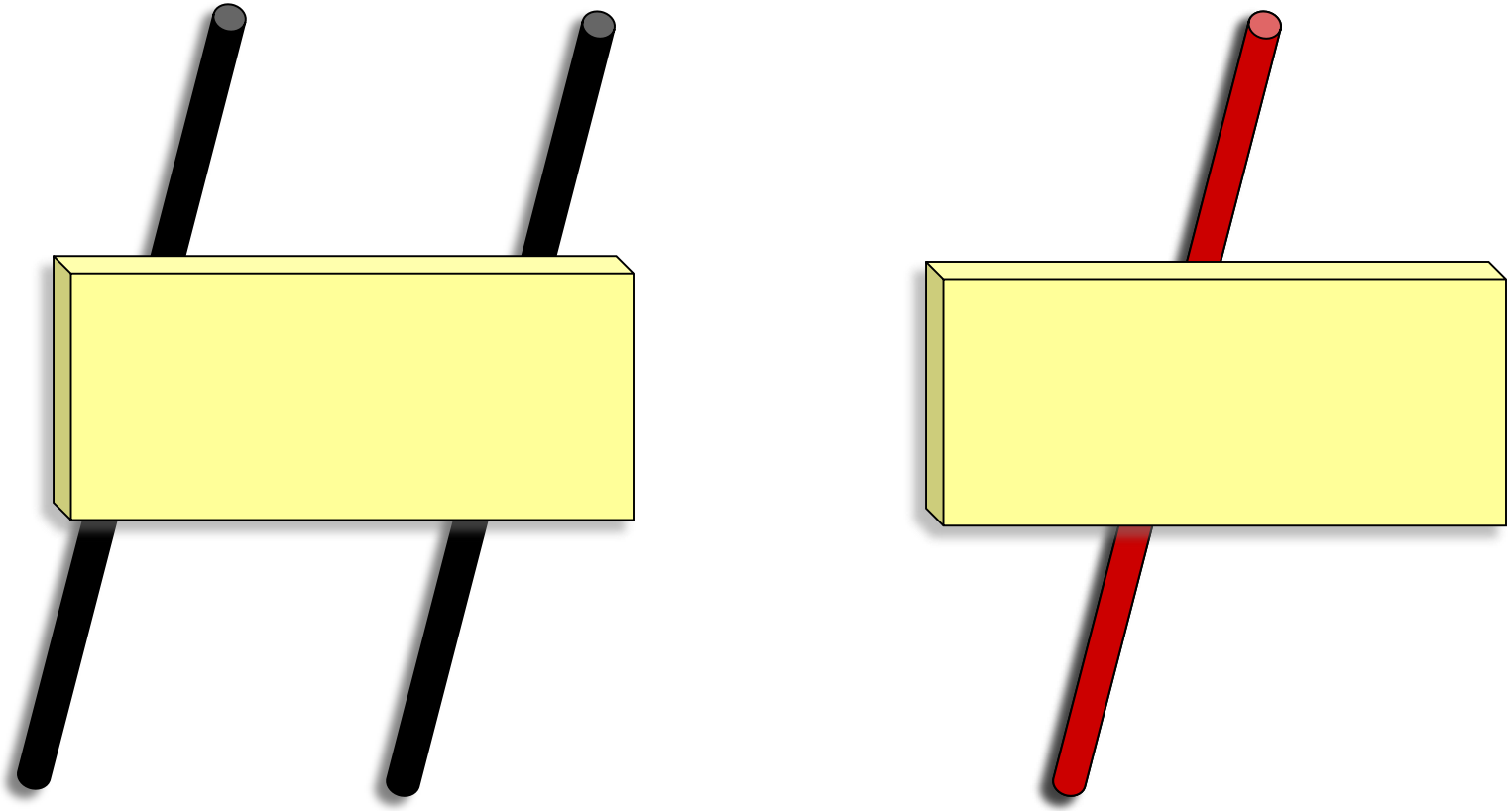
FIG. 2. The stimulus objects.

common motion → connected object
independent motion → separate objects
no effect of shape, texture or substance properties of the rings.

Same effects in the visual and haptic modes: one model at work in both modalities?

(Streri & Spelke papers, 80s & 90s)

Only motion?



Both displays elicited high attention.
Only the motion display was seen as connected behind the occluder.

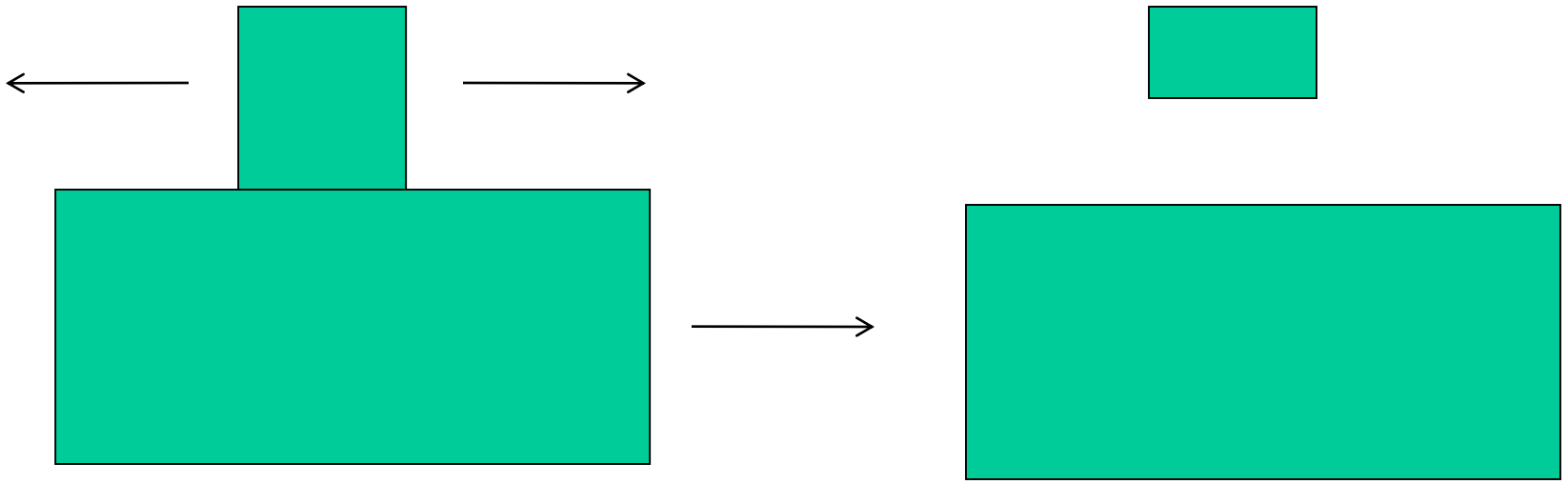
Motion, not color change (other changes?)

(Jusczyk, et al., 1990s)

Only motion?

Objects adjacent vertically

Objects separated vertically

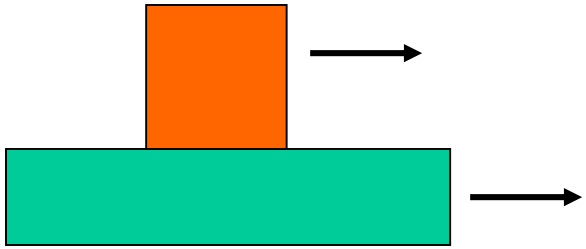


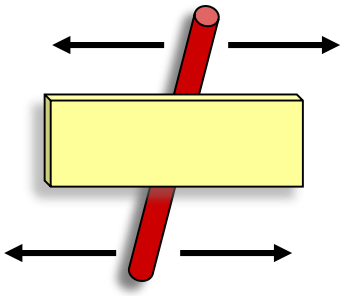
common motion --> connected
opposite motion --> not connected
no motion: inconsistent findings, often connected or ambiguous

not connected, regardless of motion

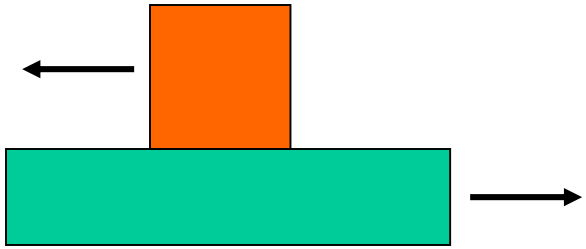
(Hofsten/Spelke/Kestenbaum, Needham)

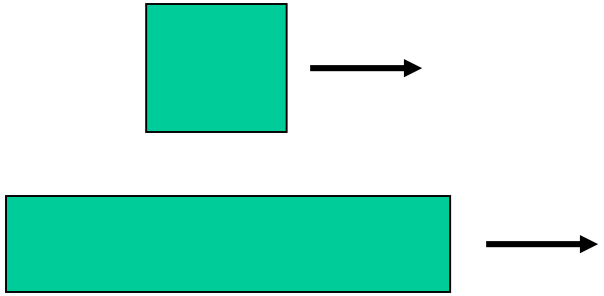
First principle of object representation: Cohesion





Surfaces that move together with no visible gap between them probably lie on the same object.

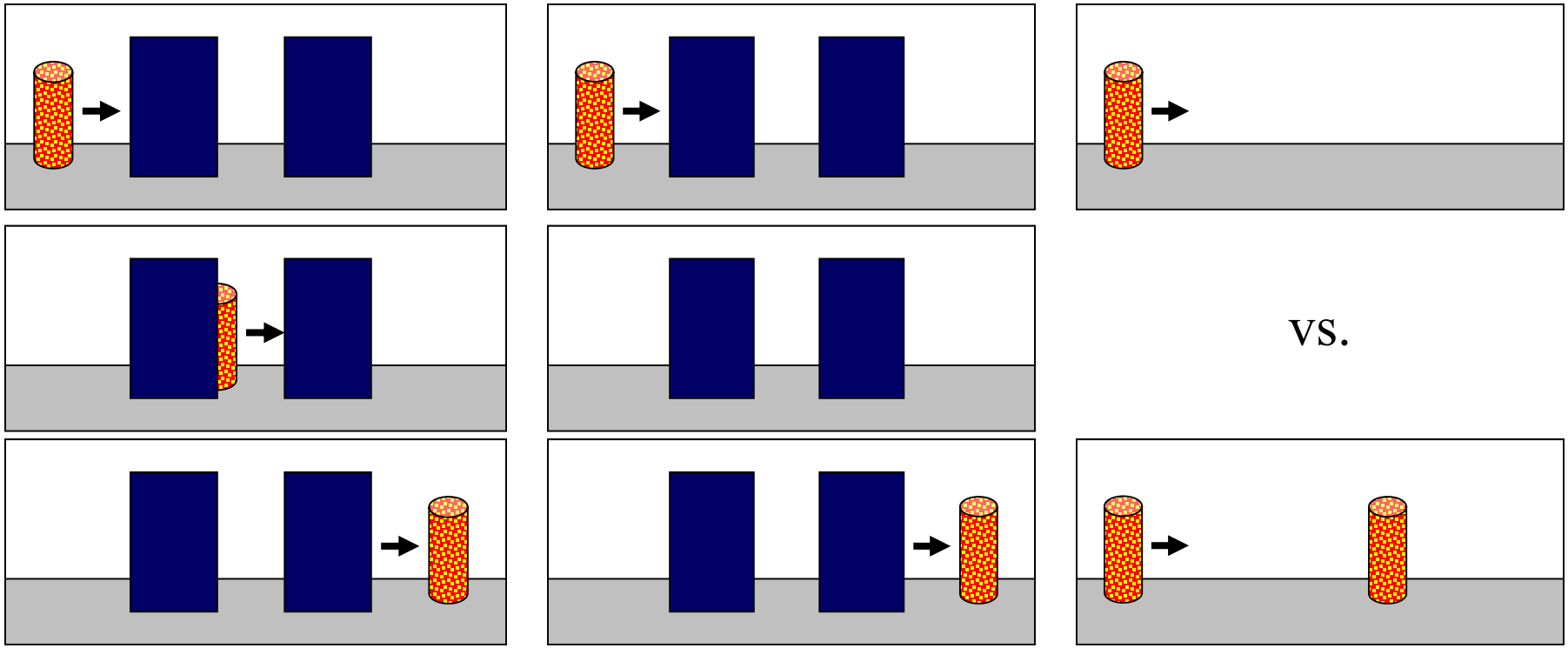




Surfaces that move separately, or are separated by a visible gap, probably lie on distinct objects.

(Spelke, 1990)

Can infants use motion to perceive object persistence or distinctness when objects move fully out of view?



Group 1:
continuous motion

Group 2:
discontinuous motion

Test

A second principle of object representation: continuity.

If motion is continuous, likely 1 object. If discontinuous, likely 2 objects.

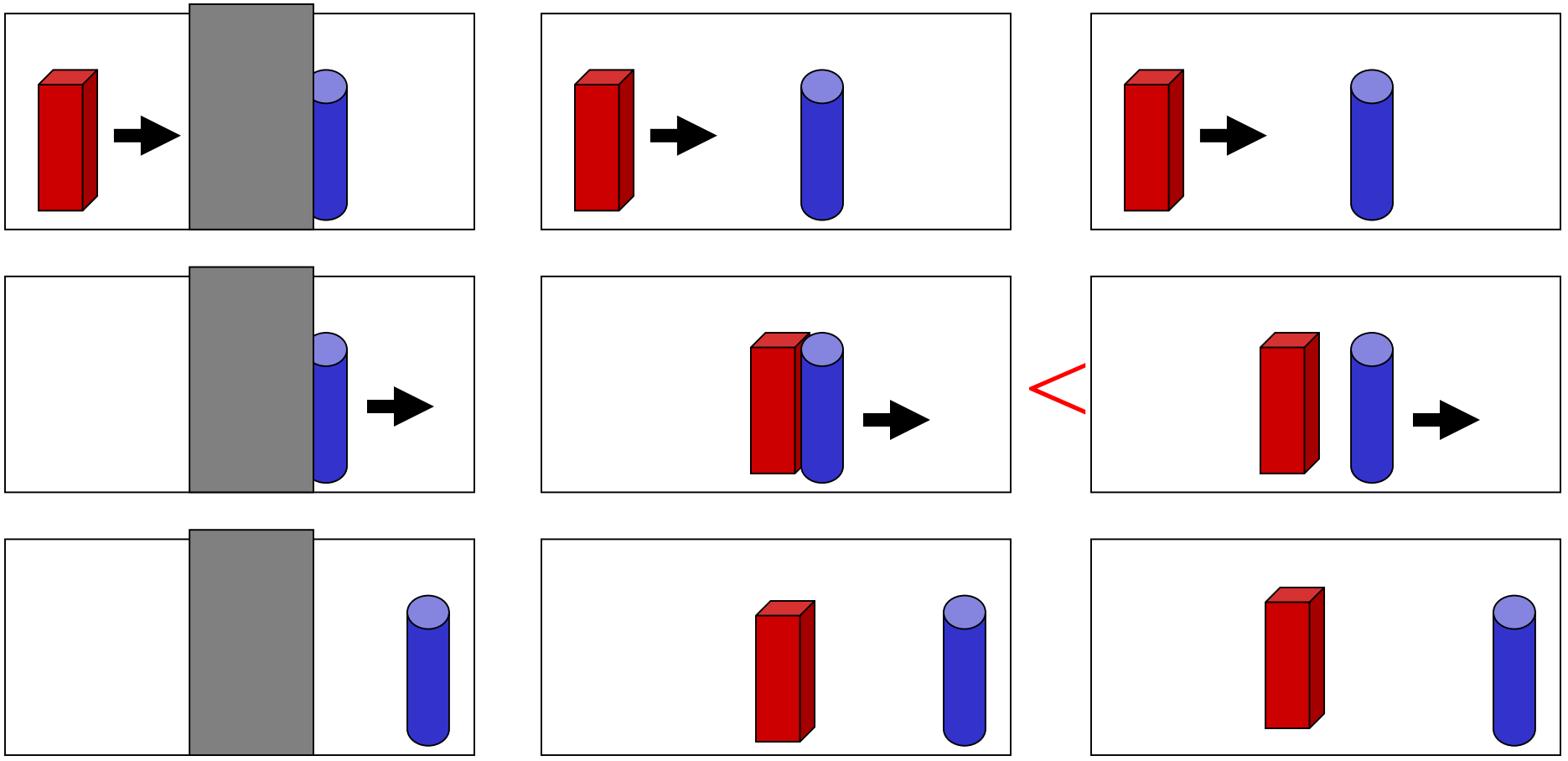
(Spelke et al, 1995)

Stronger tests with older infants (10-12 months)

Number of cookies, not number of acts or of visible cookie events.

(Feigenson & Carey, 2003)

Collisions (3+ months)

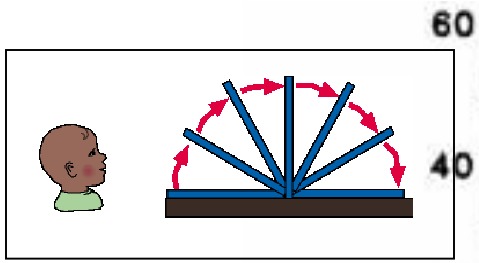


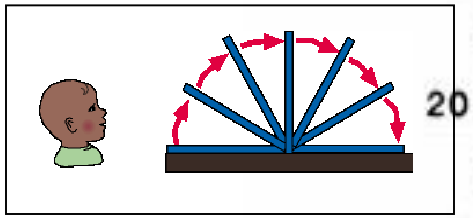
Habituation | Contact Test | No Contact Test

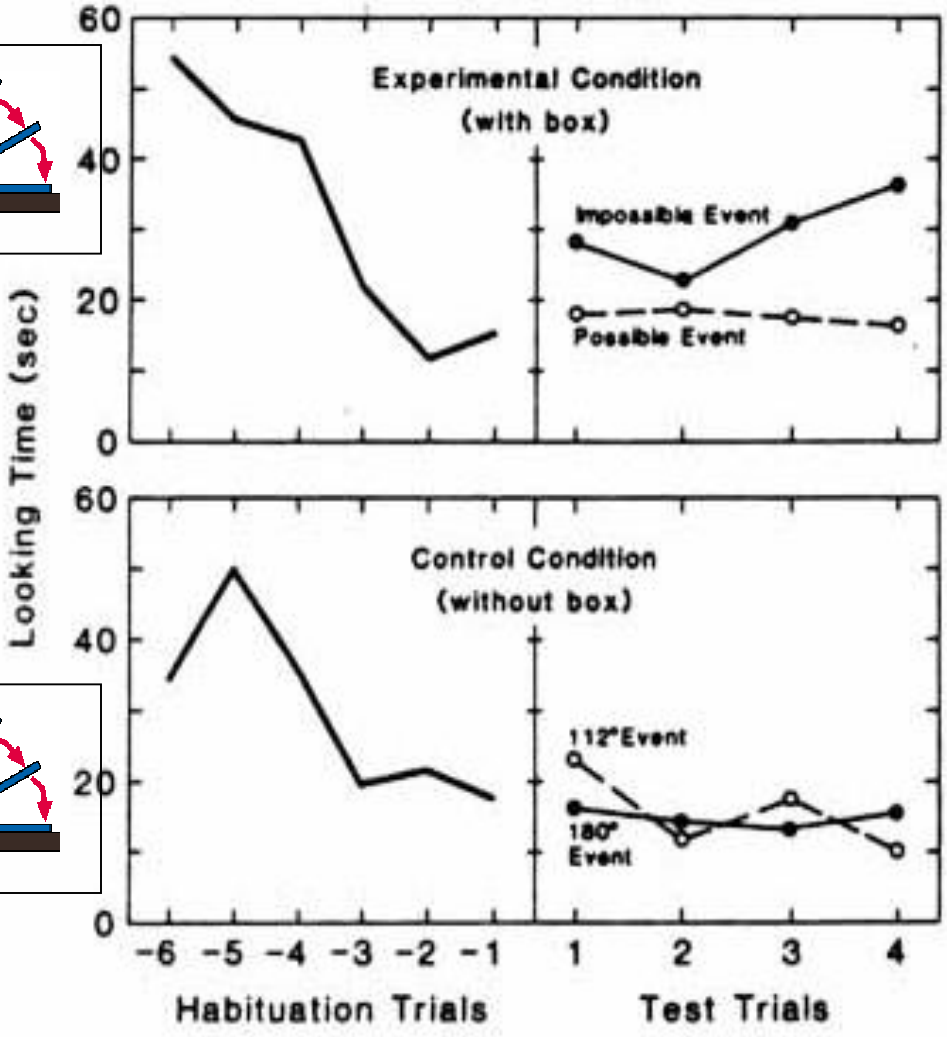
Infants infer that the block hit the cylinder behind the occluder....
when the 2nd object moves but not when it beeps & changes color.

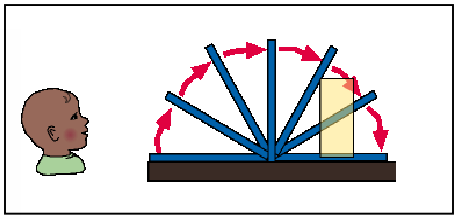
(Ball, 1973; Kotovsky & Baillargeon, 1994; Muentener & Carey, 2010)

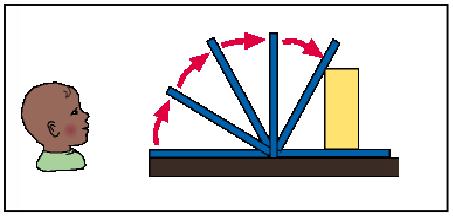
Solidity (3-4 months)

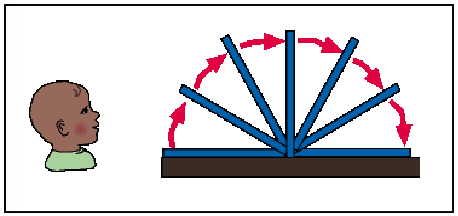


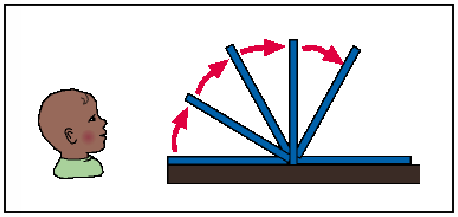










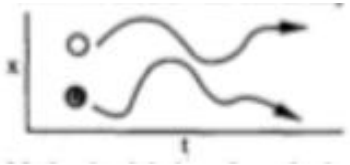


Infants represent hidden objects as permanent and solid

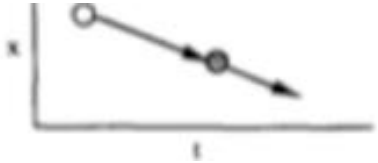
(Baillargeon, et al., 1985; Baillargeon, 1987)

Object representations at 4 months

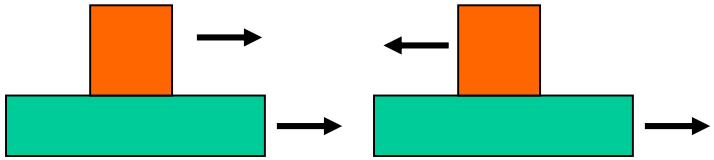
Cohesion, Continuity, Contact



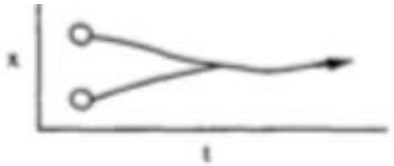
no splitting



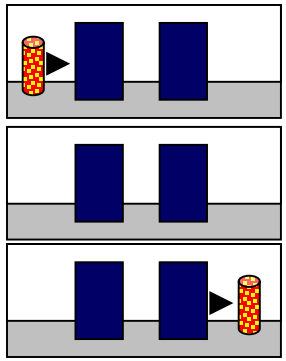
no merging

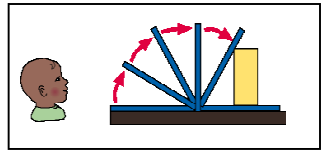


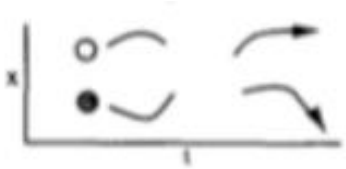
no gaps



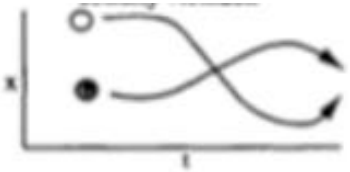
no intersections



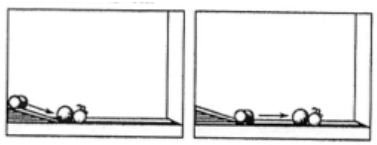


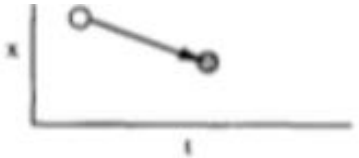


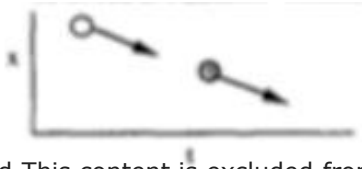
action on contact

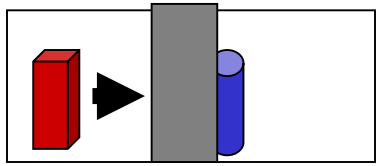


no action at a distance





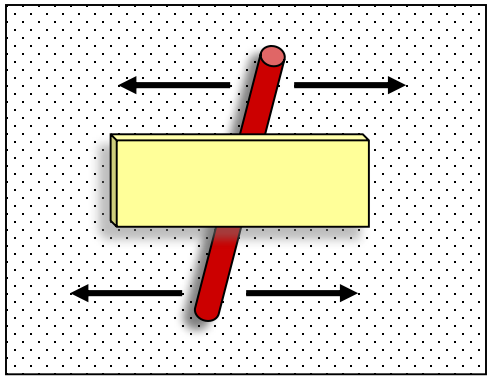


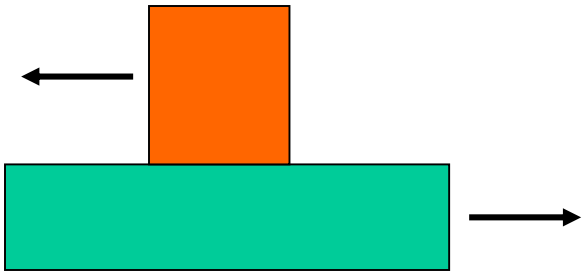


Source: Spelke, Elizabeth S., Ann Phillips, and Amanda L. Woodward. "Infants' knowledge of object motion and human action." (1995).

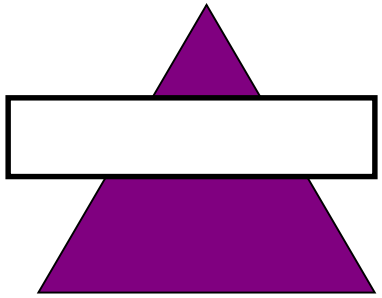
Infants' perception of objects is limited

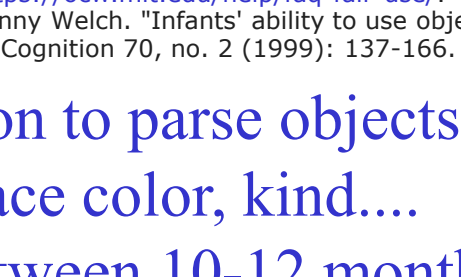
success

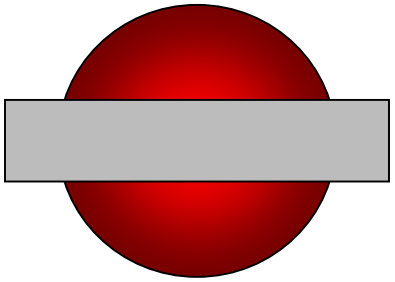




failure



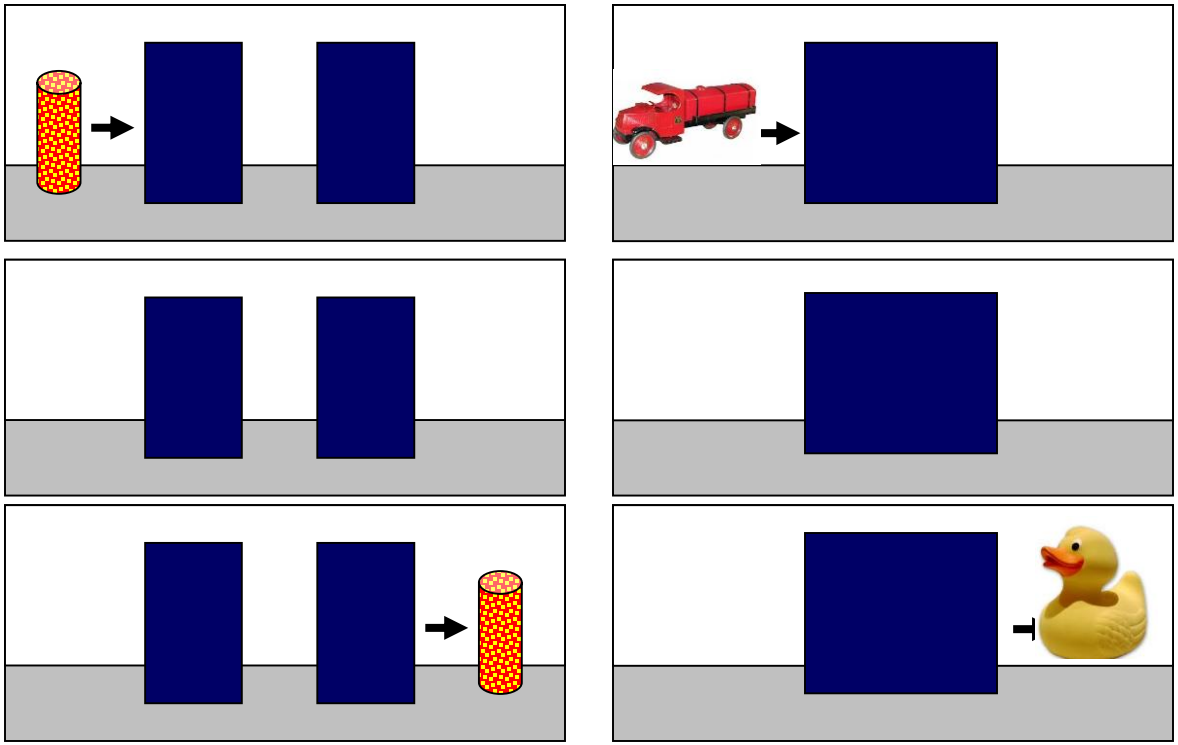




Infants use limited information to parse objects:
motion but not shape, surface color, kind....
(kind info begins to be used between 10-12 months)

(Xu et al., 1999)

Infants' tracking of hidden objects is limited

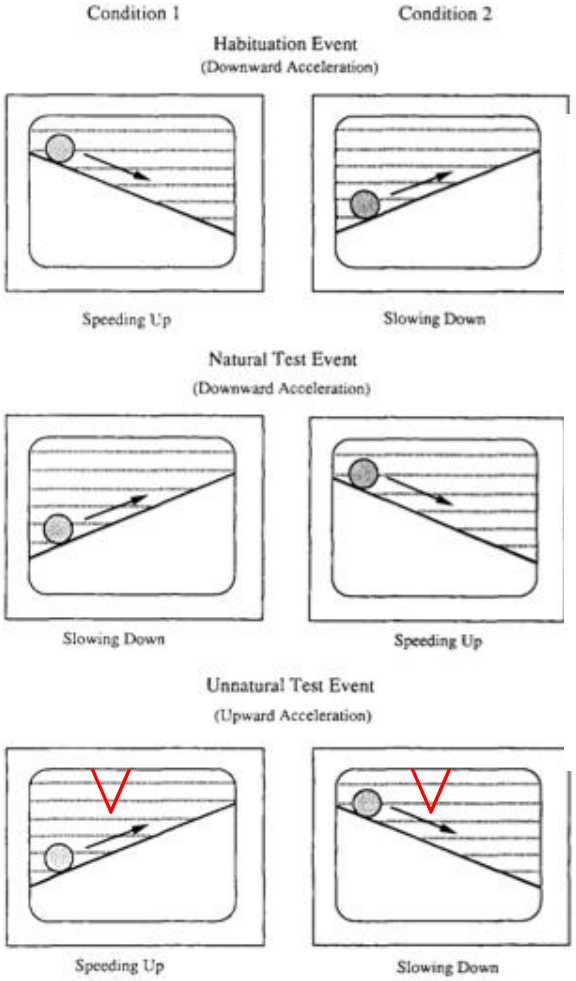


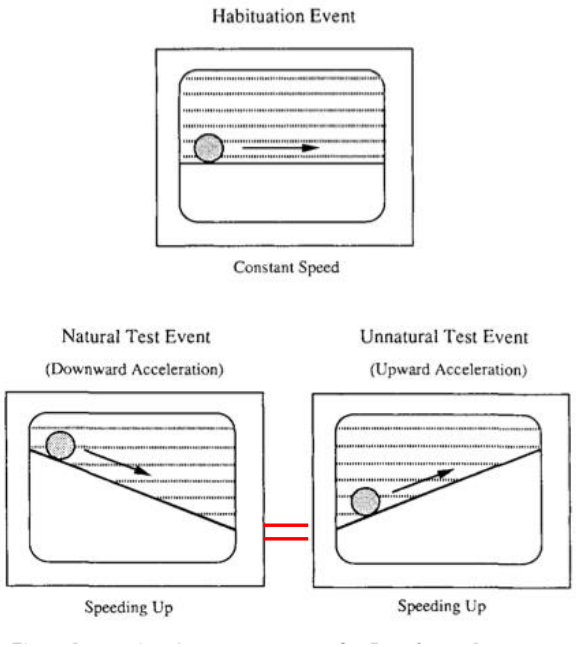
(2 objects) (ambiguous)

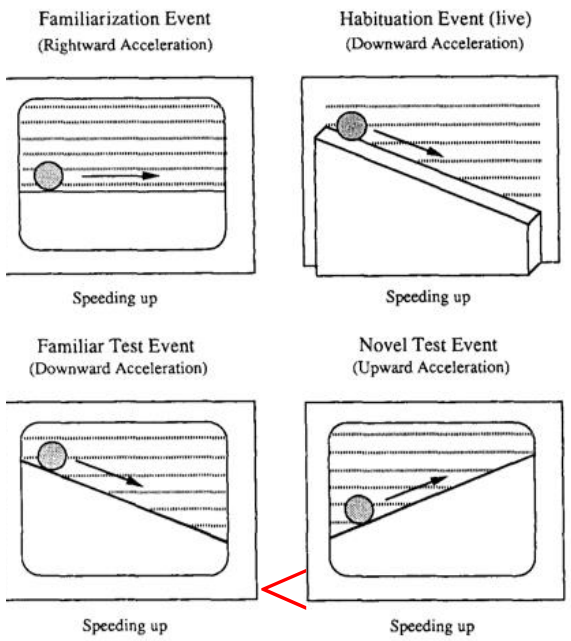
Source: Xu, Fei, and Susan Carey. "Infants' metaphysics: The case of numerical identity." Cognitive psychology 30, no. 2 (1996): 111-153. https://doi.org/10.1006/cogp.1996.0005.

Infants use limited information to track objects over occlusion.
Success with toy ducks & trucks between 10-12 months.
Interesting effects of language.... (Xu & Carey, 1996)

Developments within infancy: Gravity at 5 months







no expectation

control: just fine

expect wrong motion

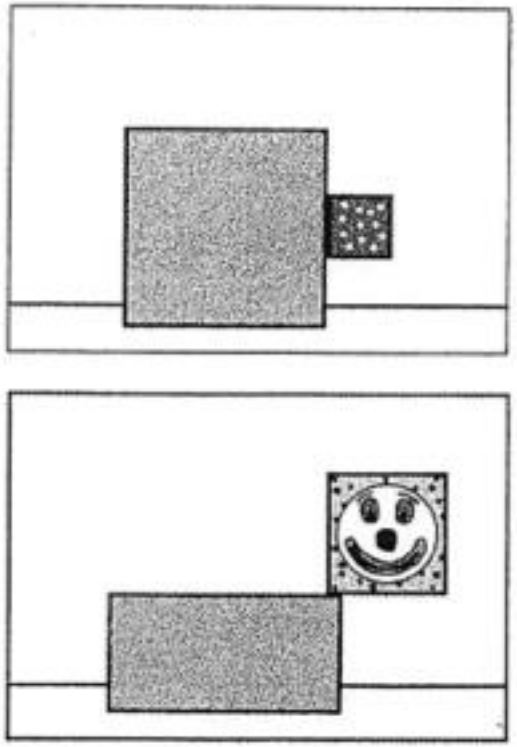
7 month olds succeed at these tasks.

Source: Kim, In Kyeong, and Elizabeth S. Spelke. "Infants' sensitivity to effects of gravity on visible object motion." Journal of Experimental Psychology: Human Perception and Performance 18, no. 2 (1992): 385. https://doi.org/10.1037/0096-1523.18.2.385.

Sensitivity to some effects of gravity develops from 5-7 months.

(Kim & Spelke, 1992)

Gravity



first success around 5 months

first success around 6-7 months

Source: Baillargeon, Renée. "Infants' understanding of the physical world." Journal of the Neurological Sciences 143, no. 1-2 (1996): 199.

What are infants coming to understand, and how should we characterize their understanding: local rules? general forces? something else?

What do young infants fail to understand: do they expect forces but not know their magnitude or direction?

Tomer: in progress!

Baillargeon et al., 1995

Object perception at the start of visual experience

Most of these abilities have not been tested in newborn infants
(exception: partly occluded objects)

Almost all have been tested in other animals, from monkeys to birds and fish: Other animals can do what infants do.

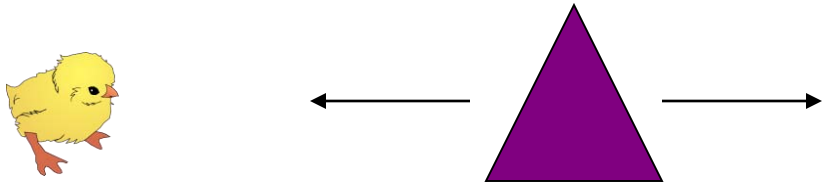
Controlled reared studies of precocial animals have probed representations of objects in visual arrays at the start of visual experience.

Ex: domestic chicks
An "imprinting" method: isolate chick at hatching and familiarize with one moving object; chick will approach that object in new environments.

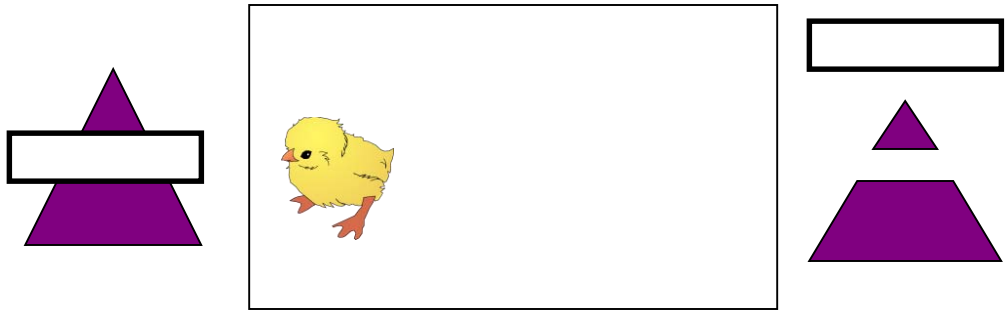
Courtesy of Giorgio Vallortigara. Used with permission.

Amodal completion in chicks

imprinting phase (day 1, home cage, no occluded objects)



test phase (day 2, new cage)

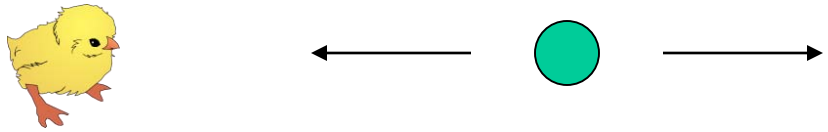


Perception of occluded objects without prior visual experience of occlusion (NB: with or without motion: better than infants).

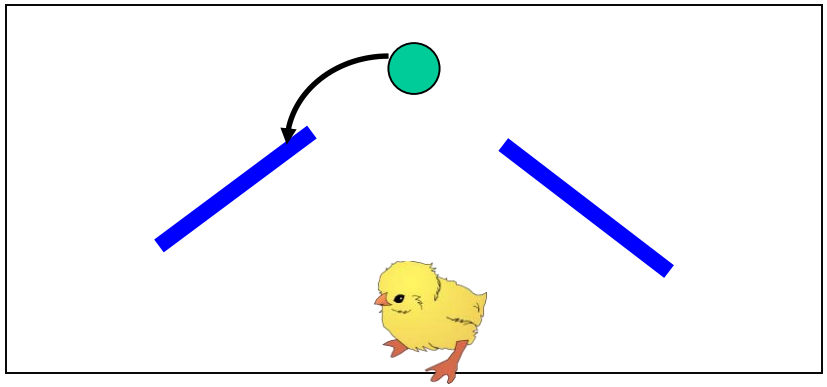
Regolin & Vallortigara, 1995

Object permanence in chicks

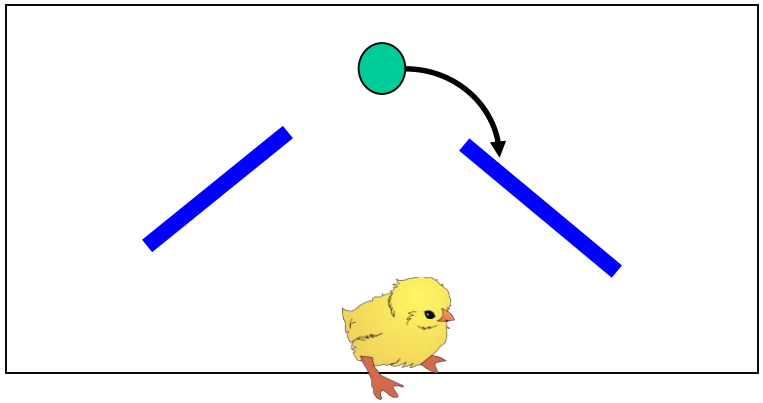
imprinting phase (day 1, home cage)



Piaget's stage 4 test:



Piaget's stage 5 test:



Chicks solve all Piaget's search tasks to stage 5 at one day of age! (human infants take 12 months to catch up....)

Regolin & Vallortigara, 1995

Solidity in chicks

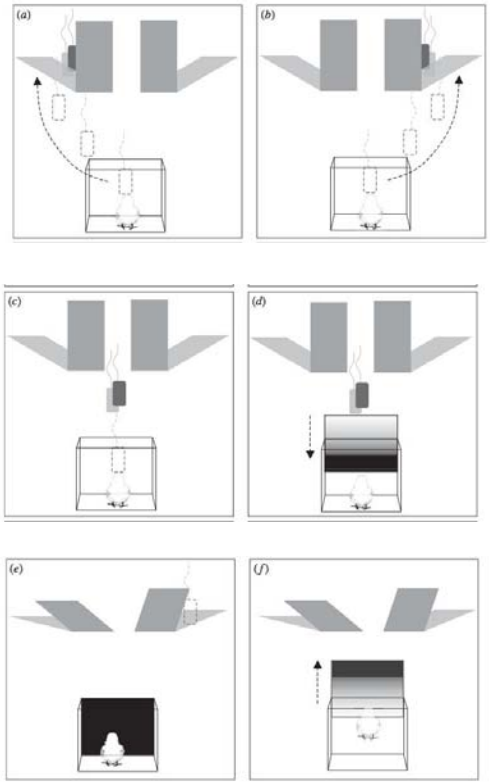
Imprinting with glass wall preventing any contact with the object (hereafter, Mom).

Familiarization: Mom moves behind each screen and reappears there.
Then the display is covered before Mom turns; she reappears at each side.

Test: Screens are rotated, Mom does not reappear, chick is released. Chicks use degree of rotation to infer where Mom is and go directly to that screen.

Knowledge of solidity is innate in chicks: Chicks apply solidity to objects with no prior experience of its effects on objects. It *could* be innate in humans.

Courtesy of Giorgio Vallortigara. Used with permission.



Source: Chiandetti, Cinzia, and Giorgio Vallortigara. "Intuitive physical reasoning about occluded objects by inexperienced chicks." Proceedings of the Royal Society of London B: Biological Sciences 278, no. 1718 (2011): 2621-2627.

Chiandetti & Vallortigara, 2011

Object knowledge in infants: Further questions

Do infants have, and build further, a model of the physical world that is compositional and causal? Do they seek to understand how the world works and explain the events they see?

Or, do they just have, and learn more, ways to predict how their perceptual experiences of objects will change over time?

At older ages (8-11 months), the evidence favors compositional, causal models.

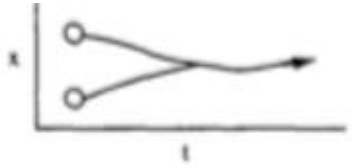
At younger ages, no clear evidence yet....

Compositionality

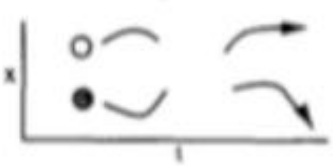
(8 months and up)

no splitting

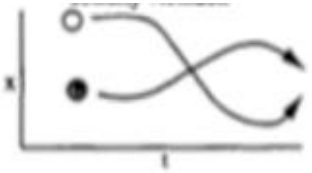
no merging



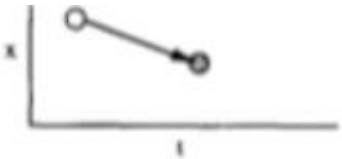
no gaps



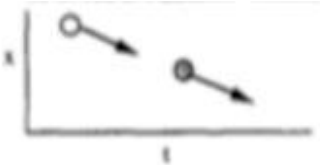
no intersections



action on contact



no action at a distance



Experiments (Carey):
show infants an object that violates cohesion:

- sand pile
- block constructions
- a cookie broken in 2

Test whether infants expect the object to obey the other constraints.

They do not.
Evidence against one constraint weakens expectations about the others.

Huntley-Fenner & Carey, 2002; Muentener & Carey, 2010; Cheries et al., 2008)

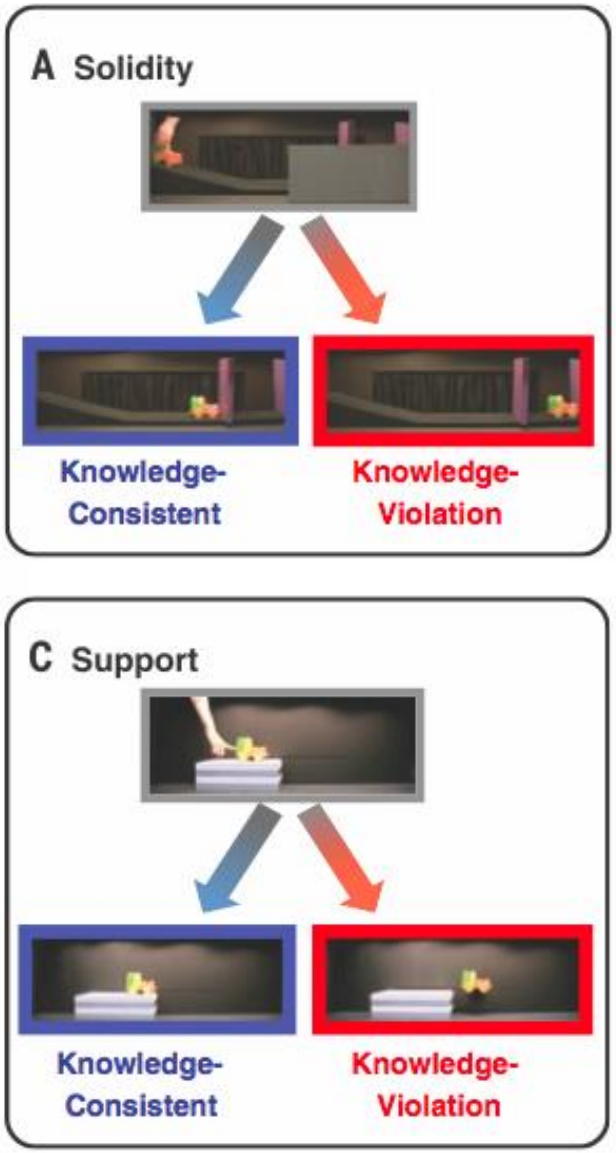
Causality

(11 months)

measure learning and exploration.

Learning: with looking time held constant, infants learn more about objects that violate solidity or gravity.
Duration of looking *is* a sign of exploration and learning, but a bad one (here, equal looking, unequal learning).

Exploration: specific to the violation.
--after solidity violation, banging
--after support violation, dropping.
Older infants actively seek to understand the causes of the events they failed to predict (Laura, Thurs.)



Stahl & Feigenson, *Science,* 2015

Core knowledge of objects: Summary and questions

From early in development, infants have a system for representing objects and inferring their future or unseen motions and interactions.

The system is compositional, at least in older infants: they don't learn a list of local properties of how objects behave.

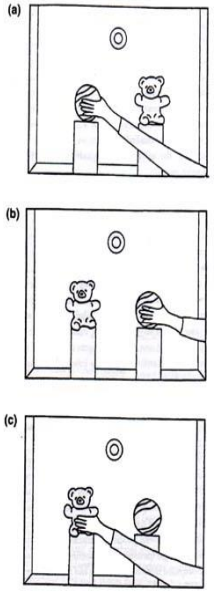
At the end of infancy, it also captures causal understanding: infants seek to explain the events they see.

Are infants Newtonians from the beginning (maybe partial/deficient ones) or do they start as Keplerians?

we have the tools to find out: Tomer's research program.

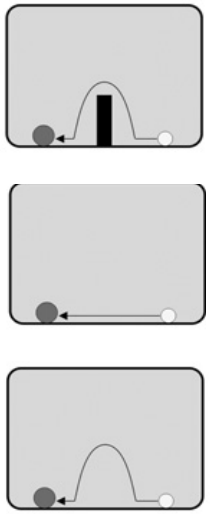
Infants' concepts of agents (6-12 months)

agents act (self-propelled, goal-directed motion)
agents act on objects that are or were visually accessible
agents act efficiently
agents cause things to happen
including things that violate constraints on objects.



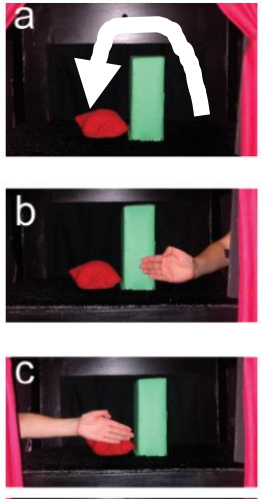
Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission. Source: Woodward, Amanda L. "Infants selectively encode the goal object of an actor's reach." Cognition 69, no. 1 (1998): 1-34.

Source: Luo, Yuyan, and Susan C. Johnson. "Recognizing the role of perception in action at 6 months." Developmental science 12, no. 1 (2009): 142-149.

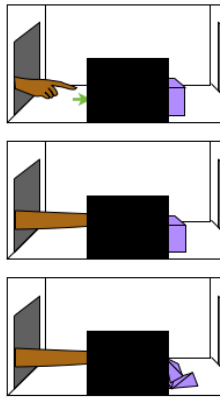


Source: Gergely, György, Zoltán Nádasdy, Gergely Csibra, and Szilvia Bíró. "Taking the intentional stance at 12 months of age." Cognition 56, no. 2 (1995): 165-193.

Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.
Source: Pauen, Sabina, and Birgit Träuble. "How 7-month-olds interpret ambiguous motion events: Category-based reasoning in infancy." Cognitive psychology 59, no. 3 (2009): 275-295.



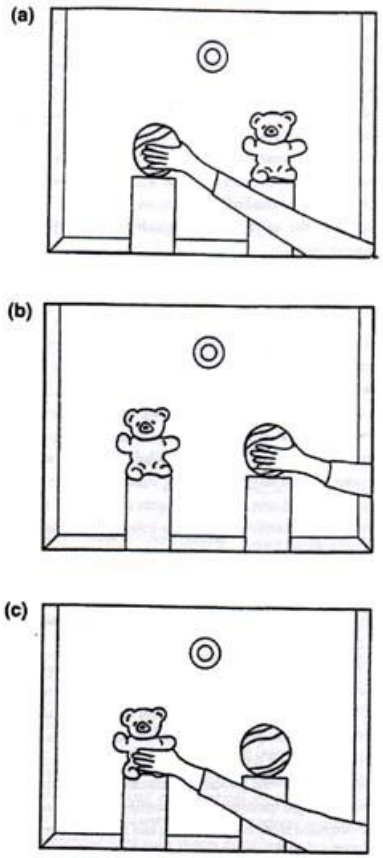
Source: Saxe, Rebecca, J. B. Tenenbaum, and Susan Carey. "Secret agents inferences about hidden causes by 10-and 12-month-old infants." Psychological Science 16, no. 12 (2005): 995-1001.



Woodward, 1998, Luo & Johnson, 2009, Gergely et al., 1995, Pauen & Trauble, 2009, Saxe et al., 2006

Core knowledge of agents?

These abilities are found in infants aged 6 months or more. Younger infants fail some of these tests.



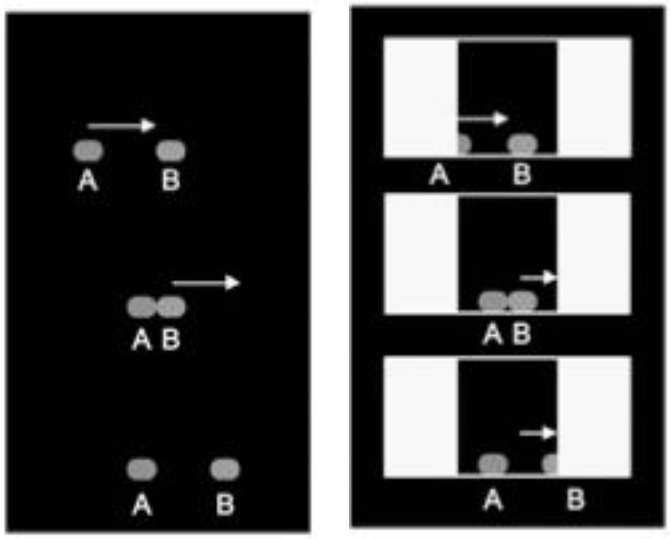
Success at 5 months, failure at 3 months.

Do infants have any unlearned abilities to represent agents?

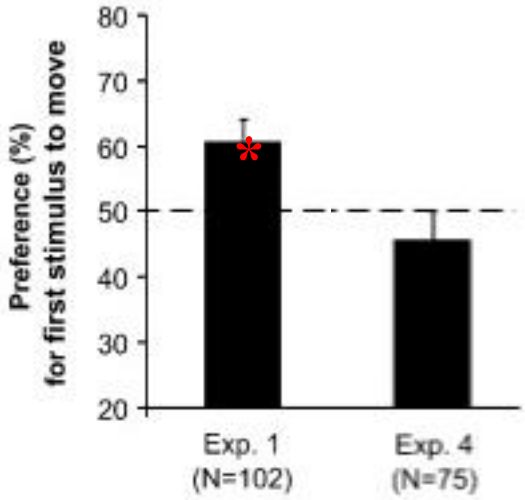
Woodward, 1998, 2000, 2003

Suggestions from controlled-reared animals

Newly hatched chicks: imprinting method.



Exp. 1 Exp. 4



A is self-propelled

A causes B's motion

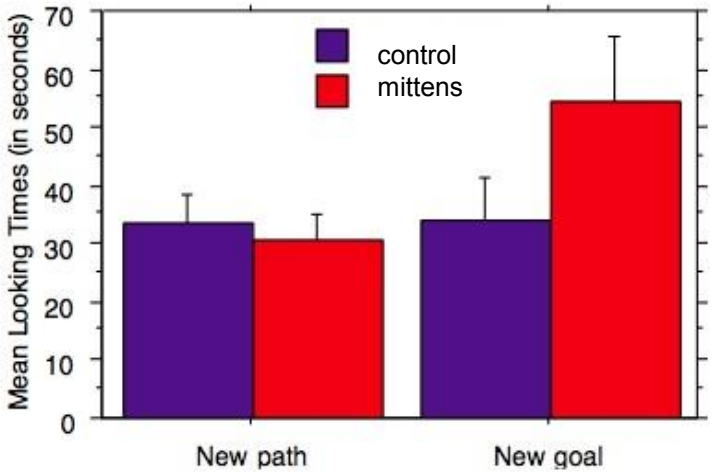
Some parts of the older infant's agent concept are innate in chicks: an existence proof that they *could* be innate in humans.

Mascalzoni, Regolin & Vallortigara, *PNAS,* 2010

But some parts are learned....

The "sticky mittens" experiments (3-month-old infants)

exp: mittens → test
control: test → mittens



After brief experience reaching successfully for objects, infants represented another person's reaching as goal-directed.

Evidence that experience affects infants' action representations.

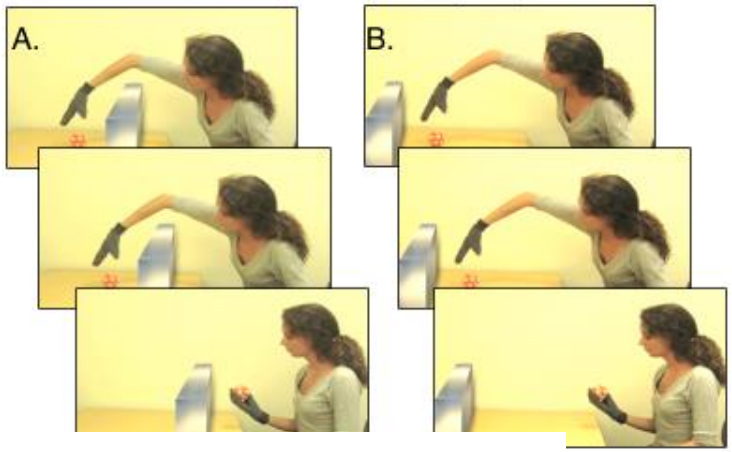
But do any action concepts predate this experience?

Sommerville, et al., *Cognition,* 2005

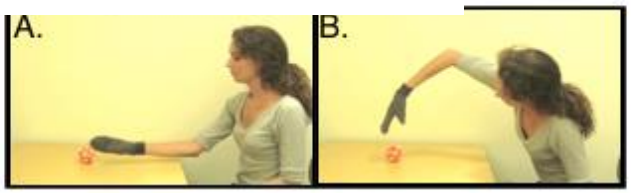
more sticky mittens experiments

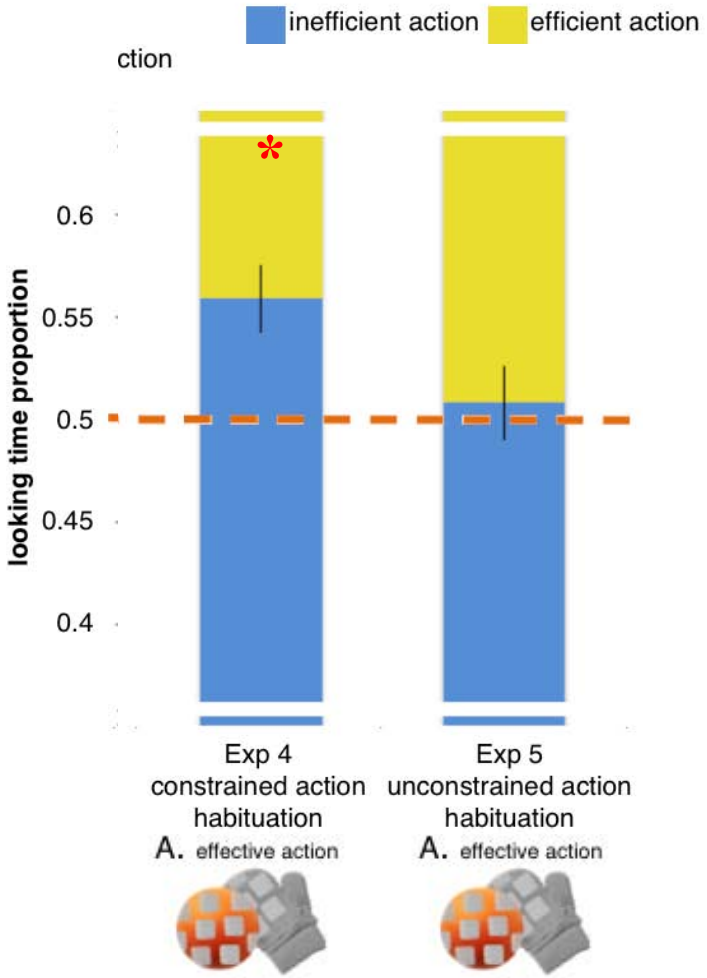
Training with no barriers

Repeated presentation:



Test:



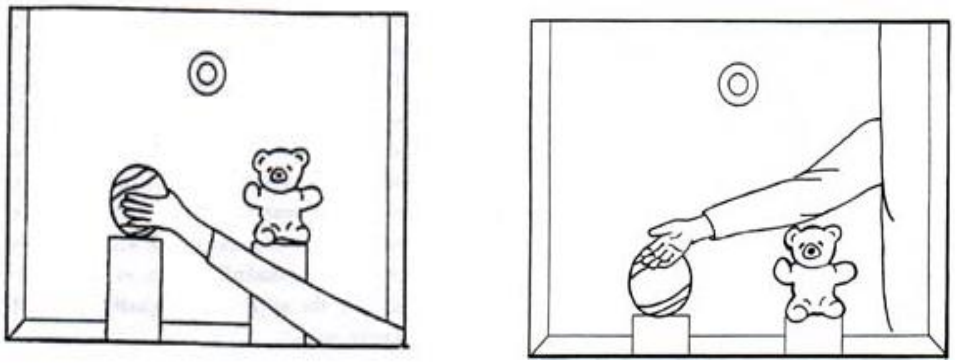


Infants expect straight motion only when the agent's previous actions were constrained by a barrier (and therefore efficient).

Skerry, et al., *PNAS,* 2013

Action experience and agent concepts

Infants have to learn what movements are goal-directed actions. Infants' own action experience is a useful source of information.



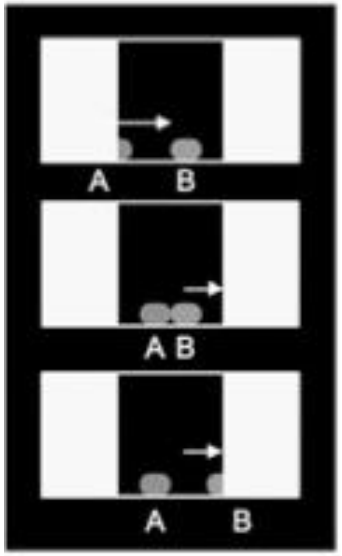
Source: Woodward, Amanda L. "Infants selectively encode the goal object of an actor's reach." Cognition 69, no. 1 (1998): 1-34.

But infants don't learn, from their own action experience, that agents' actions are efficient and constrained by barriers.

Untested: do infants learn this from prior visual experience, or would newborn infants and controlled-reared chicks also represent agents as efficient actors?

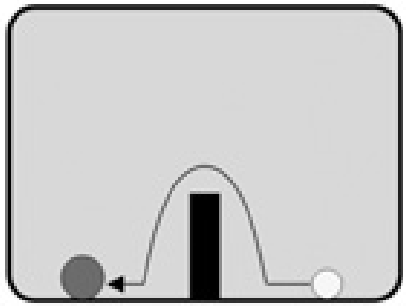
Early knowledge of agents

agents are self-propelled and cause changes in objects on contact.
agents' actions are goal-directed and efficient.
agents act on things to which they have perceptual access.



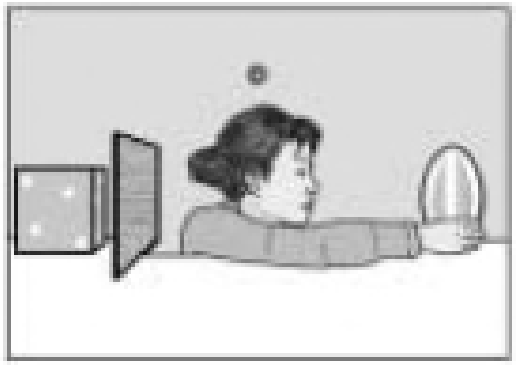
Courtesy of National Academy of Sciences, U. S. A. Used with permission.
Source: Mascalzoni, Elena, Lucia Regolin, and Giorgio Vallortigara. "Innate sensitivity for self-propelled causal agency in newly hatched chicks." Proceedings of the National Academy of Sciences 107, no. 9 (2010): 4483-4485.

A made B move.



Source: Gergely, György, Zoltán Nádasdy, Gergely Csibra, and Szilvia Bíró. "Taking the intentional stance at 12 months of age." Cognition 56, no. 2 (1995): 165-193.

White's goal is Gray; White reached Gray by taking the shortest available path.



Source: Luo, Yuyan, and Susan C. Johnson. "Recognizing the role of perception in action at 6 months." Developmental science 12, no. 1 (2009): 142-149.

She may take the ball but not the cube as her goal

Infants' knowledge of agents is limited

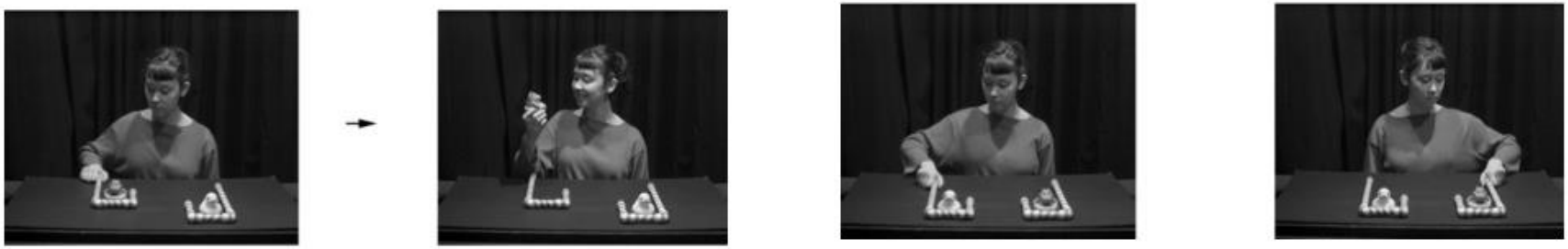
Agents' actions depend on visual access but not direction of gaze; agents don't share attention: a limited understanding of seeing.

Source: Luo, Yuyan, and Susan C. Johnson. "Recognizing the role of perception in action at 6 months." Developmental science 12, no. 1 (2009): 142-149.

Source: Poulin-Dubois, Diane, Alexandra Polonia, and Jessica Yott. "Is False Belief Skin-Deep? The Agent's Eye Status Influences Infants' Reasoning in Belief-Inducing Situations." Journal of cognition and development 14, no. 1 (2013): 87-99.

Source: Phillips, Ann T., Henry M. Wellman, and Elizabeth S. Spelke. "Infants' ability to connect gaze and emotional expression to intentional action." Cognition 85, no. 1 (2002): 53-78.

Infants attribute first-order but not second-order goals to agents.



Source: Sommerville, Jessica A., Elina A. Hildebrand, and Catharyn C. Crane. "Experience matters: The impact of doing versus watching on infants' subsequent perception of tool-use events." Developmental psychology 44, no. 5 (2008): 1249.

So far, no aspect of young infants' agent representations appears to be unique to humans (but efficiency hasn't been tested in animals).

Luo & Johnson,2006, Phillips, et al., 2002, Poulin-Dubois et al., 2013
Sommerville et al., 2008 Sommerville & Woodward, 2005
Flombaum & Santos, 2005, Santos et al., 2006, Call et al., 2000

Agents and objects: open questions

Agents can do things objects can't do (they cause their own changes in motion, have goals, perceive objects in some sense), and infants are sensitive to these differences.

Agents also *are* objects (they move continuously, act on contact, don't break into pieces, can't pass through walls....), and infants are sensitive to these properties.

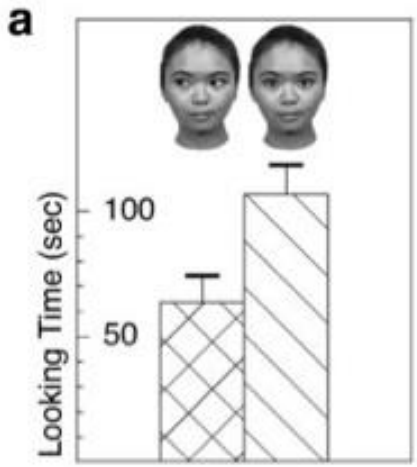
Do objects and agents form a hierarchy for infants?

How much knowledge of objects enters into infants' reasoning about agents' goals, preferences, and actions?

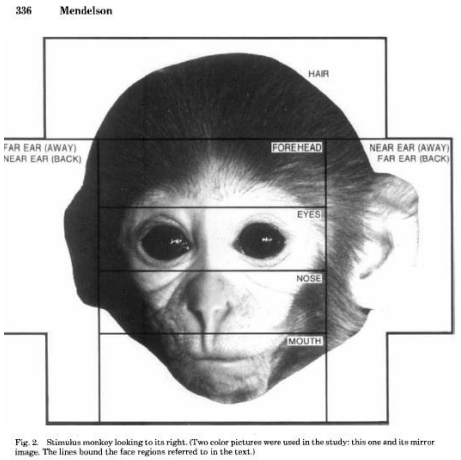
These are unanswered but answerable questions.

Social partners

(newborn infants)



Courtesy of National Academy of Sciences, U. S. A. Used with permission.
Source: Farroni, Teresa, Gergely Csibra, Francesca Simion, and Mark H. Johnson. "Eye contact detection in humans from birth. " Proceedings of the National Academy of Sciences 99, no. 14 (2002): 9602-9605.
Copyright © 2002 National Academy of Sciences, U.S.A.



Courtesy of American Psychological Association. Used with permission.
Source: Mendelson, Morton J., Marshall M. Haith, and Patricia S. Goldman-Rakic. "Face scanning and responsiveness to social cues in infant rhesus monkeys." Developmental Psychology 18, no. 2 (1982): 222.

Newborn infants (human & monkey) engage in mutual gaze

Farroni et al., *PNAS,* 2002 Mendelson, et al., *Dev Psych,* 1982 Suomi, Parr, Matsuzawa...

Social partners

Source: Meltzoff, Andrew N., and M. Keith Moore. "Imitation of facial and manual gestures by human neonates." Science 198, no. 4312 (1977): 75-78.

Ferrari, Pier F., Elisabetta Visalberghi, Annika Paukner, Leonardo Fogassi, Angela Ruggiero, and Stephen J. Suomi. "Neonatal imitation in rhesus macaques." PLoS Biol 4, no. 9 (2006): e302. https://doi.org/10.1371/journal.pbio.0040302. License CC BY.

Newborn infants imitate people who look at them and then gesture (and so do infant chimpanzees and monkeys)

Meltzoff & Moore, *Science,* 1977

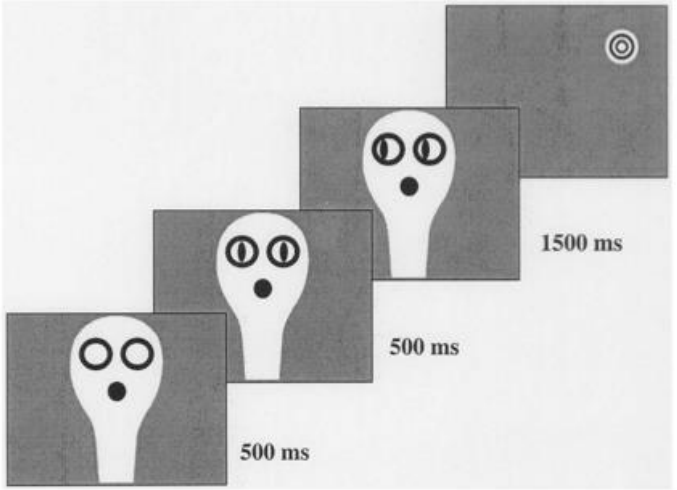
Myowa-Yamakoshi et al., *Dev. Sci.* 2004; Ferrari et al., *PLoS Bio.* 2006

Social partners

(2-month-old infants)

(newborn infants)

Figure removed due to copyright restrictions. Please see the video.
Source: Hood, Bruce M., J. Douglas Willen, and Jon Driver. "Adult's eyes trigger shifts of visual attention in human infants." Psychological Science 9, no. 2 (1998): 131-134.



Source: Farroni, Teresa, Stefano Massaccesi, Donatella Pividori, and Mark H. Johnson. "Gaze following in newborns." Infancy 5, no. 1 (2004): 39-60.

Newborn infants attend where a person shifts her gaze

NB: no gaze shift if the face stays present: *not* sharing attention to objects

mutual attention? empathy?

Hood, et al., *Psych Sci,* 1998

Farroni et al., *Infancy,* 2004

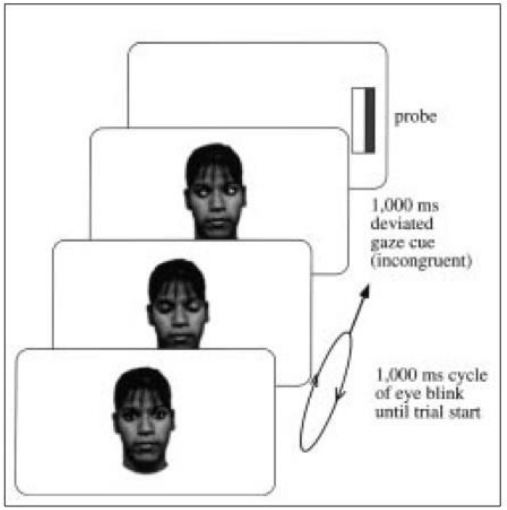
Hypothesis: core social knowledge

social partners signal their engagement by direct gaze
engaged social partners align their actions
engaged social partners share phenomenal states (attention, emotion)

you are engaged with me.

Source: Meltzoff, Andrew N., and M. Keith Moore. "Imitation of facial and manual gestures by human neonates." Science 198, no. 4312 (1977): 75-78.

I am acting with you.



I feel your feelings.

Resource: Brains, Minds and Machines Summer Course

Tomaso Poggio and Gabriel Kreiman