The early emergence of theory of mind in human infants

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Taking into account others' different perspective

Conflicting

X points to the salt to get sugar.
No problem in giving her the sugar
as this is what she meant.

Just different

M: 'Nice dog'
Baby: 'Vaf vaf'
M: 'Don't pull the dog's ear'
Baby: 'No, vaf vaf'

Everyday social interactions, from crossing the street or playing soccer to criminal justice, require efficient abilities to compute others' mental states.

Special attention others' mental states may explain:

- the unique collaborative structure of human societies

- allow efficient social learning

-see danger
-see Ann does not see
-prepare to warn

-Ann looks at danger
-withdraw warning

-Ann does not move
-"she did not see"
  WARN!

image from Fall Line Skiing

IN 2 SECONDS

-encoded event and its consequences

-recomputed what Ann can see **3x**

- prepared to modify your behavior accordingly **3x**
-Ann did not do much

image from Fall Line Skiing

Theory of mind (ToM)

Standard view

> **effortful** (Apperly et al 2009)
> **late developing** (Wellman et al, 2001)
> **relies on language**
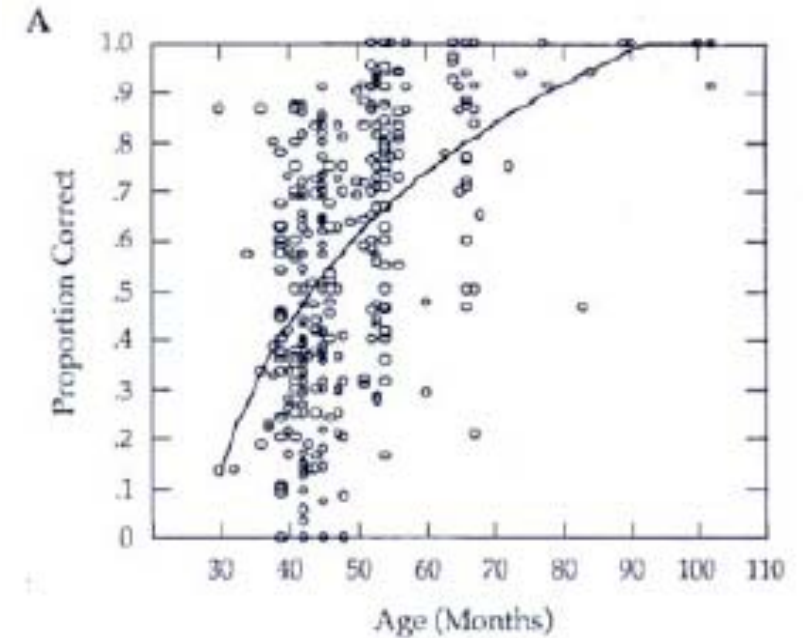> **explanatory purposes**

Explicit ToM

Alternative view

> **effortless & spontaneous**
> **early onset**
> **not relay on language**
> **predictive purposes**

Implicit ToM

The litmus test: the explicit verbal false belief task
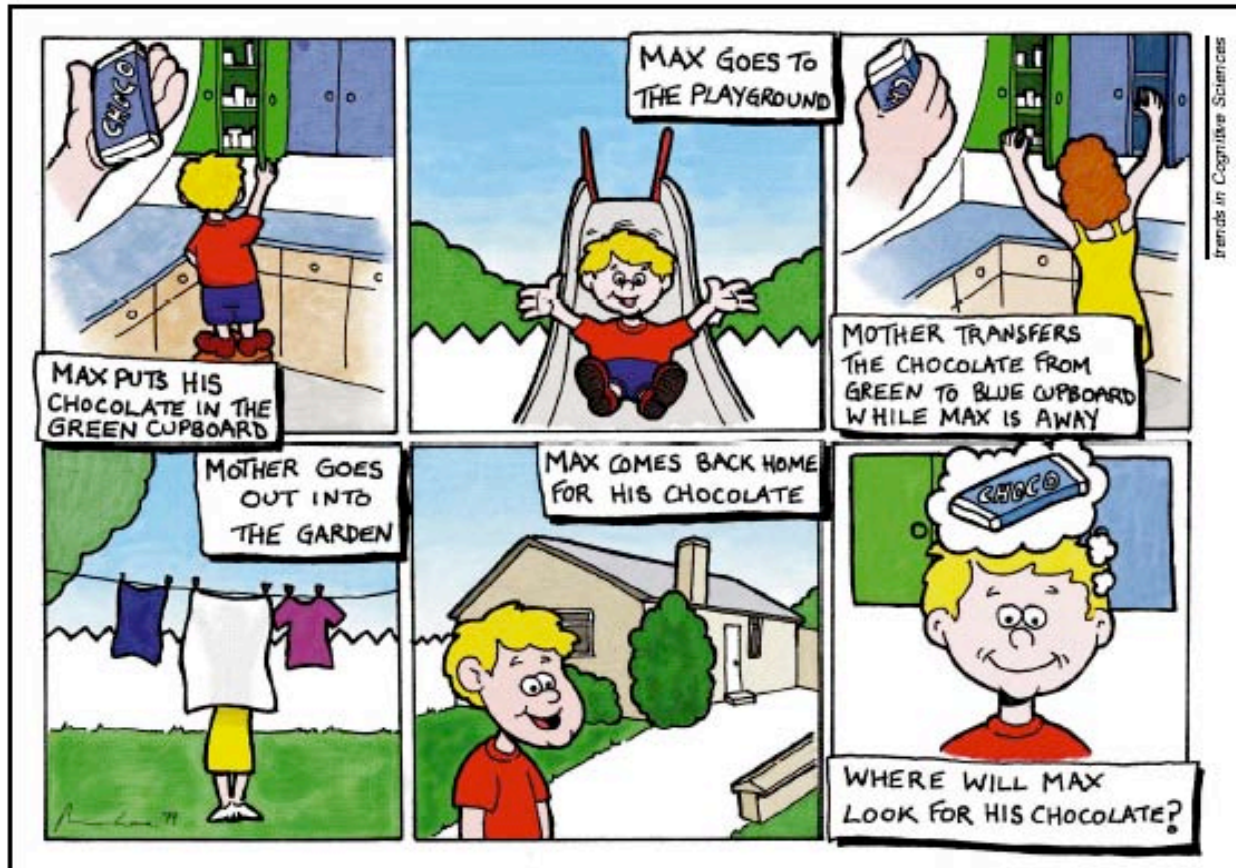
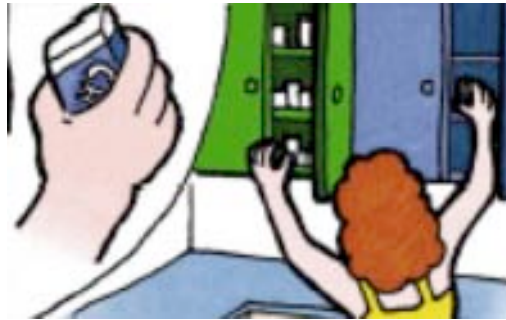Wimmer & Perner, 1983
illustration from Perner & Lang 1999

Wellman, Cross & Watson 2001

When is the belief computed?

At hiding

0-27 s

At replacing

28-46 s

At Maxi's return

47-55 s

prospective ToM vs.
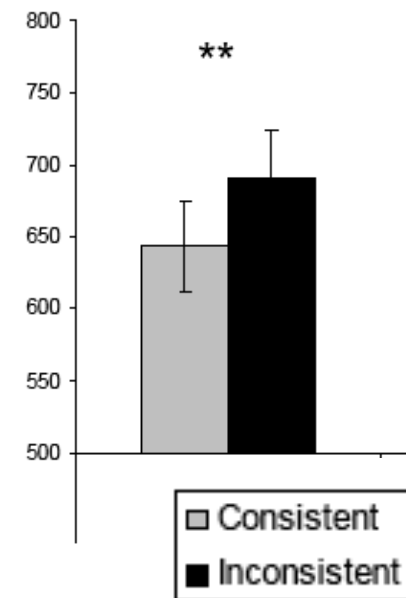retrospective ToM

illustration from Perner & Lang 1999

Implicit perspective taking: Adults

Numerical judgments:
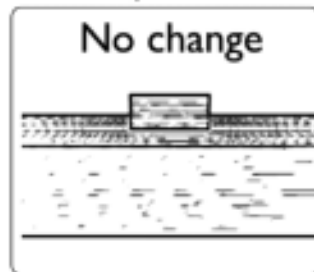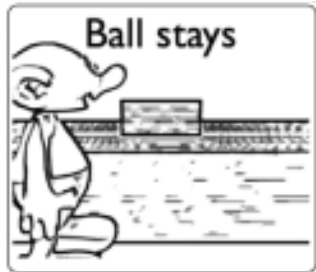"Is the number of dots 2?"

Inconsistent

Consistent

Samson et al 2010, and many other studies involving L2
perspective taking (6-9) VSPT, social interactions

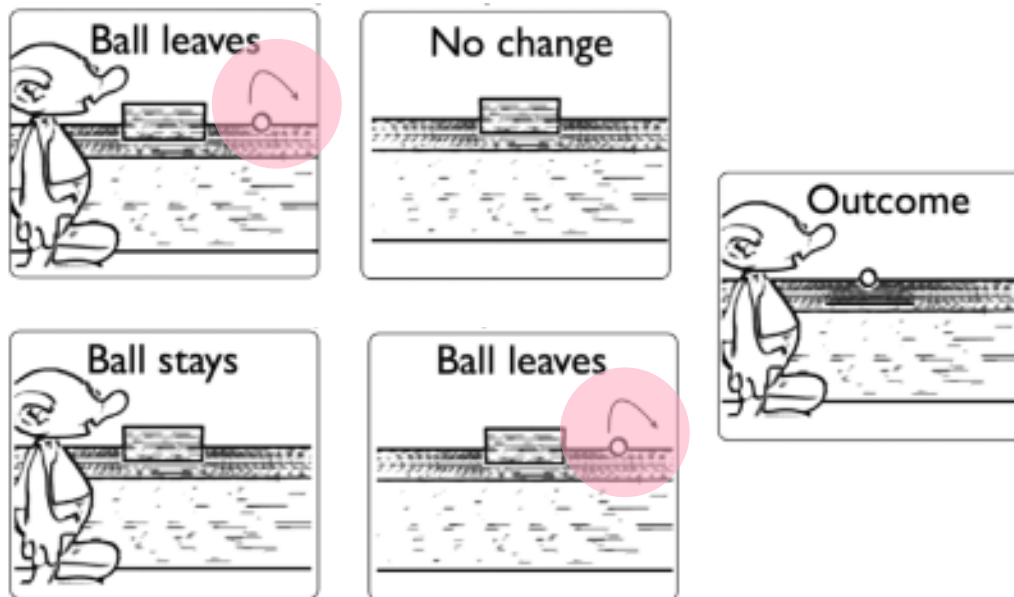# Implicit ToM: Adults
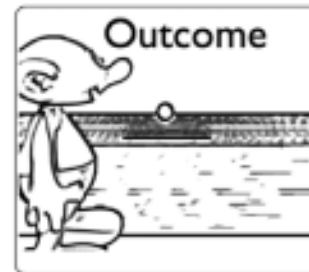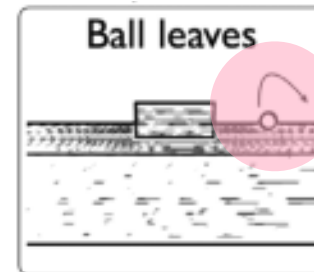
Object detection
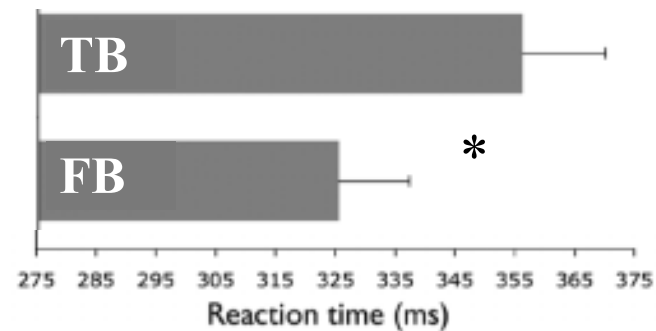

True belief
TB

False belief
FB

Kovacs et al 2010

Implicit ToM: Adults

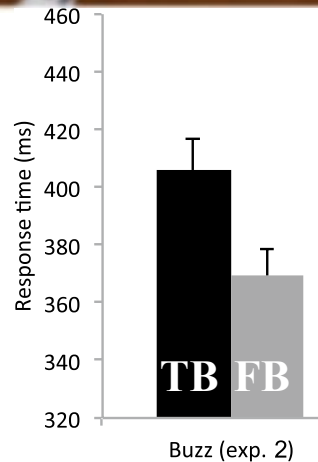## Object detection

True belief TB

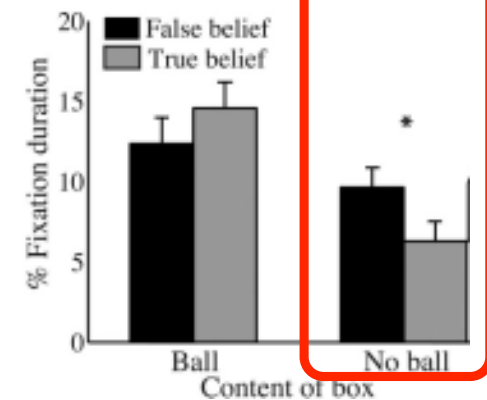**False belief FB**

Kovacs et al 2010

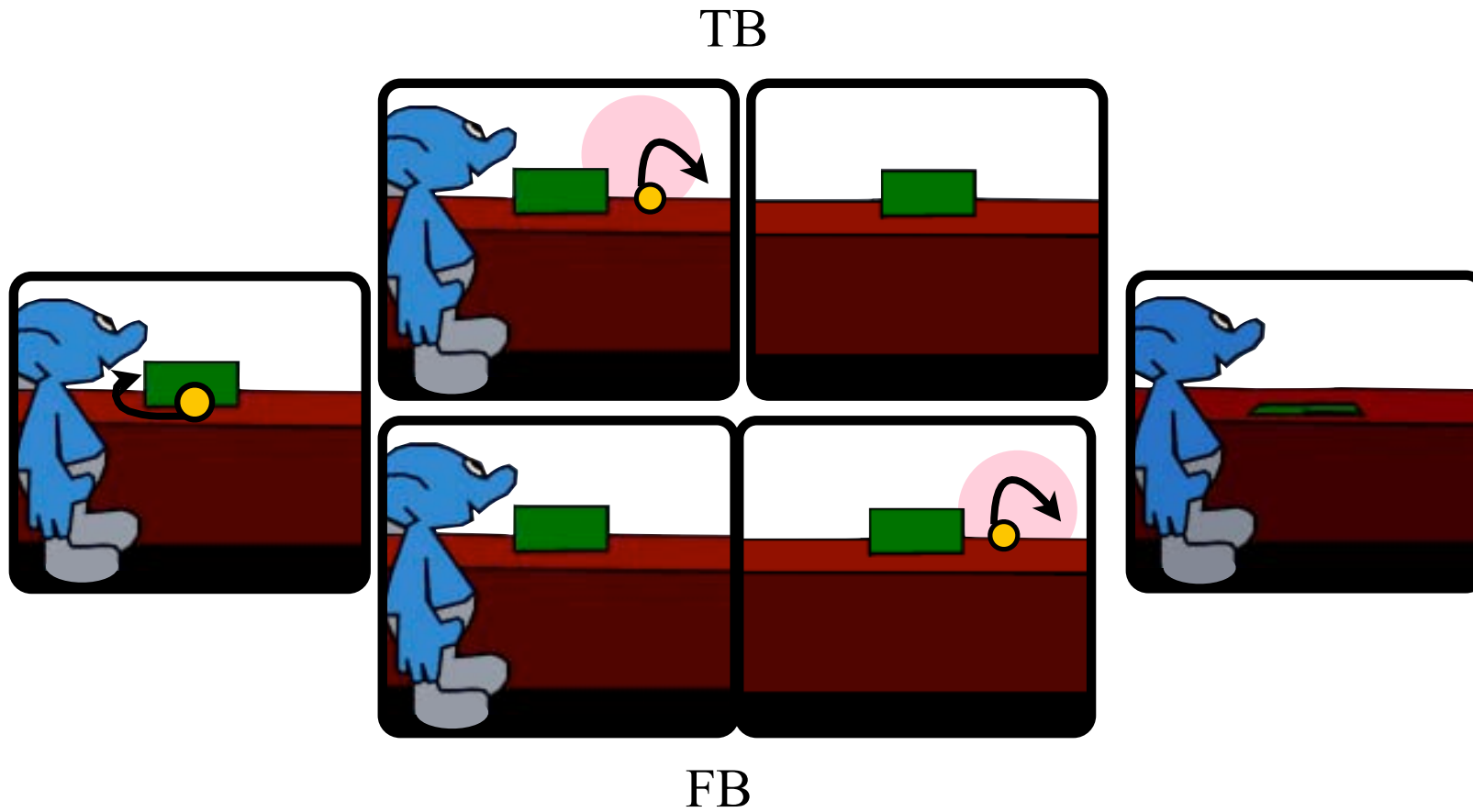# Implicit ToM: Adults

Object detection (RT)

Bardi et al, 2017, 2018; Meert et al, 2017;Deschrijver, et al, 2016; Nijhof, et al, 2017, Falk & Strickland in prep;

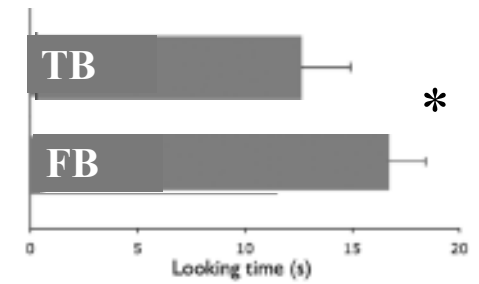## Eye movements motion trajectories

Schneider et al 2012, van der Wel, et al 2014, choice: Buttelmann et al 2017

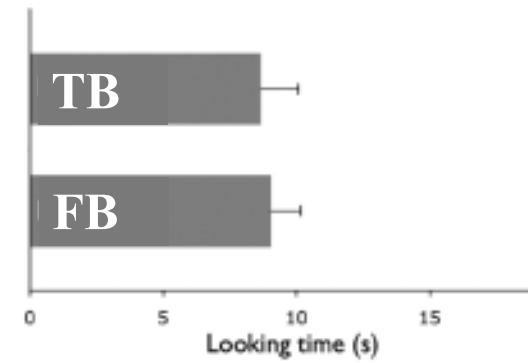# Implicit ToM: Infants
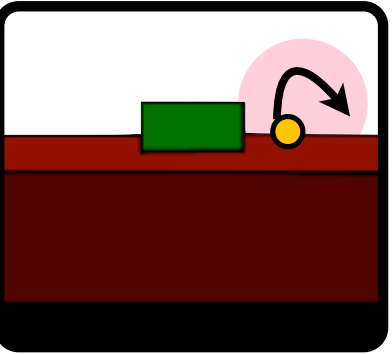

TB

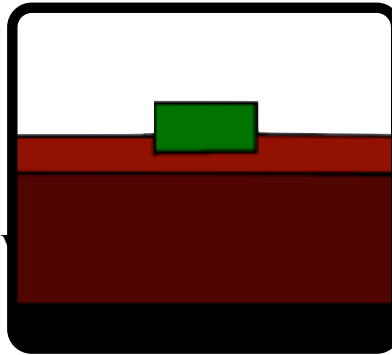FB

Violation of expectation

7-mo-old infants
Kovacs et al 2010

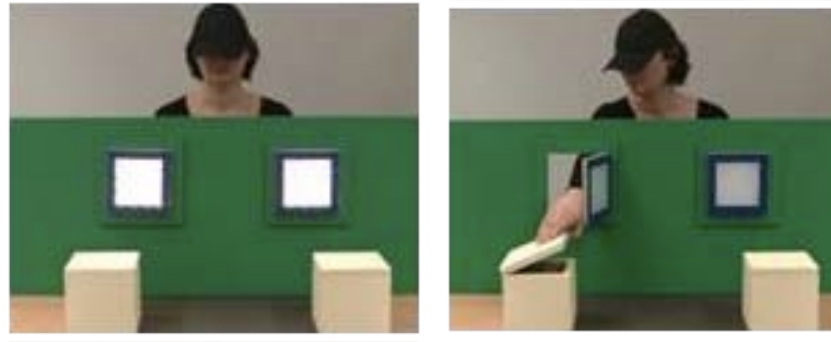# Implicit ToM: Infants

Control

TB

No outcome!!!

FB

7-mo-old infants
Kovacs et al 2010

Implicit ToM: Infants

Looking time
7-12-15-etc mo old

Anticipation
(eye tracking14-18-24 mo)

Searching, helping
pointing (15-18 mo)

Onishi & Baillargeon,2005; Surian et al, 2007, Scott et al, 2009, 2010,2015, Song et al 2008

Southgate et al 2007, Senju et al, 2011; Surian Geraci, 2012, Buttelmann &Kovacs, in rev but see Kulke et al 2018

Buttelmann et al, 2009; 2014; Kampis& Kovacs, in rev; Knudsen & Liszkowski, 2011; Kovacs et al prep

Can we explain infants' performance with low level accounts?

More than 30 studies using various tasks/ measurements (Scott & Baillargeon 2017)

3-way associations/relations: Agent-object-location
(Perner & Ruffman 2005; Butterfil & Apperly, 2010)
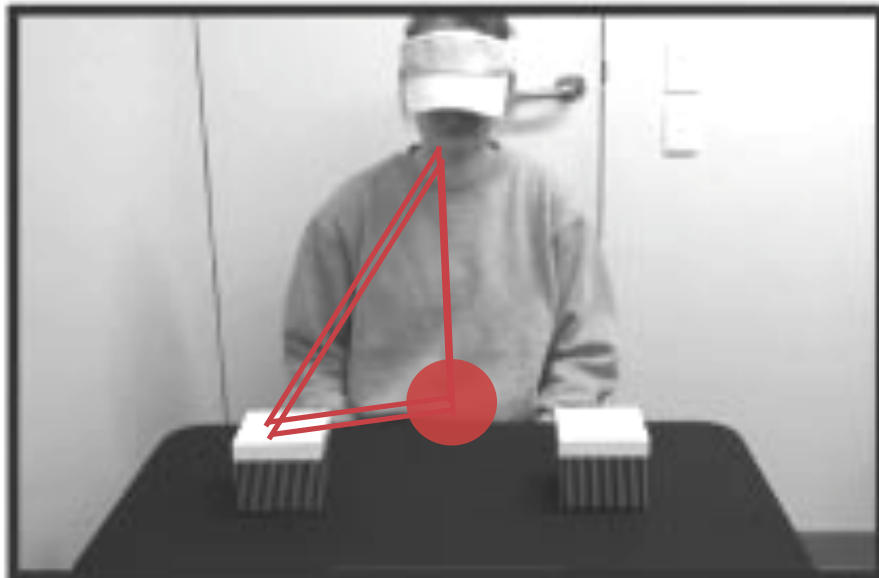
Apes: Krupenye et al 2016
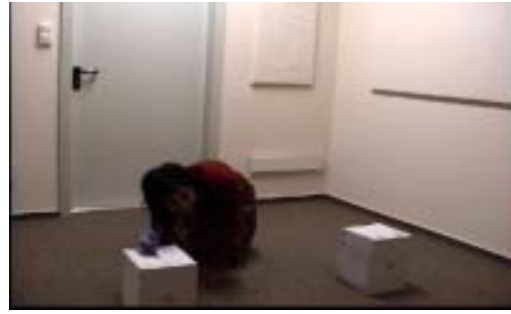

Agent

Object

Location
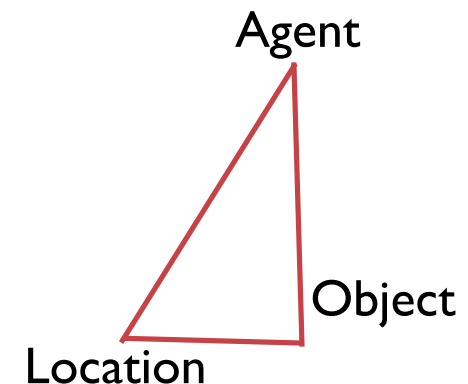
But see Senju et al 2011; Kano et al 2017, etc
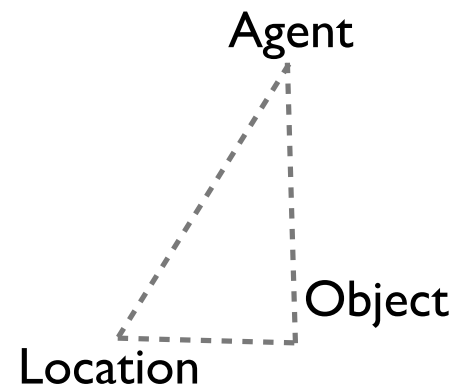
Excluding 3 way associations

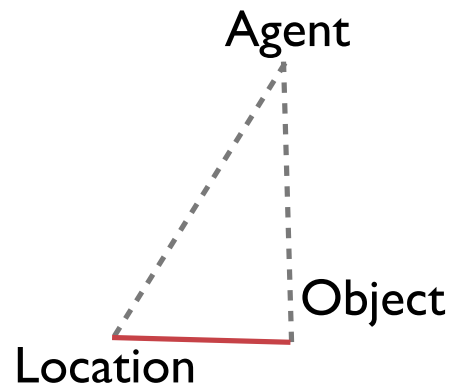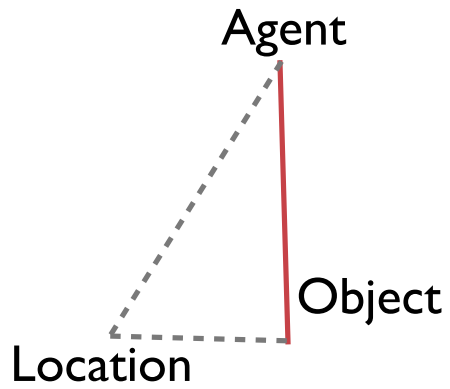

Invisible hiding by E1

Object reveled by E2
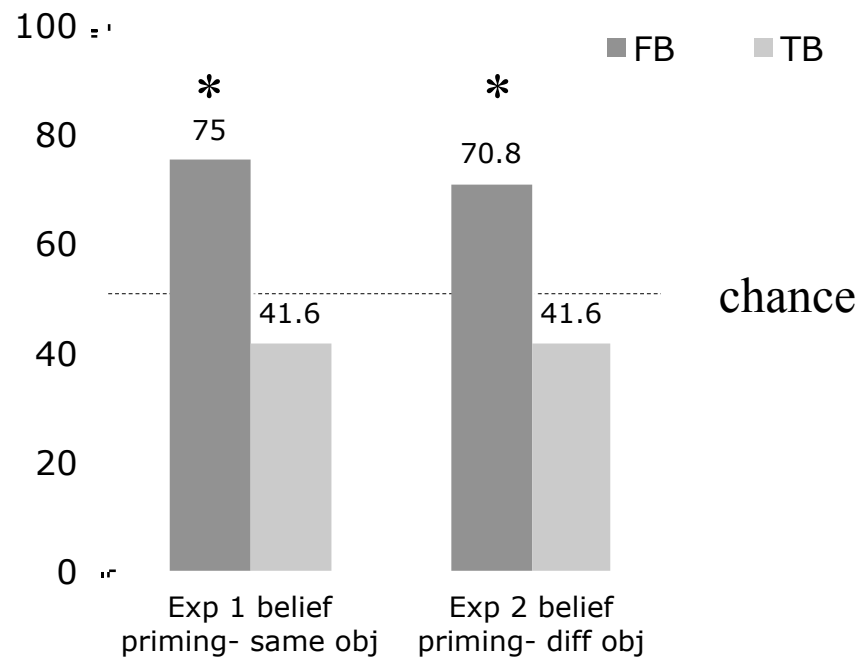
Re-hiding by E2

Infant searching

Belief prime (obj last seen)

Belief prime (obj last seen)

15-mo-olds

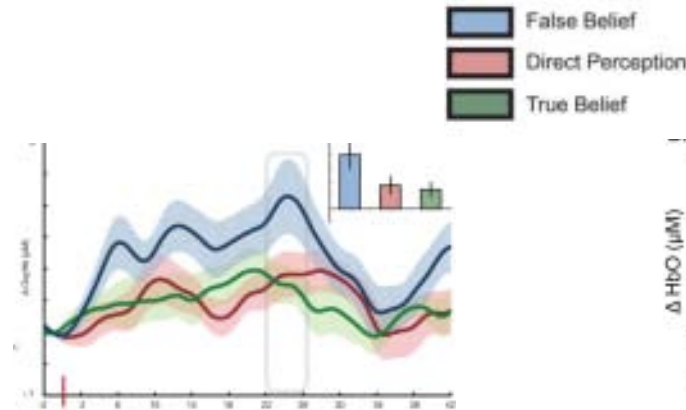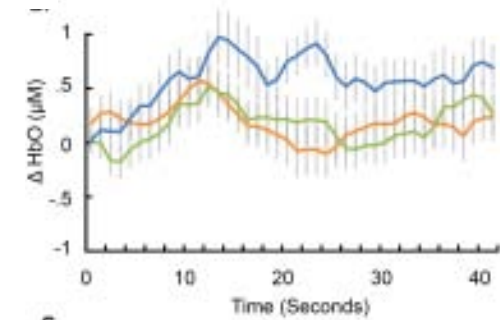# More reasons to believe that infants compute beliefs: recruiting the same brain areas as adults

FB

TB

DP
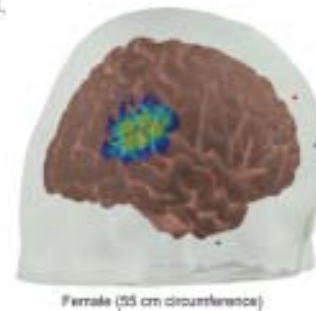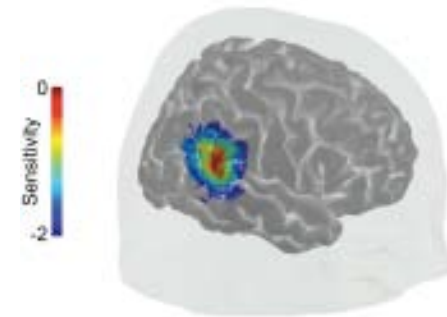
Adults

6 mo old infants

Right TPJ activation as measured by fNiRS

Hyde et al 2015, 2018

Characteristics of belief representations

- **Do infants use the common brain networks** to compute the content of others' beliefs as for 1st person representations?
        -evidence from gamma oscillations
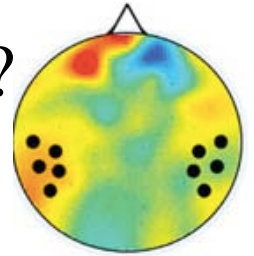
-]   v com   to inferences
re_arding o_   ___ 1st pe_
            -evi   _eting c

- **Is the format different from 1st person representations? possibly propositional**
        -indirect evidence from attributing negation

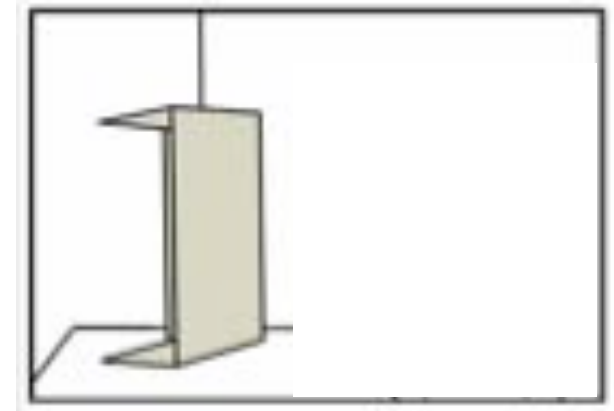# Common networks for computing the content
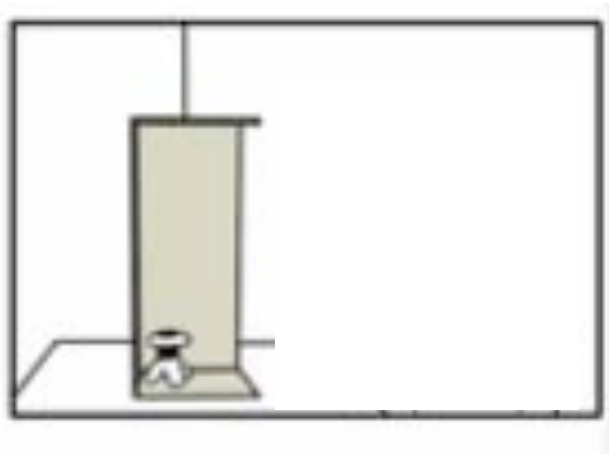
Object visible

Object occluded

Gamma oscillations

Kaufman et al, 2003,2005
6-mo-olds

sustained object rep

Common networks for computing the content

Object visible

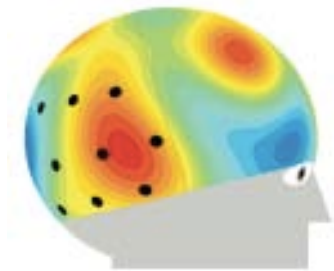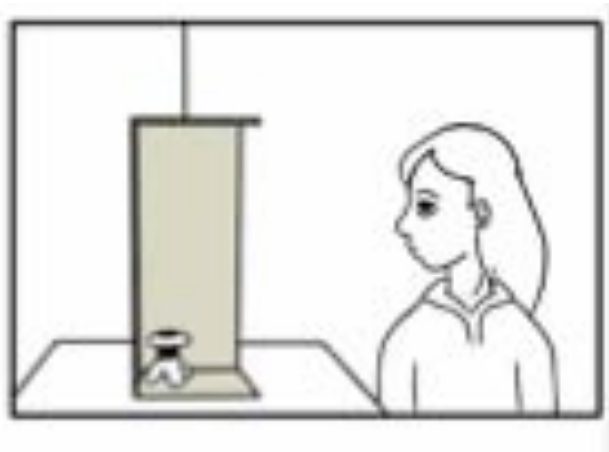Object occluded

Gamma oscillations

Kampis et al, 2015
8-mo-olds

sustained object rep

Common networks for computing the content

Object visible   Object occluded from agent   Object occluded
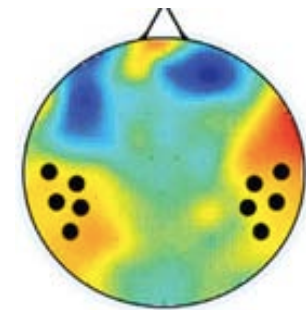

Gamma oscillations
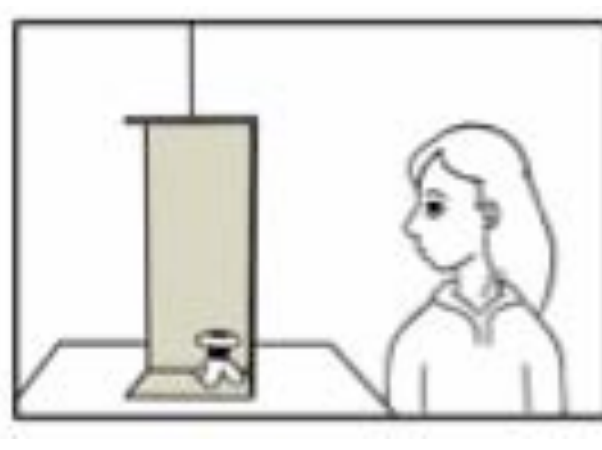
Kampis et al, 2015
8-mo-olds
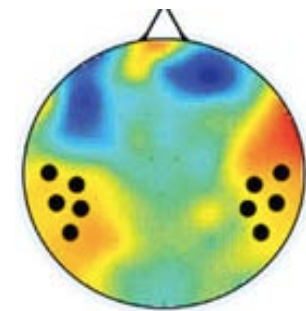
sustained object rep

Common networks for computing the content

Object visible	Object occluded from agent	Object occluded
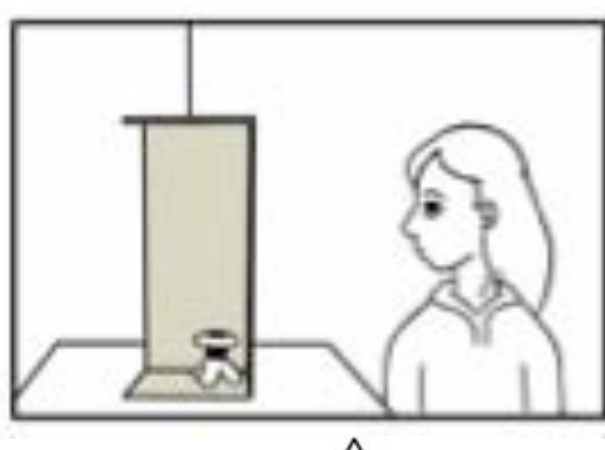
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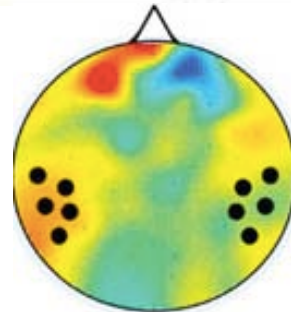
sustained object rep
for the other
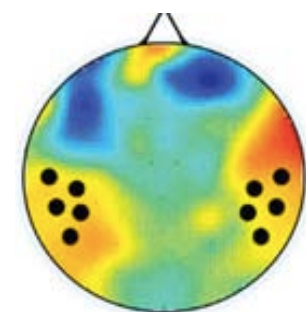
sustained object rep

Common principles

One cannot entertain 'A' and 'not A' at the same time

Common principles
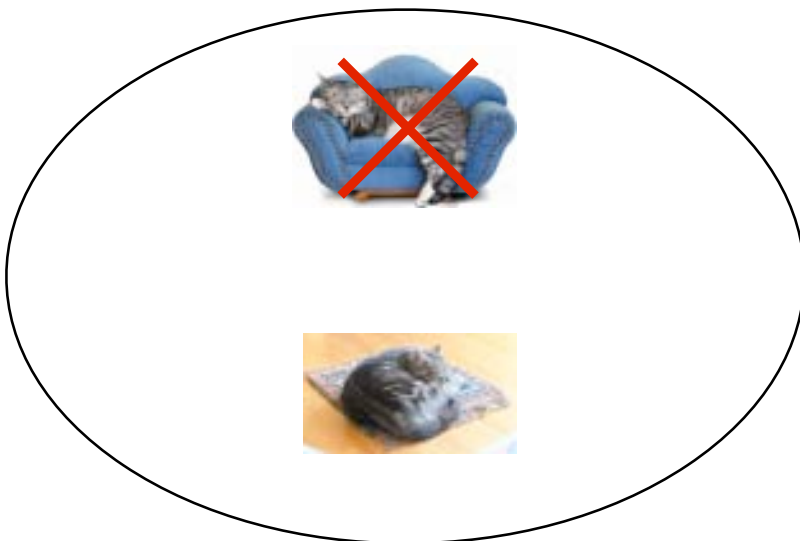
One cannot entertain 'A' and 'not A' at the same time

The principle of non-contradiction

-should apply not only to own mind but to other minds as well

Mascaro & Kovacs in rev

The principle of non-contradiction

'A' points to left

1 informant

'A' points to right

Mascaro & Kovacs in rev

The principle of non-contradiction

1 informant

'A' points to le[ft]

'A' points to right

2 informants

'B' points to left
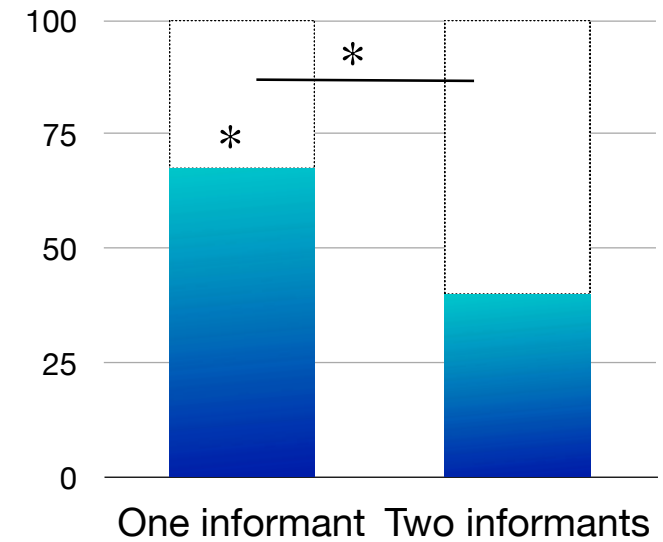
% following 2nd point
15 mo olds

Mascaro & Kovacs in rev

Different format: propositional?

Encoding absence

Expected appearance

car goes behind the screen
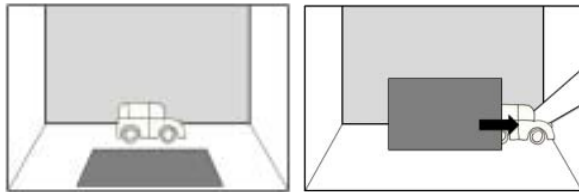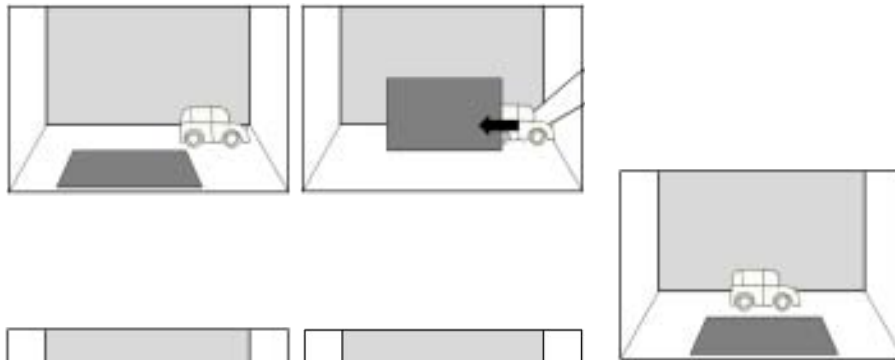
car exits

Magical appearance

6-8 mo olds
Wynn & Chiang (1998); Kaufman et al. (2005)

Different format: propositional?
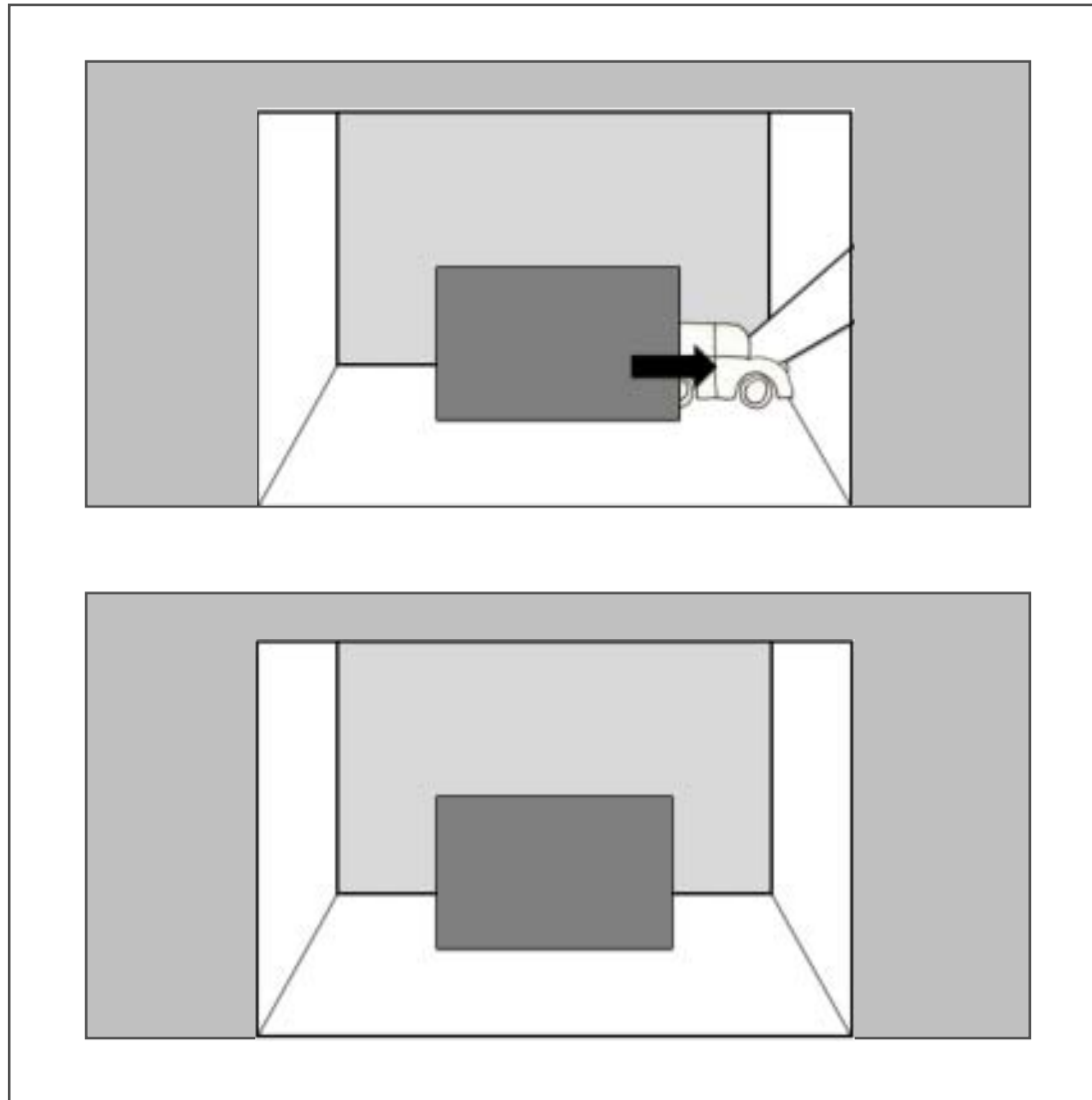
Encoding absence

Different format: propositional?

Encoding absence

The hard way:
Propositionally
via negation
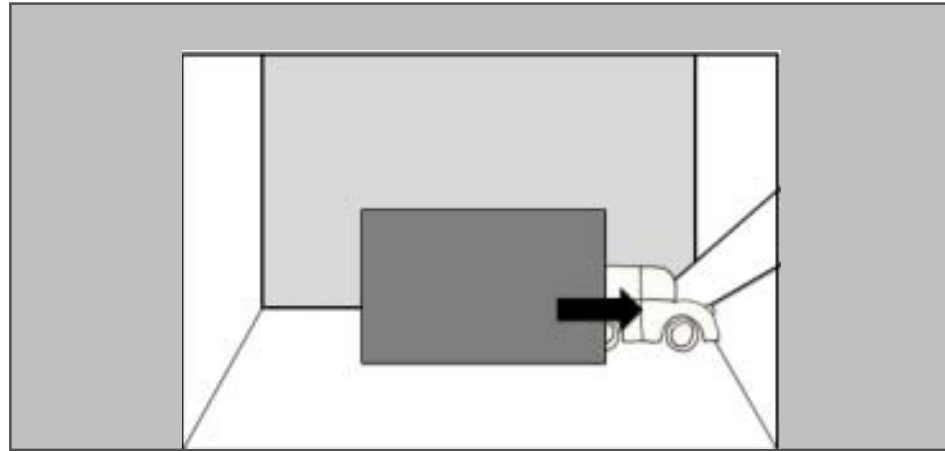
The easy way:
Through the object file
system

there is no car behind the occluder

the car is behind the curtain
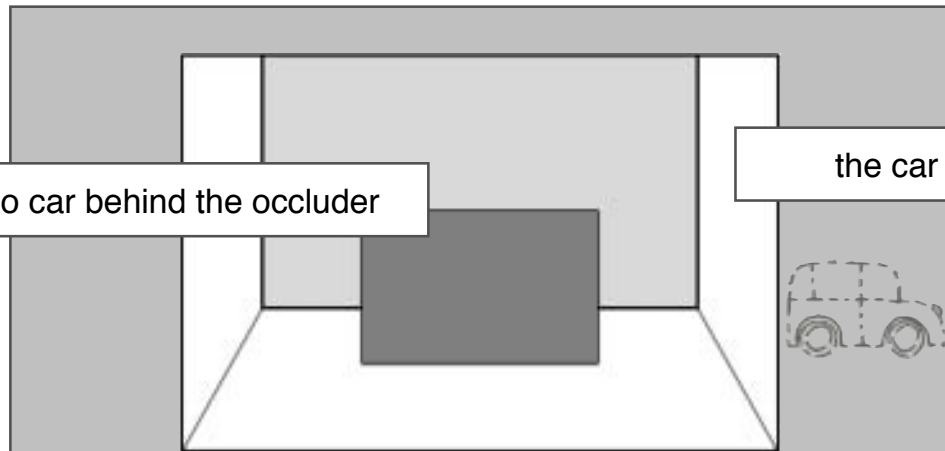
A special case of absence: "ceased existence"

The hard way: Propositionally via negation

The easy way: Through the object file system

there is no car

Object file deleted, thus nothing is encoded

Forcing the hard way: attributing ceased existence

The hard way:
Propositionally
via negation

there is no car
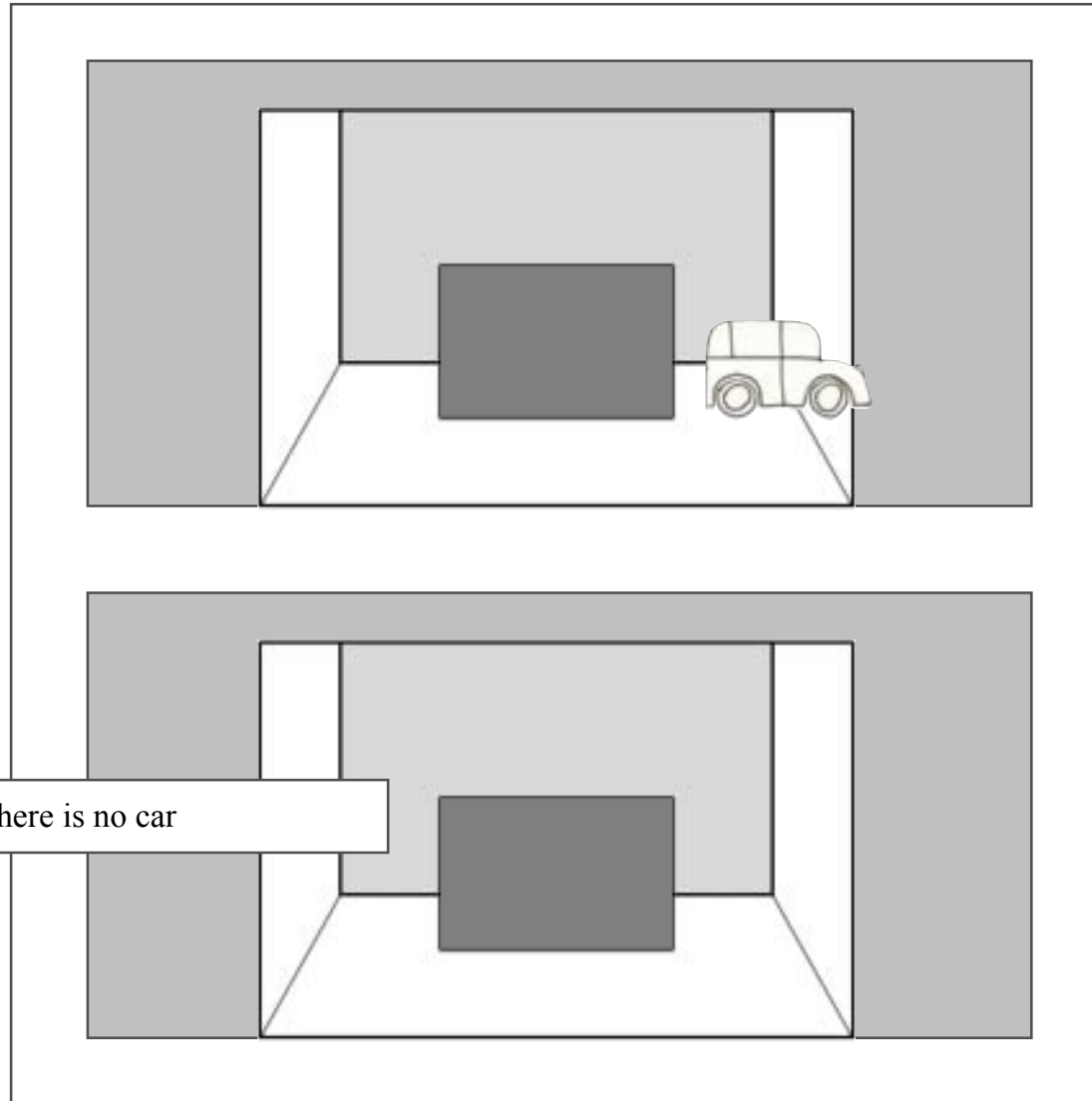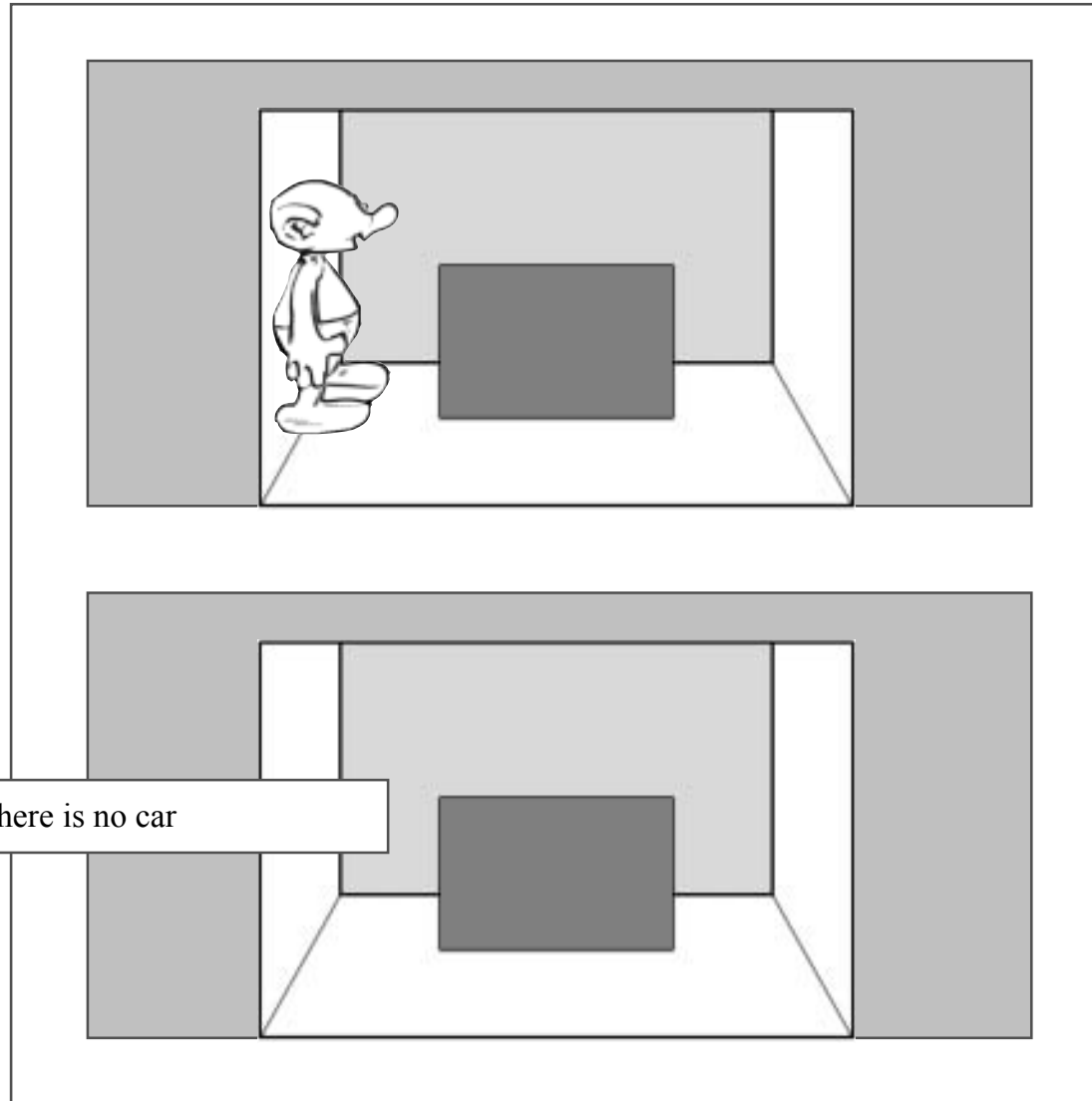
The easy way:
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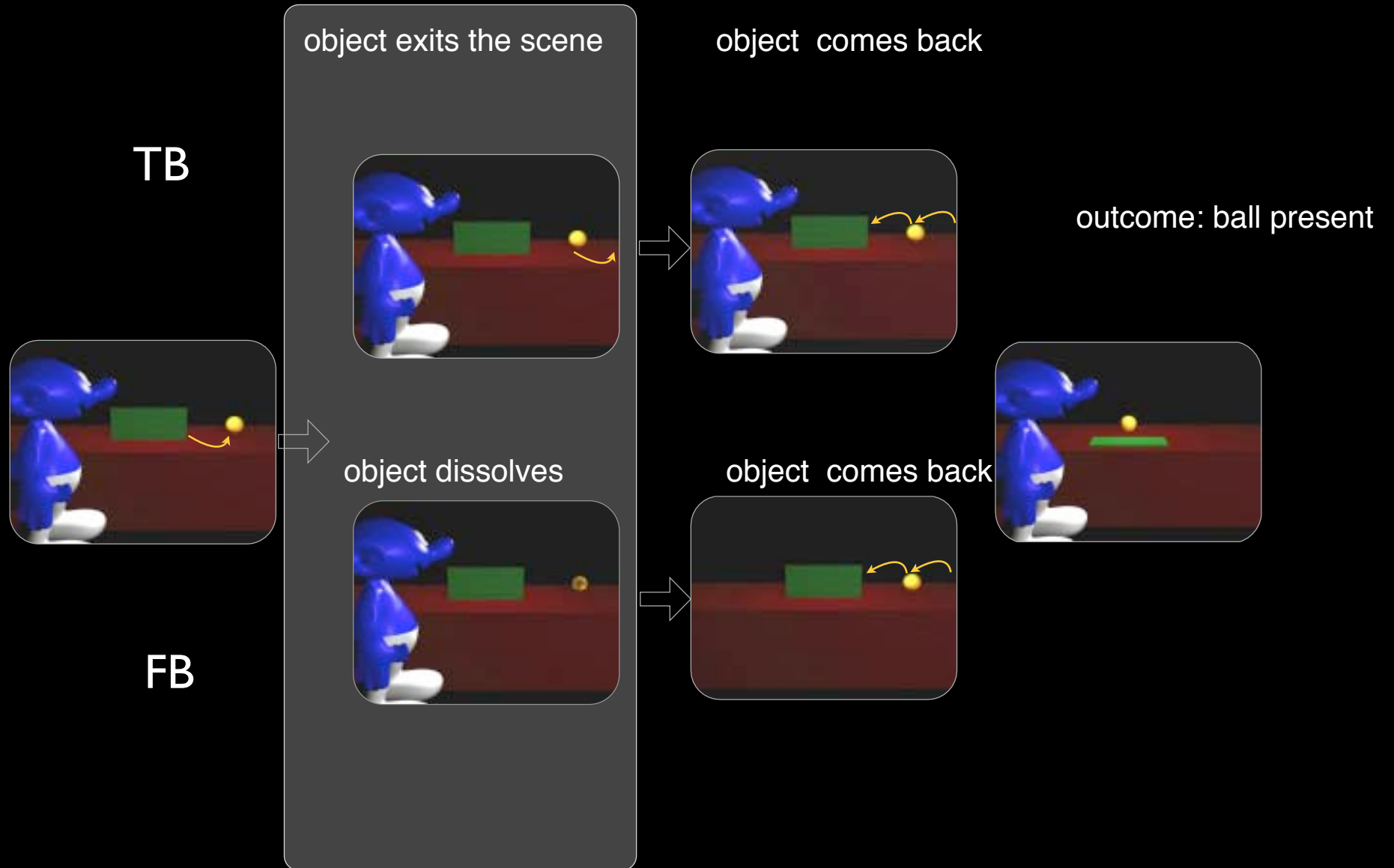
Experiment 1. TB vs FB dissolve - the hard way

Experiment 1. TB vs FB dissolve - the hard way
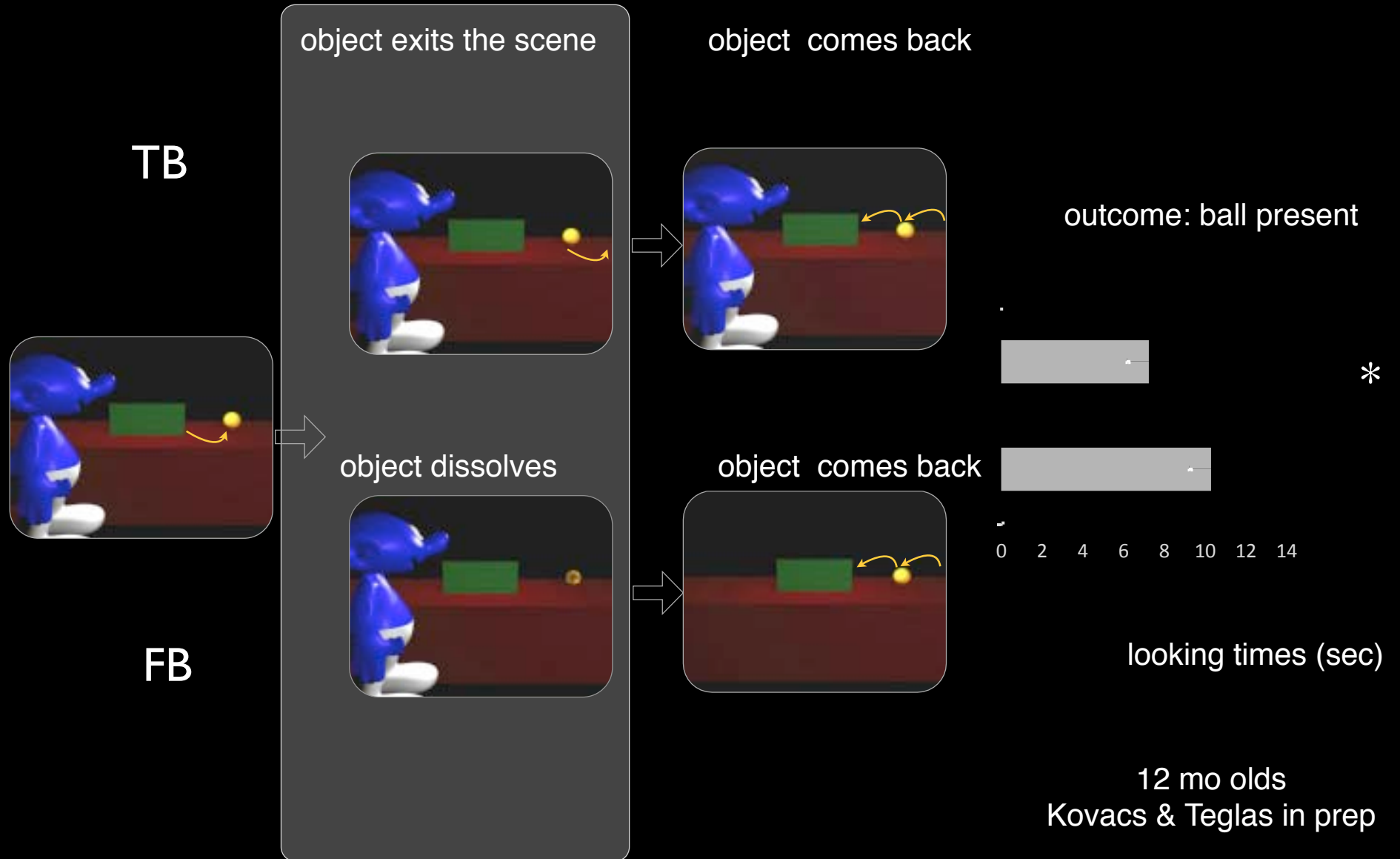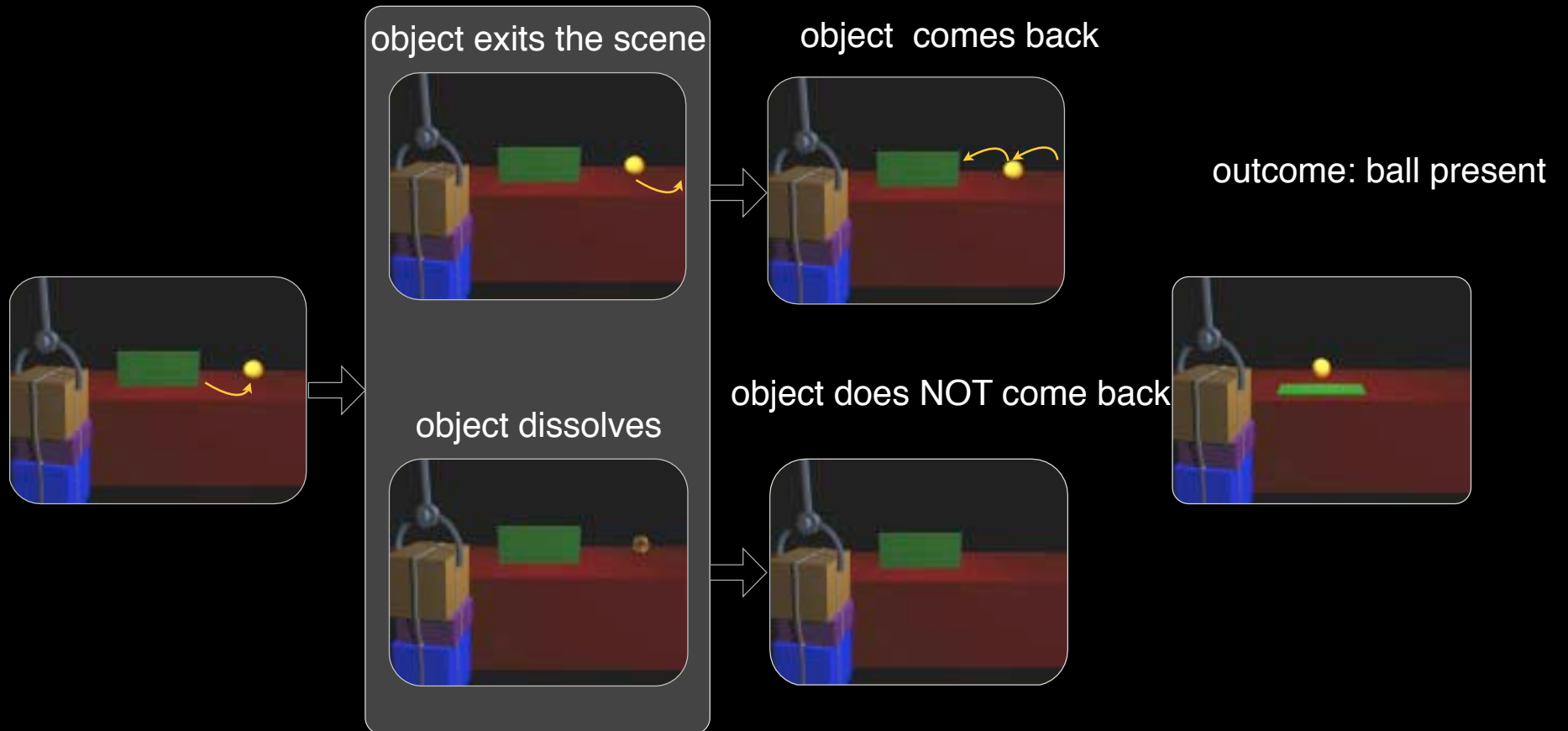
TB

object exits the scene

object comes back

outcome: ball present

FB

object dissolves

object comes back

0 2 4 6 8 10 12 14

looking times (sec)

12 mo olds
Kovacs & Teglas in prep

Experiment 2. Object present vs object absent

object exits the scene

object comes back

outcome: ball present

object does NOT come back

object dissolves

Experiment 2. Object present vs object absent

object exits the scene

object comes back

object dissolves

object does NOT come back

outcome: ball present

ns

looking times (sec)

0 2 4 6 8 10 12 14
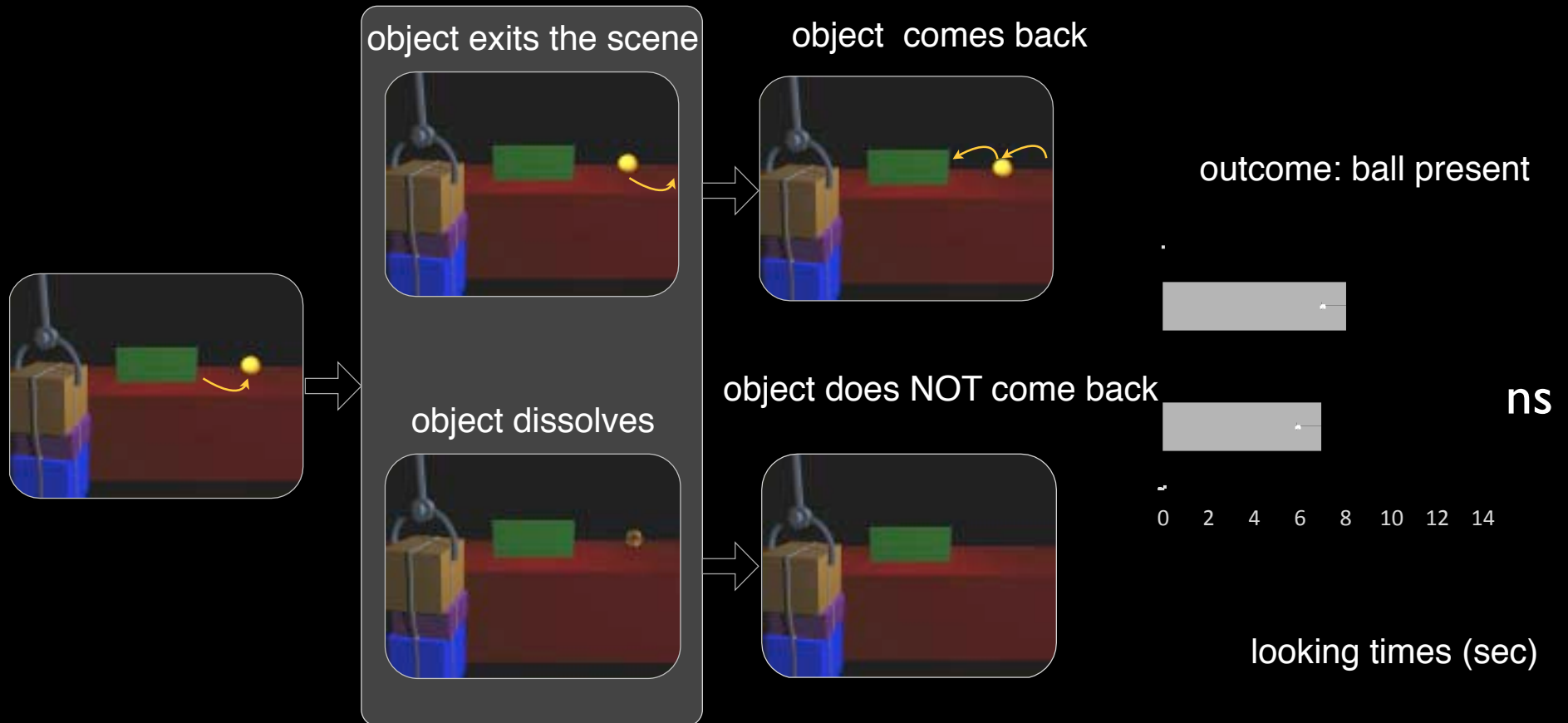
Characteristics of belief representations

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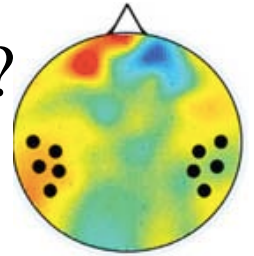
-]   v com   to inferences
regarding o   1st pe
            -evi   eting c

- **Is the format different from 1st person representations?
possibly propositional**
        -indirect evidence from attributing negation

A closer look at ToM mechanisms:
possible limitations early in development

When is the belief computed?

At hiding   **At replacing**   **At Maxi's return**

prospective ToM vs.
retrospective ToM

illustration from Perner & Lang 1999

Updating others' beliefs

Change of location:
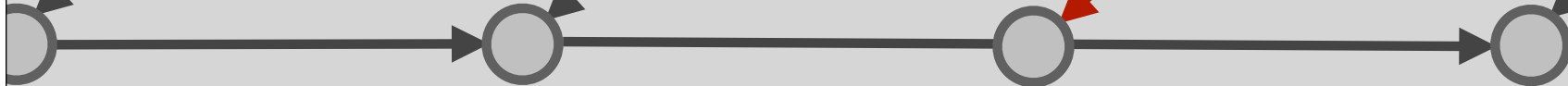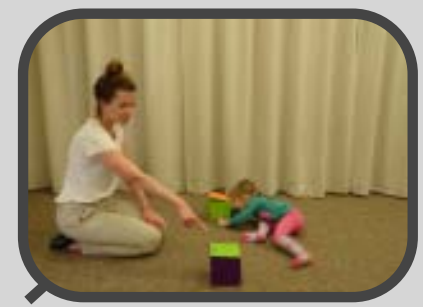**E1 wearing sunglasses -TB**   **E1: 'Give me the sefo'**
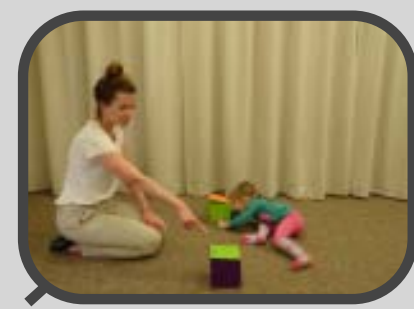
Updating others' beliefs

Change of location:
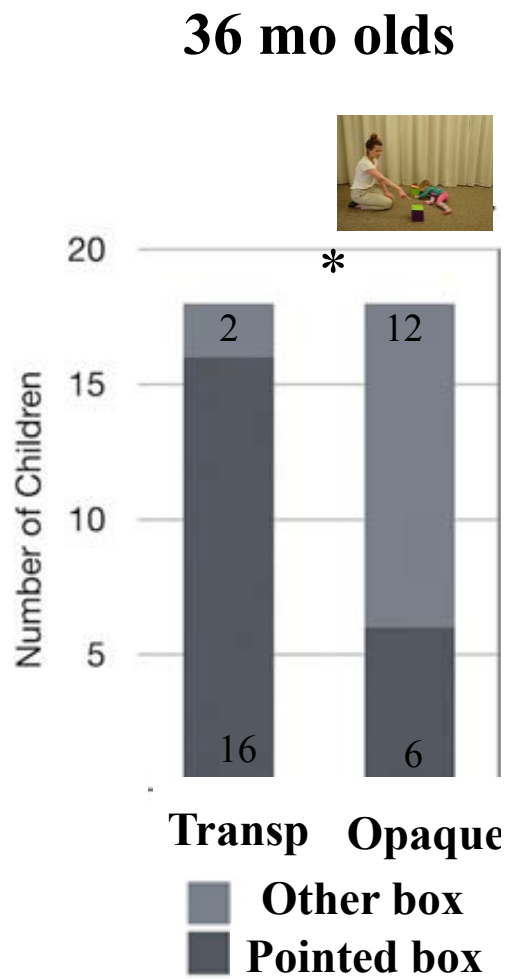**E1 wearing sunglasses -TB**

E1: 'Give me the sefo'

Sunglasses: Opaque!
Update TB to FB

Updating others' beliefs

36 mo olds　　　　**18 mo olds**

General summary

-**Spontaneous tracking of mental states** in human adults and infants

-**Keeping active alternative representations** linked to others, that influence behavior

-**Similar networks for computing the content** of attributed and 1st person representations, **same principles**, while possibly integrating them in a **different format**

-Different ToM processes:
    online belief tracking -present from very early on
    retrospective belief revision -possibly developing later, relying on episodic memory

Open questions

-Why infants go beyond the here and now and encode different perspectives?

- Is it triggered by the social environment? can it be found in other domains?

-What are the necessary prerequisites to develop a ToM?
-What is the role of experience?

- What such belief priming effects tell us about how these representations are organized?

- What features of ToM may be human specific? Encoding others' beliefs even with undefined contents, multiple flexible updates

Thank you!

Colleagues and collaborators:
-Dora Kampis, Olivier Mascaro, Ildiko Kiraly, Erno Teglas, Kata Olah, Gergo Csibra, Gyorgy Gergely, Ansgar Endress, Jaques Mehler

- the whole CDC-CEU lab

- infant and adult participants

funding: