Donders Institute
for Brain, Cognition and Behaviour

Predicting others' goal-directed actions

Eduardo Palozzi

Harold Bekkering

Radboud University Nijmegen

Tubingen
KogWis 2014

The Brain as a prediction machine

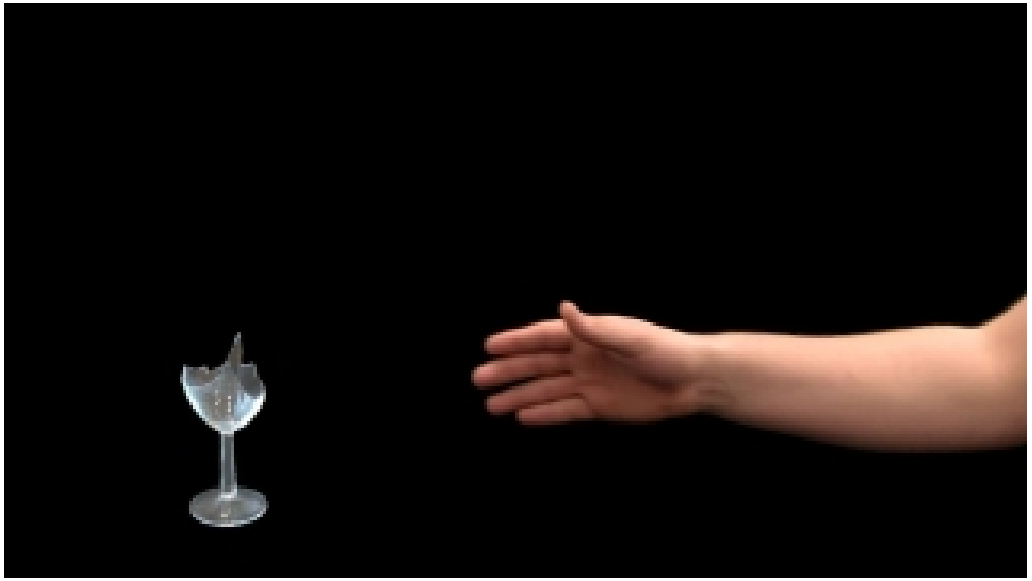
"Brains, it has recently been argued, are essentially prediction machines. They are bundles of cells that support perception and action by constantly attempting to match incoming sensory inputs with top-down expectations or predictions. This is achieved using a hierarchical generative model that aims to minimize prediction error within a bidirectional cascade of cortical processing.

Andy Clark, BBS, 2013
Karl Friston, from 2005 onwards

Predicting Human Agents

"In brief, the key thing that distinguishes biological systems from other thermodynamically open, self-organising systems is that they exhibit **goal-directed movements**. Crucially, this enables them to attain desired goal states and avoid the undesirable ones."
Friston, 2010

How do we learn to predict others' actions?



Picture from Patric Bach

You might have inborn mechanisms

- You learn from observing others
- You learn by acting yourself

Overview

- Learning from Action Experience
- Learning from Action Observation
- Comparing Predictions in Language and Action
- Conceptual Predictions
- Future Predictions

Natural Learning

Michiel van Elk

- Test case: Crawling
- Measure: EEG
  - Power of mu frequency bands: 7-9 Hz at this age
  - Greater suppression (i.e., less power) in these bands over central brain regions reflects more motor activity in the brain

    (Marshall & Meltzoff, 2012)

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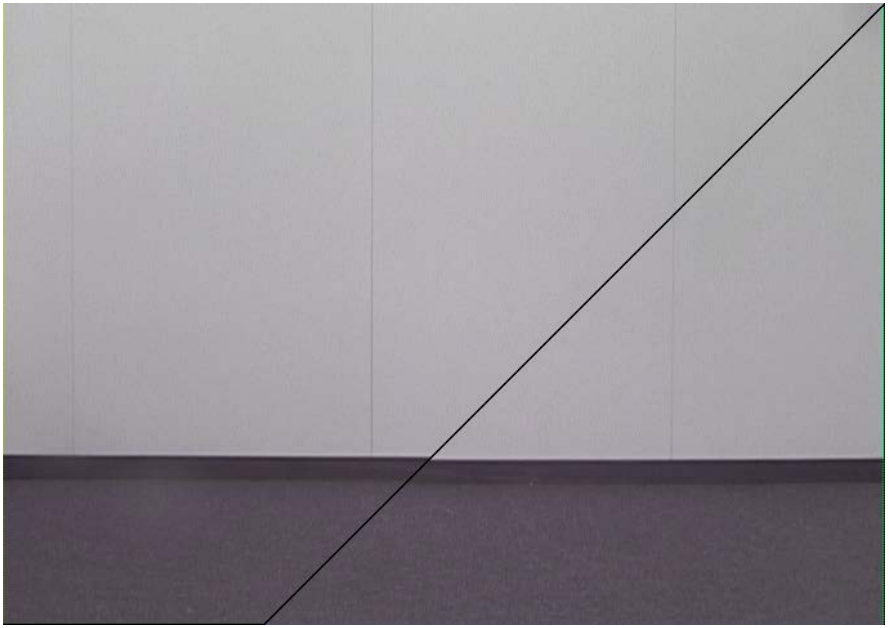
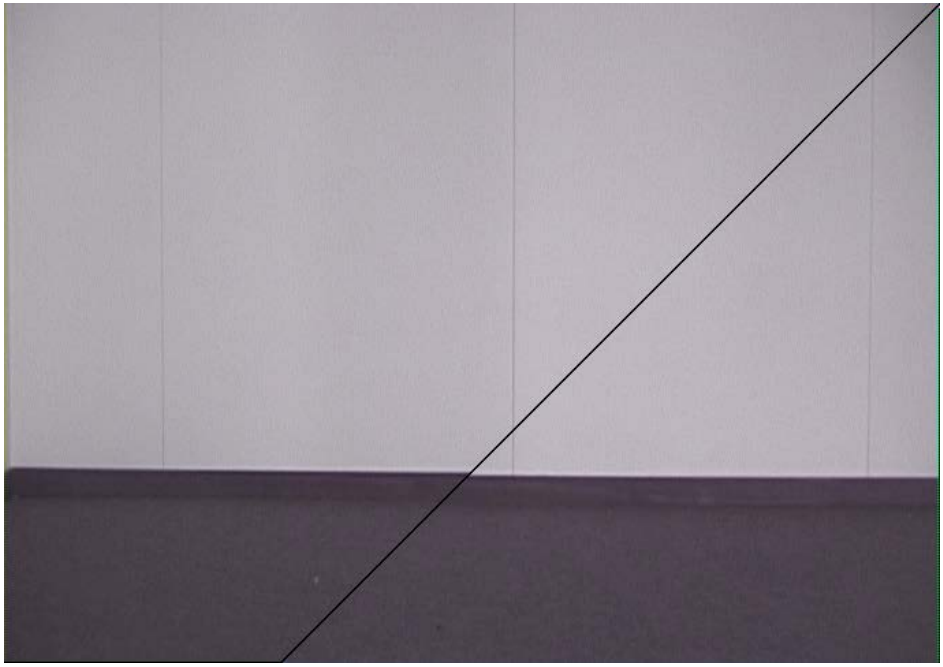
Action experience & action processing





- Sample of experienced crawlers
- Watched crawling vs walking movements, while the response of their neural motor system was measured (suppression in mu power = motor activation)

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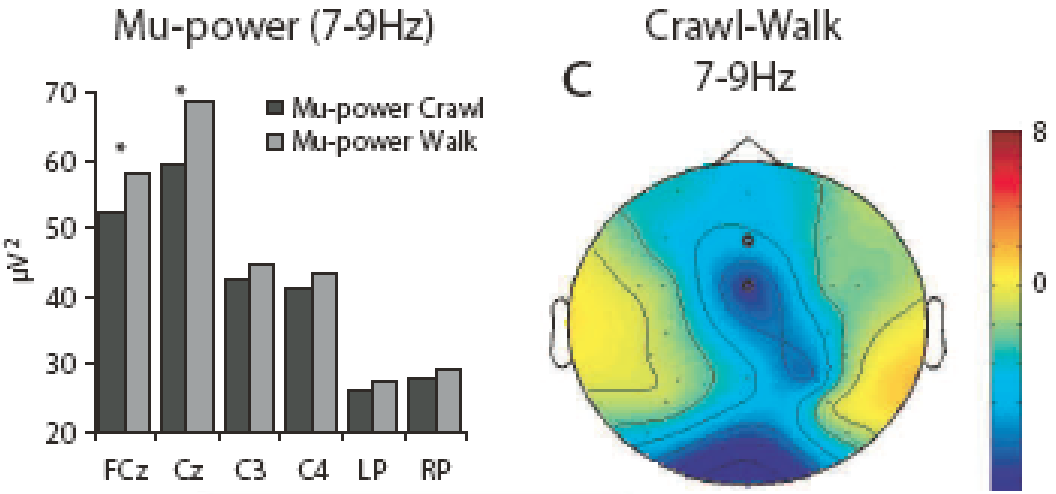
Action experience & action processing



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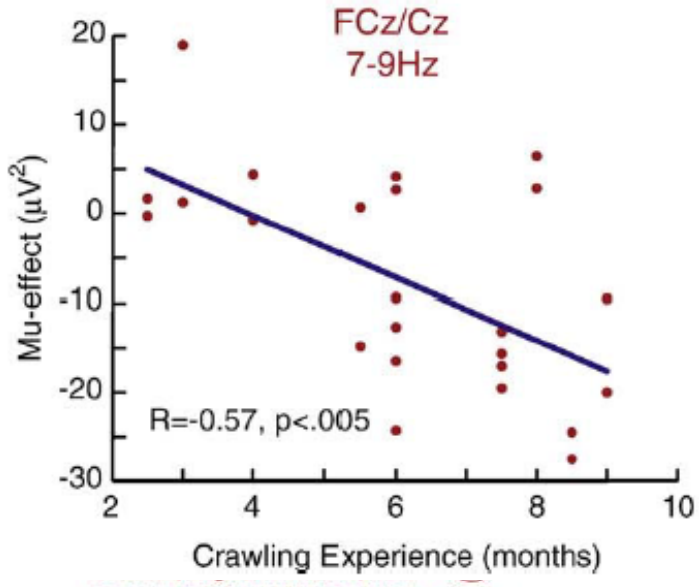
Action experience & action processing



→ Infants' motor activation during action observation is related to their experience with this action.

Development of Action Prediction

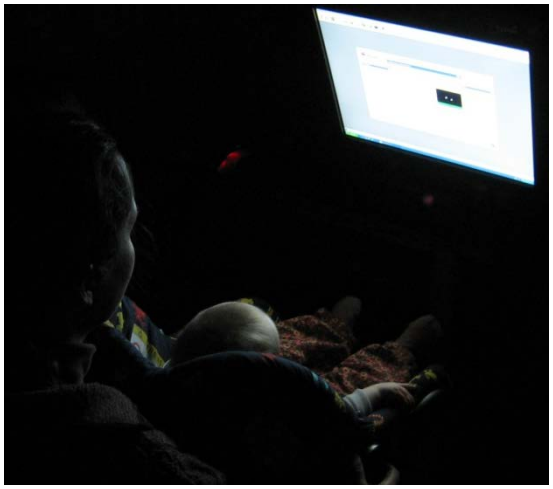
Research Question

Janny Stapel

- Predictions may be based on motor knowledge (Forward model for own actions, Wolpert & Flanagan, 2001)
- Does motor development support temporal action prediction?

Stapel, Hunnius, Meyer, & Bekkering, submitted

Infant eye-tracking



- Eye-tracking as a non-intrusive, reliable method to measure eye movements in infants
- Eye movements during action observation can inform us about how infants expect the action to unfold

Development of Action Prediction

Design

- Independent variables:
  - Movement type: Crawling, Walking, Object (non-biological)
  - Age: 13-month-old infants, 30-month-old toddlers, adults
- Dependent variable:
  - Timing of anticipatory looks to AoI

Development of Action Prediction

Stimuli



Development of Action Prediction

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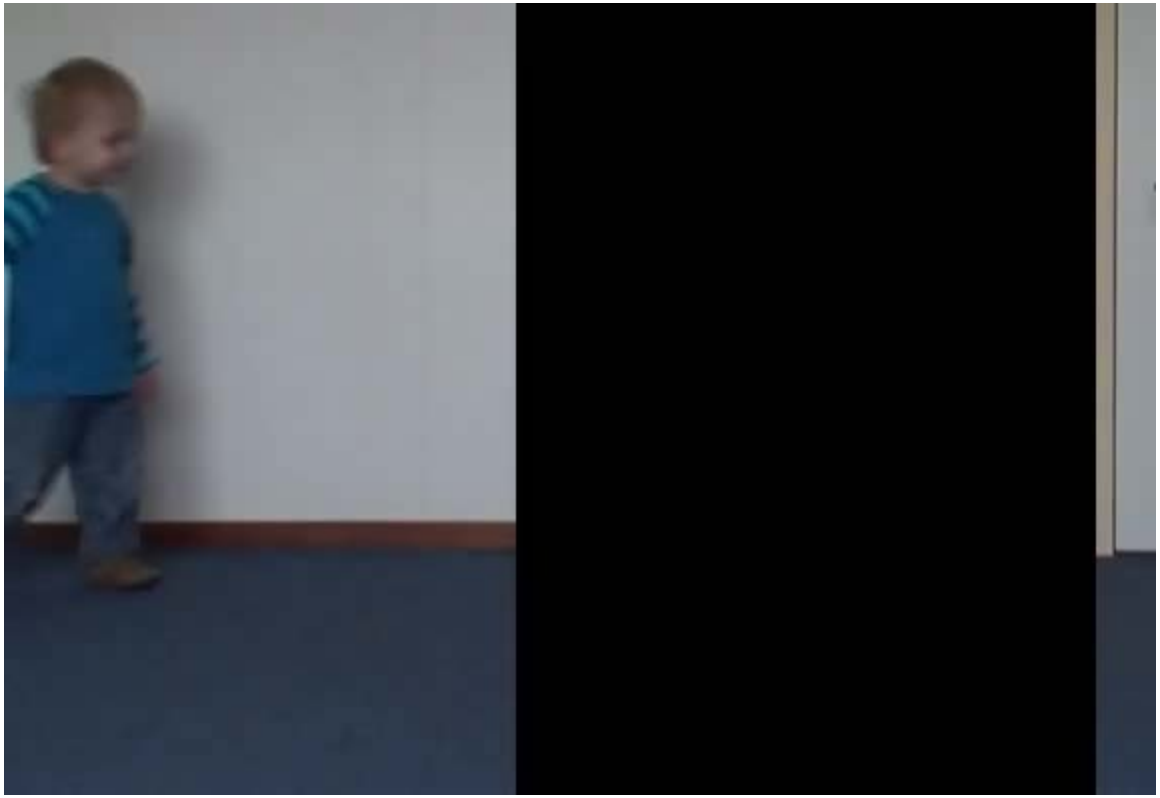
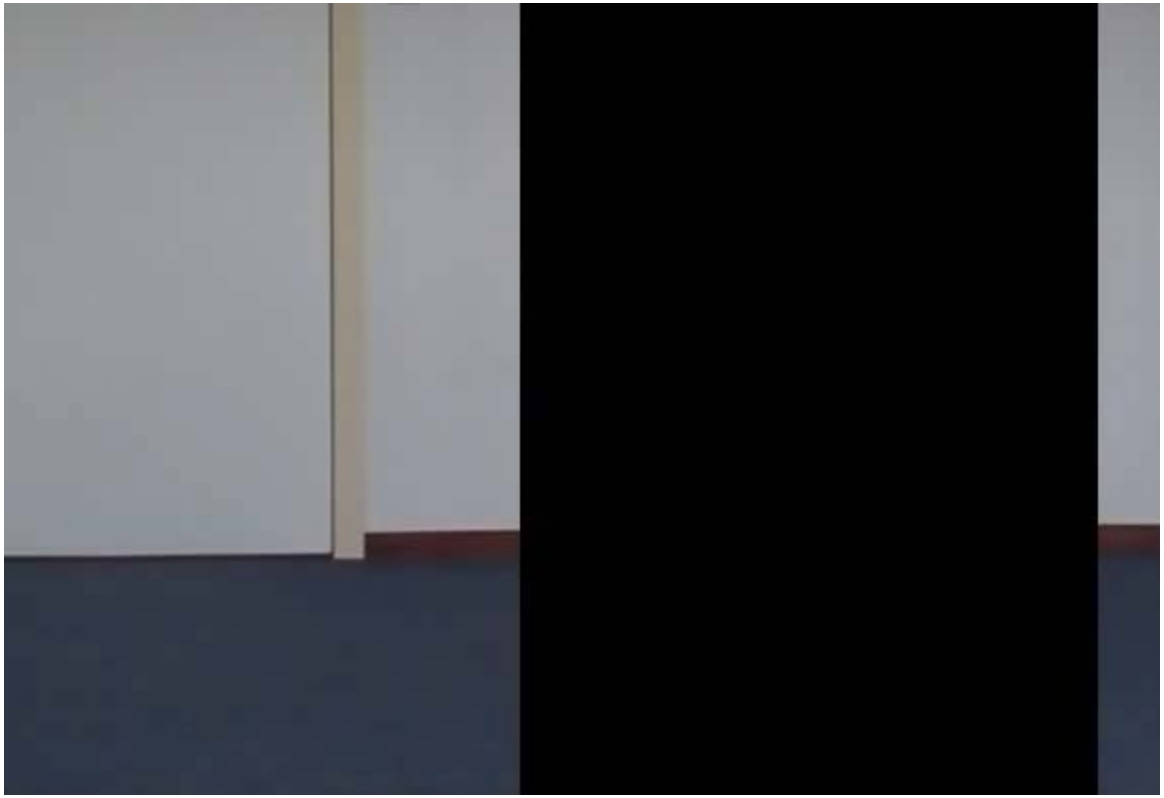
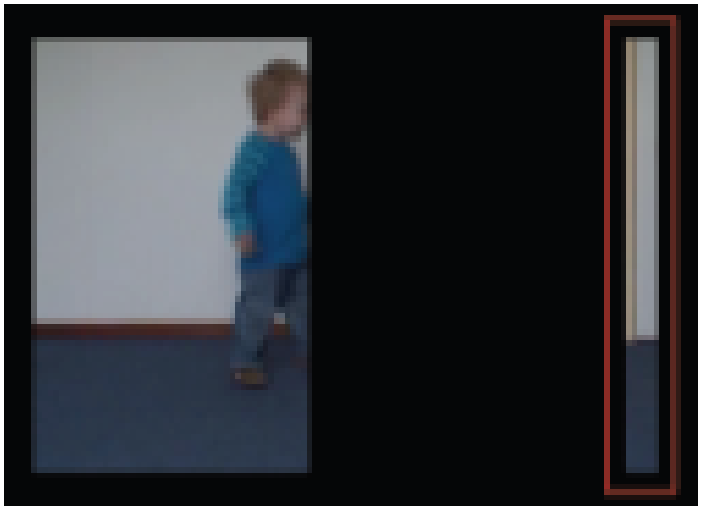


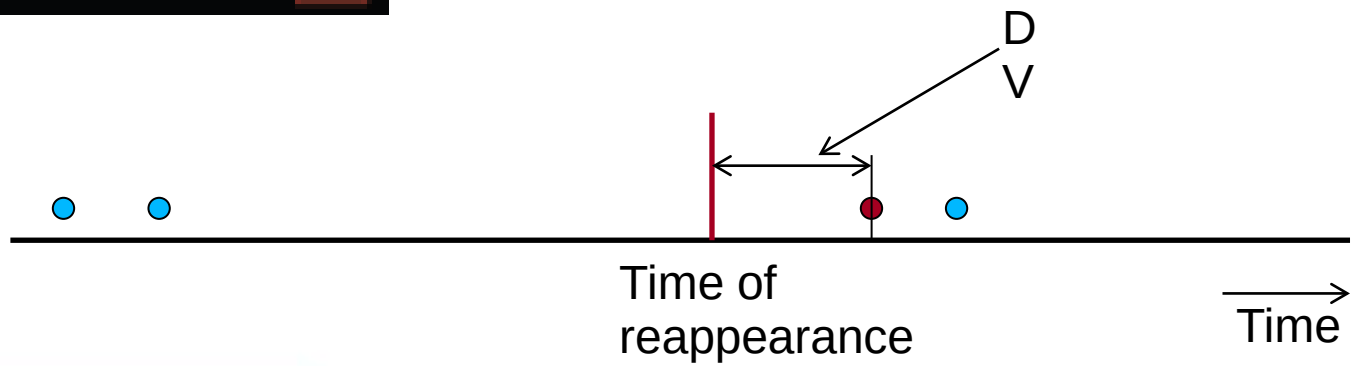
Development of Action Prediction



Development of Action Prediction

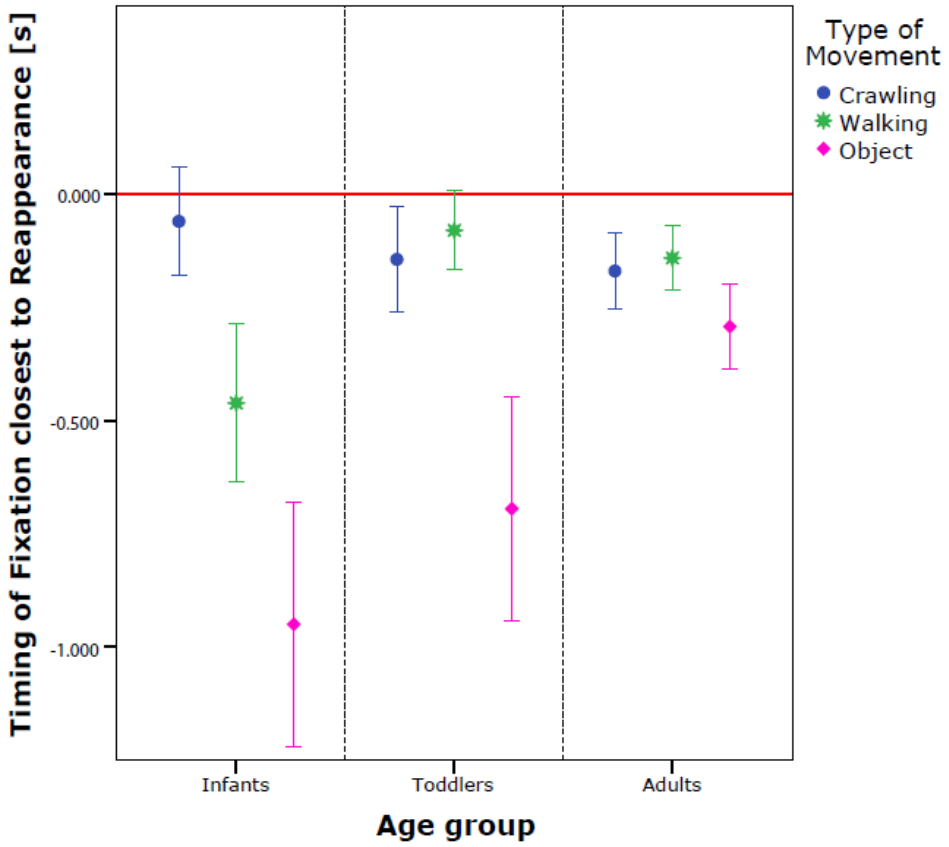
When?





Development of Action Prediction

Results



Stapel, Hunnius, Meyer, & Bekkering, submitted

Paulus, Hunnius, van Elk, & Bekkering (2012, *Developmental Cognitive Neuroscience*)

Action experience & action processing

Markus Paulus

- 8-month-old infants trained
  5 minutes a day for 1 week
- After training, their motor response to 3 different sounds was measured

Control sound

Non-action sound

Performed action sound

Paulus, Hunnius, van Elk, & Bekkering (2012, *Developmental Cognitive Neuroscience*)

Action experience & action processing

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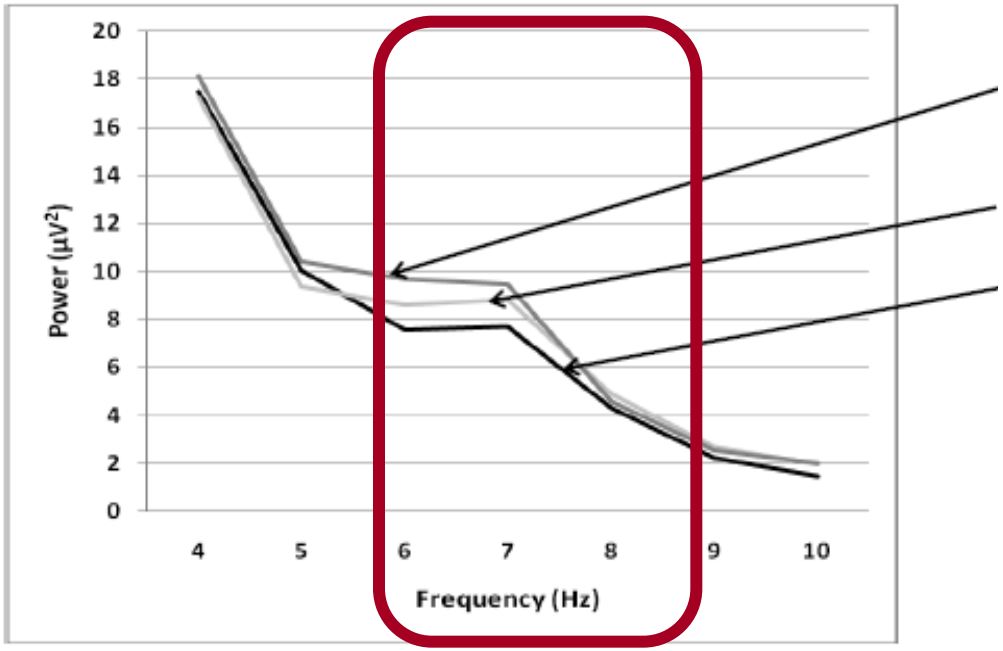

Social learning

Sabine Hunnius

- What can we learn from observations?

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Actions & objects

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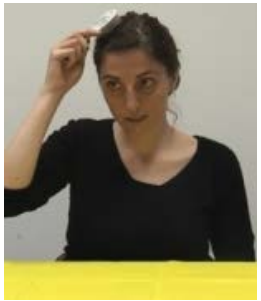
Can we socially learn about object locations?

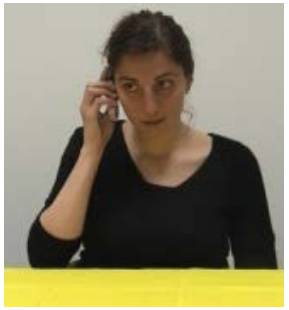
- Participants: **Infants (6-, 8-, 12-, 14-** and **16-month-olds)**
- Stimuli: Movies of a female actor using everyday objects (cup, brush, phone)
- correct goals vs. incorrect goals:

cup ➔ mouth	brush ➔ mouth
brush ➔ hair	phone ➔ hair
phone ➔ ear	cup ➔ ear

- 9 presentations of each movie, registration of eye movements





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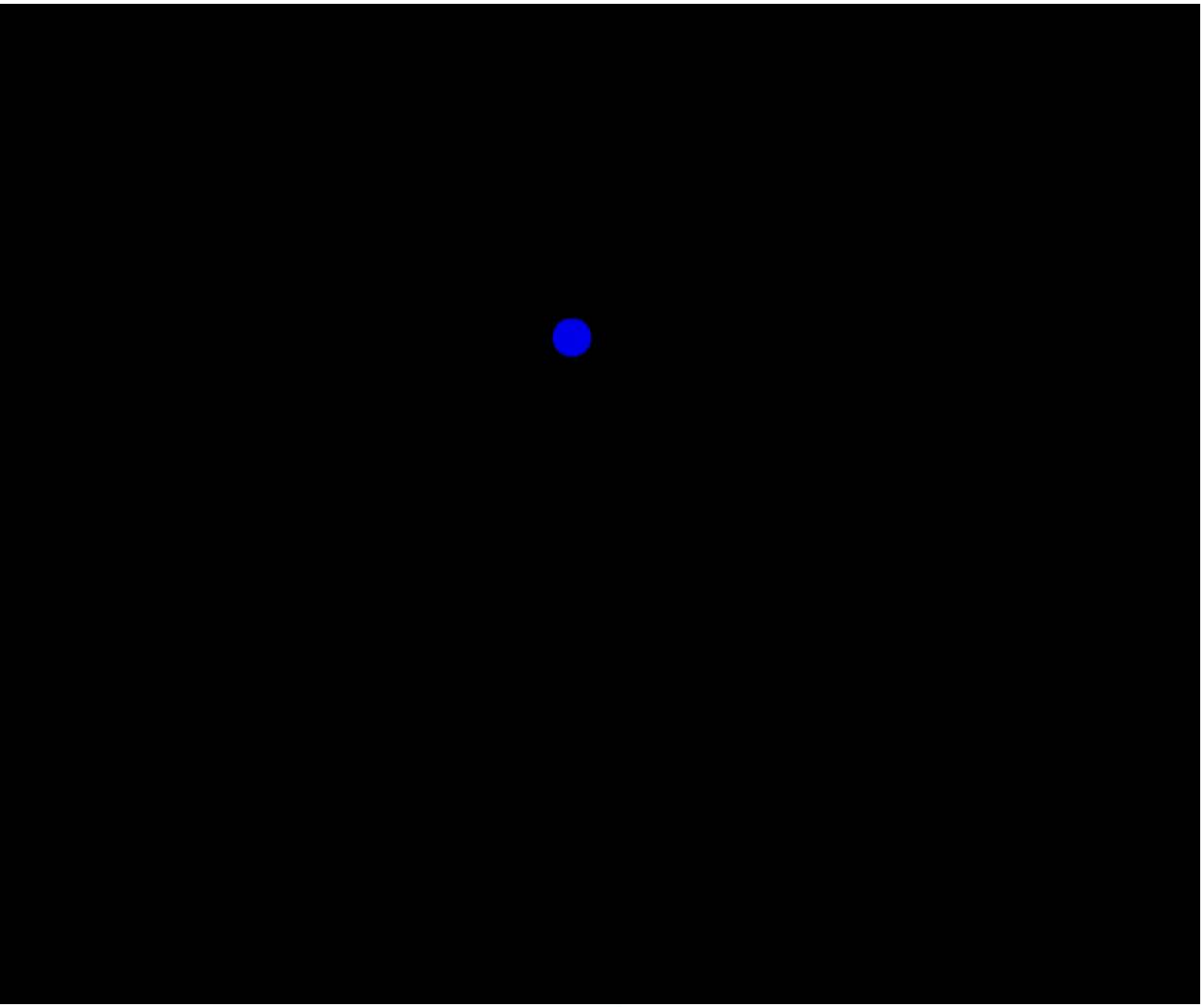
Predictive Looking



Anticipation: fixation in goal area while the object is **being lifted** (before goal area is reached)

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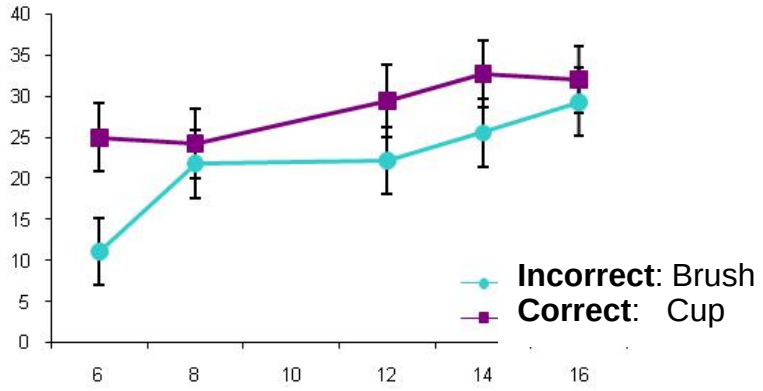
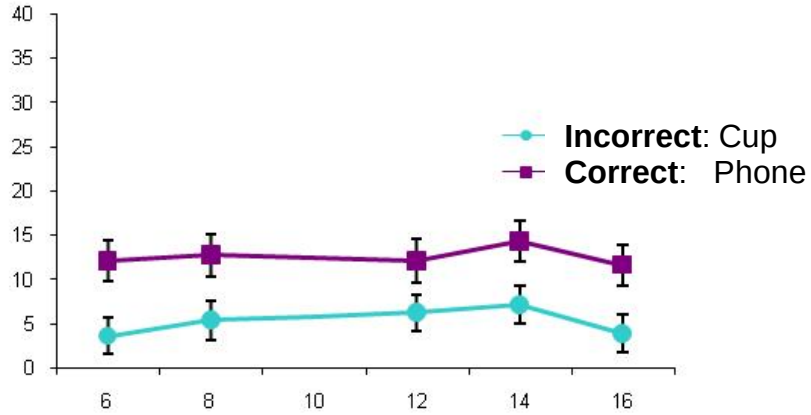
Actions & objects

Frequency of visual anticipations to

Mouth



Ear



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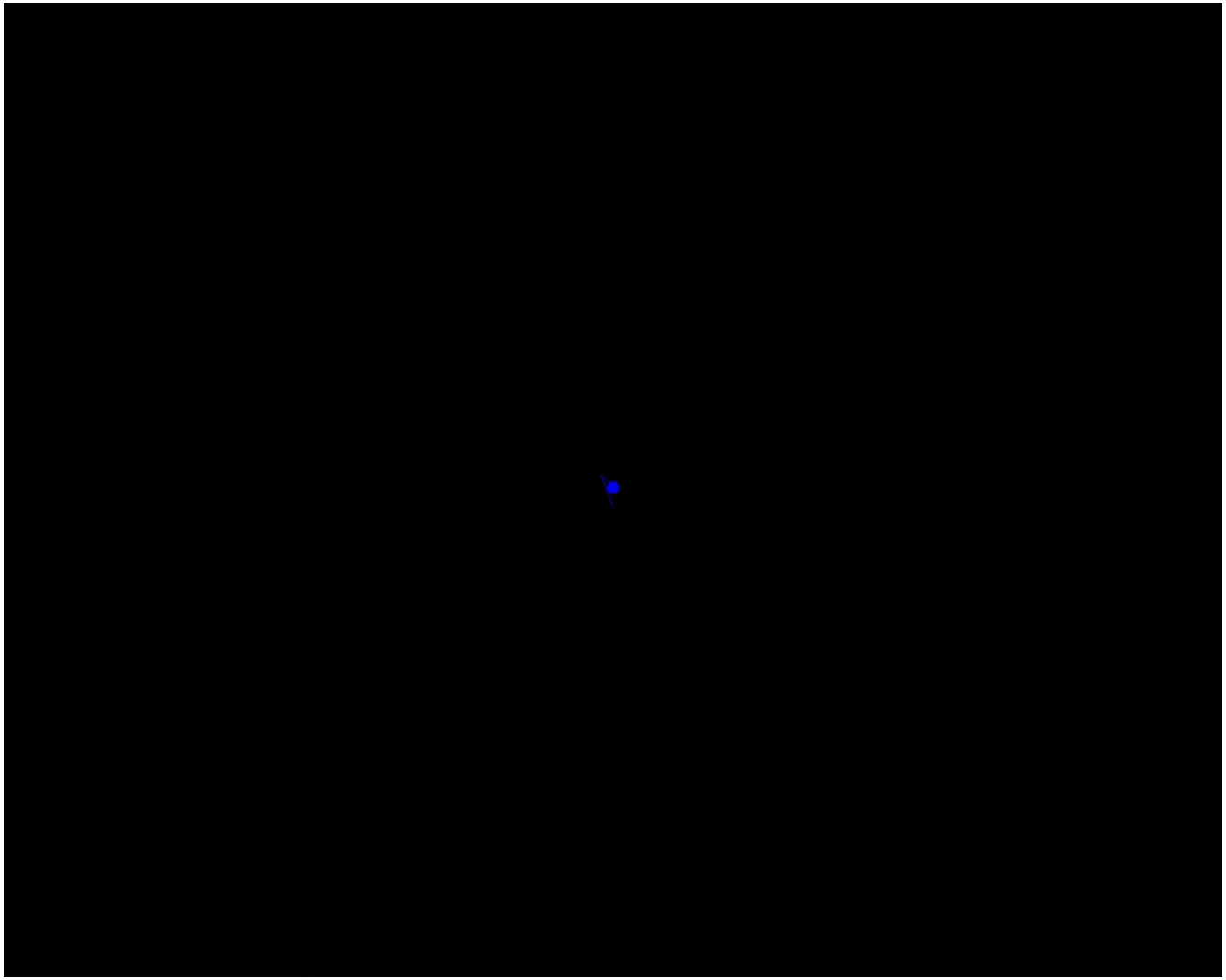
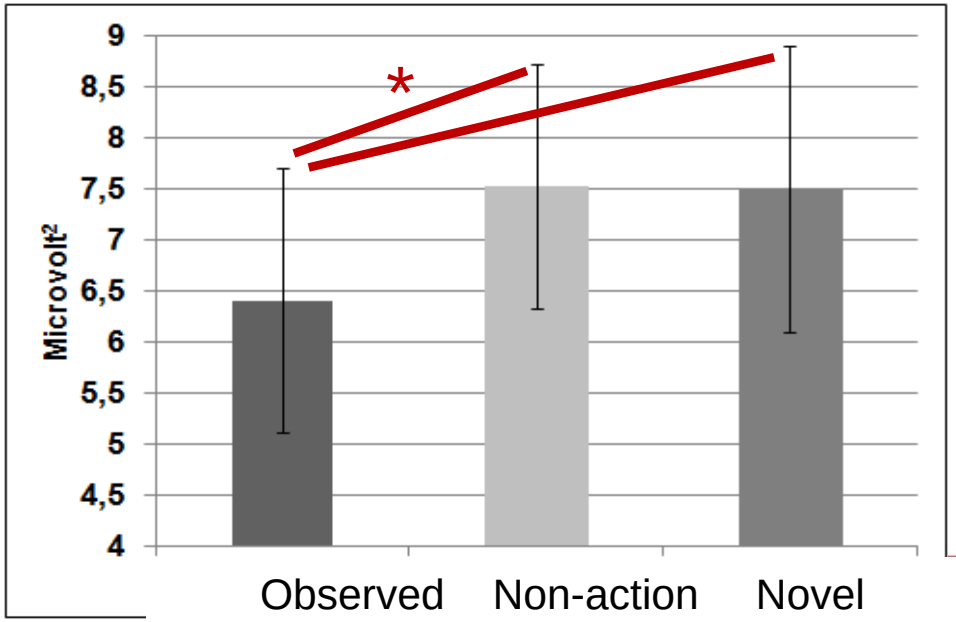
Anticipatory looks during incorrect trials



Paulus, Hunnius, & Bekkering (2013, *Social Cognitive and Affective Neuroscience*)

Observational experience, i.e. social learning

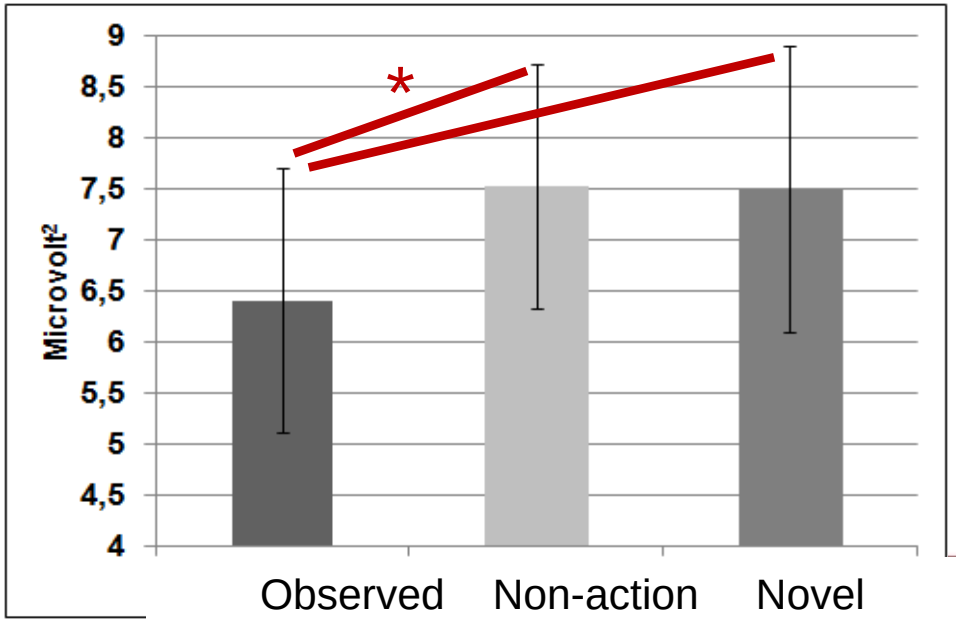
- 8- to 10-month-old infants received observational training of 5 minutes a day for 1 week
- Training contained of an action they could perform, but with a novel toy and action effect
- After training, their motor response to 3 different sounds was measured



Paulus, Hunnius, & Bekkering (2013, *Social Cognitive and Affective Neuroscience*)

Active vs observational experience

- Observational training can lead to new associations between sensory and motor representations, if the action is already in the infant's motor repertoire.



Comparing Active vs Observational learning

Sarah Gerson

- Test case: Tool-use Training
- Measure: EEG
  - Power of mu frequency bands: 6-9 Hz at this age
  - Greater suppression (i.e., less power) in these bands over central brain regions reflects more motor activity in the brain

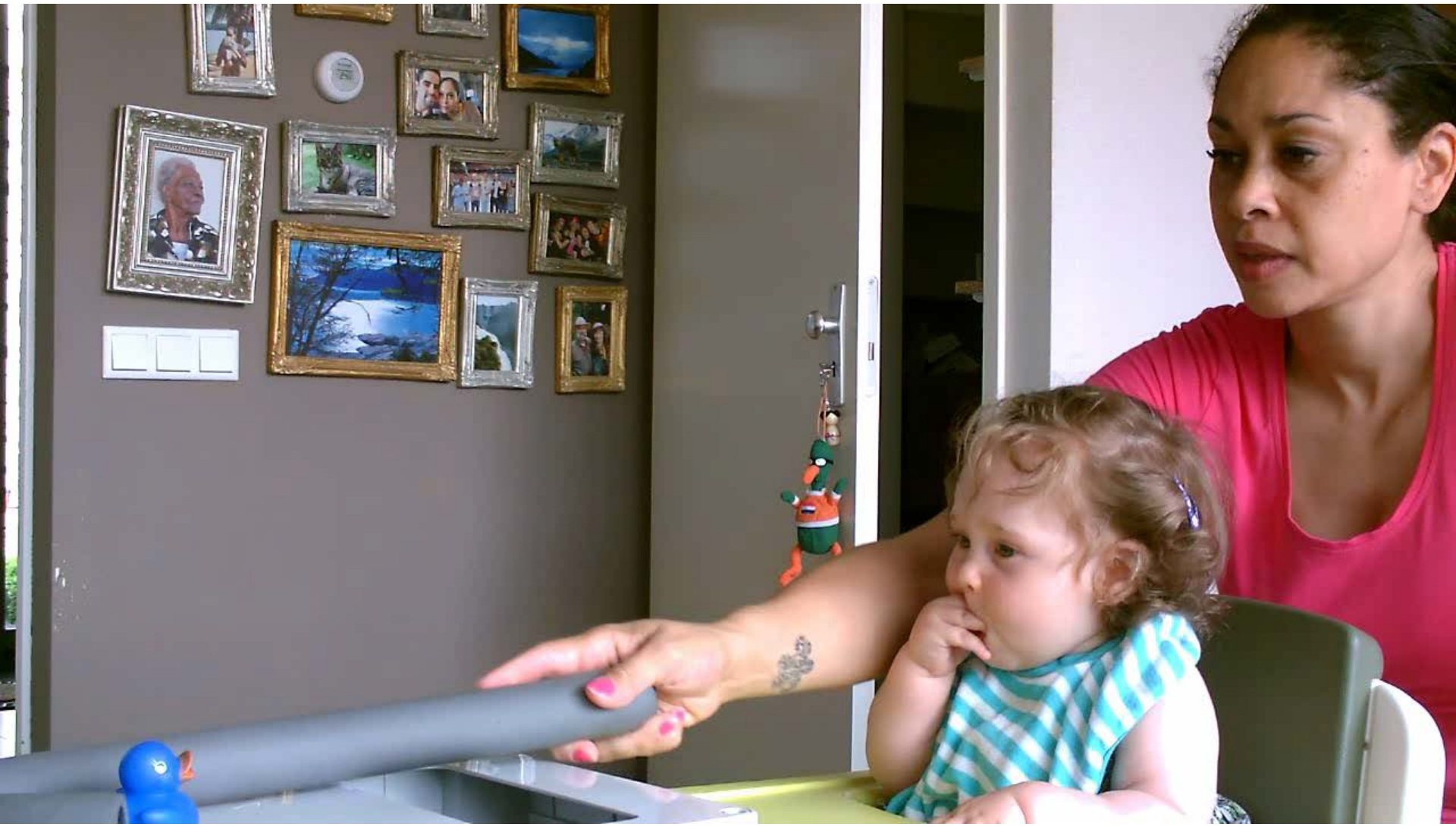
    (Marshall & Meltzoff, 2012)

Learning Procedure

- 10-month-old infants (n = 30)
- Approximately one week training session

Observational learning

- 10-month-old infants (n = 30)
- Approximately one week training session

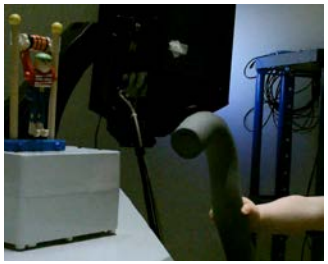


Training Results

- Compare frequency power in sounds associated with motorically learned and observed actions relative to a novel sound
- More motor activation for sounds associate with active learning than those associated observational learning

*$p < .05$
Gerson, Bekkering, & Hunnius, under review

Effects of Individual Differences in Training



No Success

Success with Parent

Success by Self

Between subjects differences during final session

Interim Discussion

- Evidence for learning by doing as well by observing
  - Modulation of the motor system is dependent upon active experience
  - Effects of individual experience in motor learning are evident in the motor system during action perception

Comparing predictions in action observation with language comprehension

Edita Poljac

- Two questions:

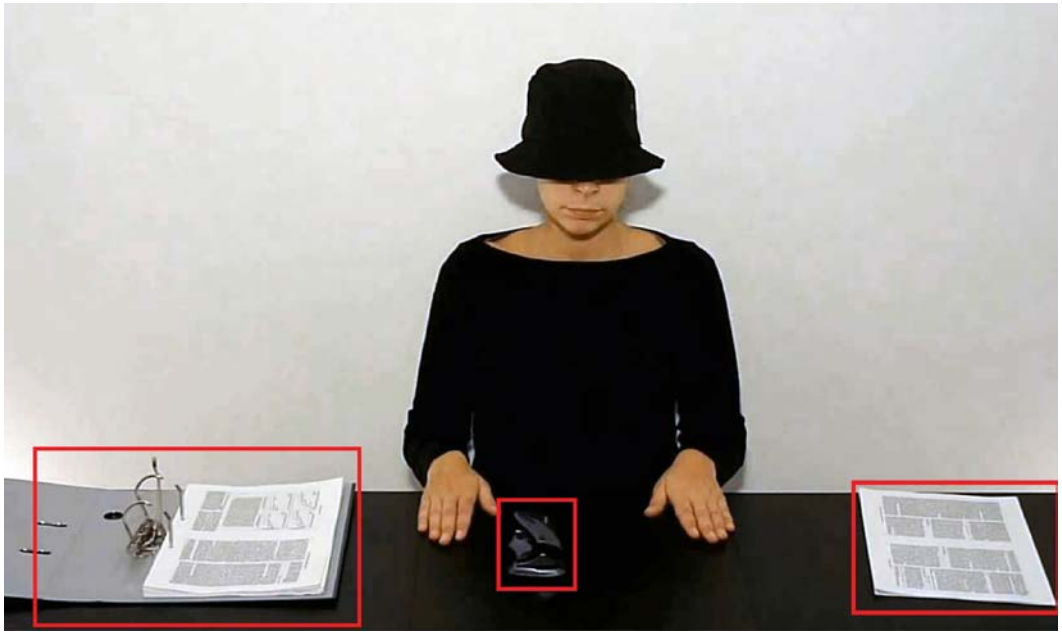
1. Are predictions when listening about a certain action comparable to observing this action performed?

2. Are predictions based on movement related mechanisms only, or also based on conceptual knowledge beyond the one-to-one-mapping?

Poljac, Dahlslätt, & Bekkering
Language and Cognitive Processes, 2013

Experimental set-up

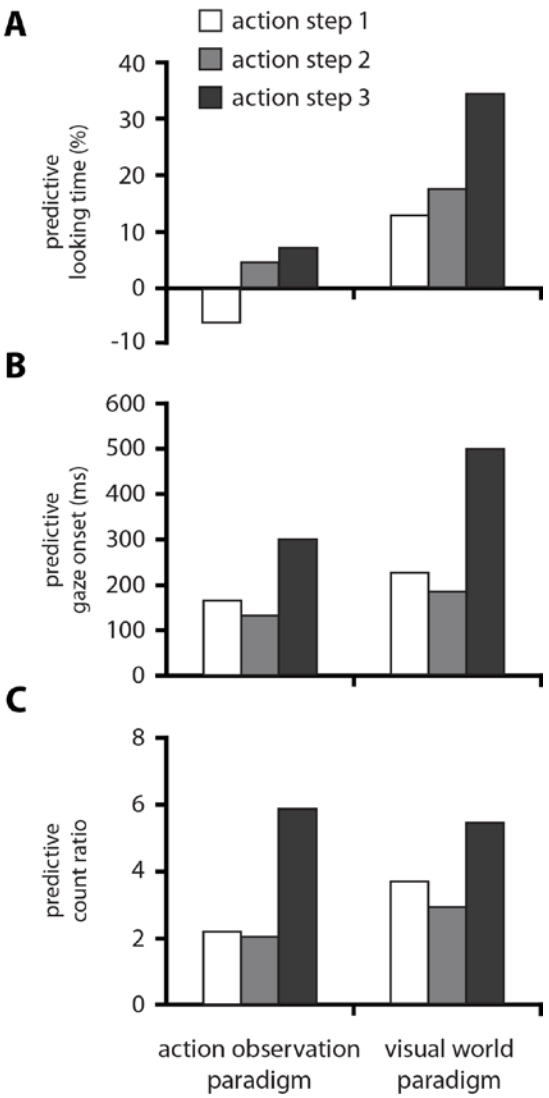
- Two paradigms:
  1. action observation (video)
  2. visual world paradigm (picture + auditory stream)
- Task: observe and indicate if an action fails (catch trials)



'The girl **takes** carefully a bunch of paper and **slides** it in the hole puncher. Then she punches holes in it and **puts** it in the ring binder'.

Experimental set-up

Predictive eye gazes



- predictions in both action and language
- the patterns of predictive eye movements are similar for action and language
- the anticipations are significantly larger for the final action in both tasks

Discussion: Anticipatory eye movements in Language and Action

- Similar predictive eye movements are observed in both tasks, suggesting that the same generative model is used for predictions in language comprehension and action observation, but ... this needs to be properly tested: neuroimaging, different populations of patients.

- The predictions are not purely based to a feedforward mechanism of the ongoing movements, rather they might refer to the inclusion of higher prior knowledge along the action observed/heared, i.e. conceptual knowledge, see also talk of Sasha Ondobake in the Manual Action symposium.

-

The ability to predict other individuals' behavior does not purely rely on proprioceptive predictions

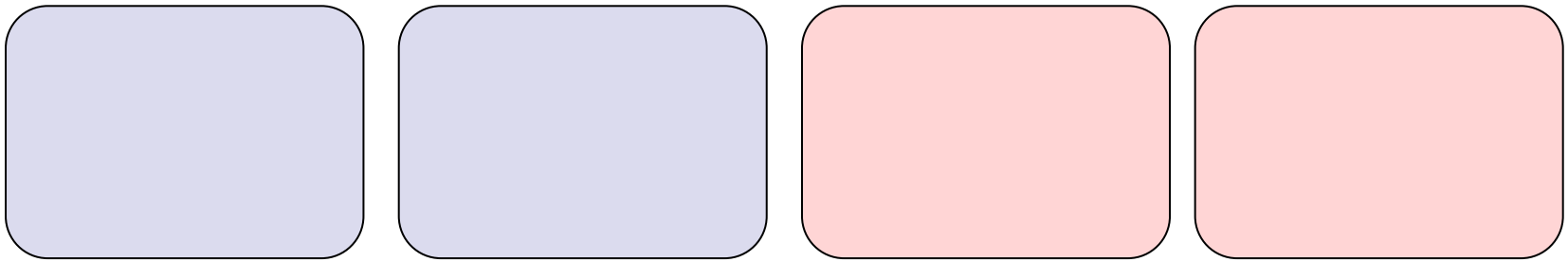
Interplay between conceptual and perceptual processes

Sasha Ondobaka

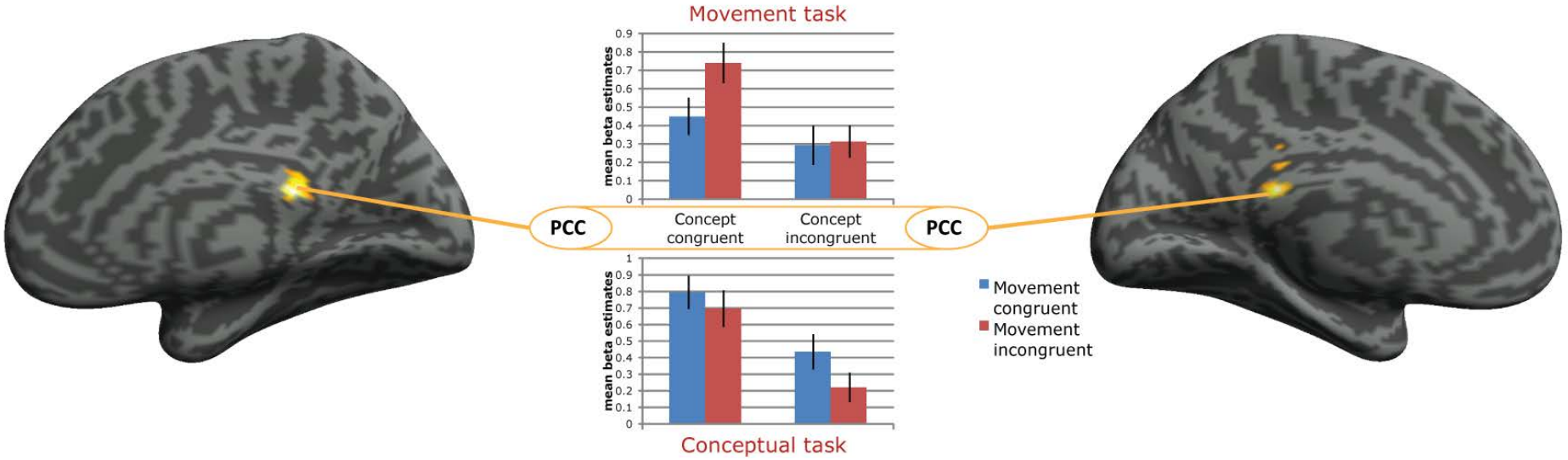
Aim: Examine the neural bases of the interplay between conceptual and movement processes in action inference.

- Does predictive processing of observed movements depend on conceptual expectations about the purpose of involved objects?

Task x Conceptual-congruency x Movement-congruency



Conceptual congruent > incongruent (overall)

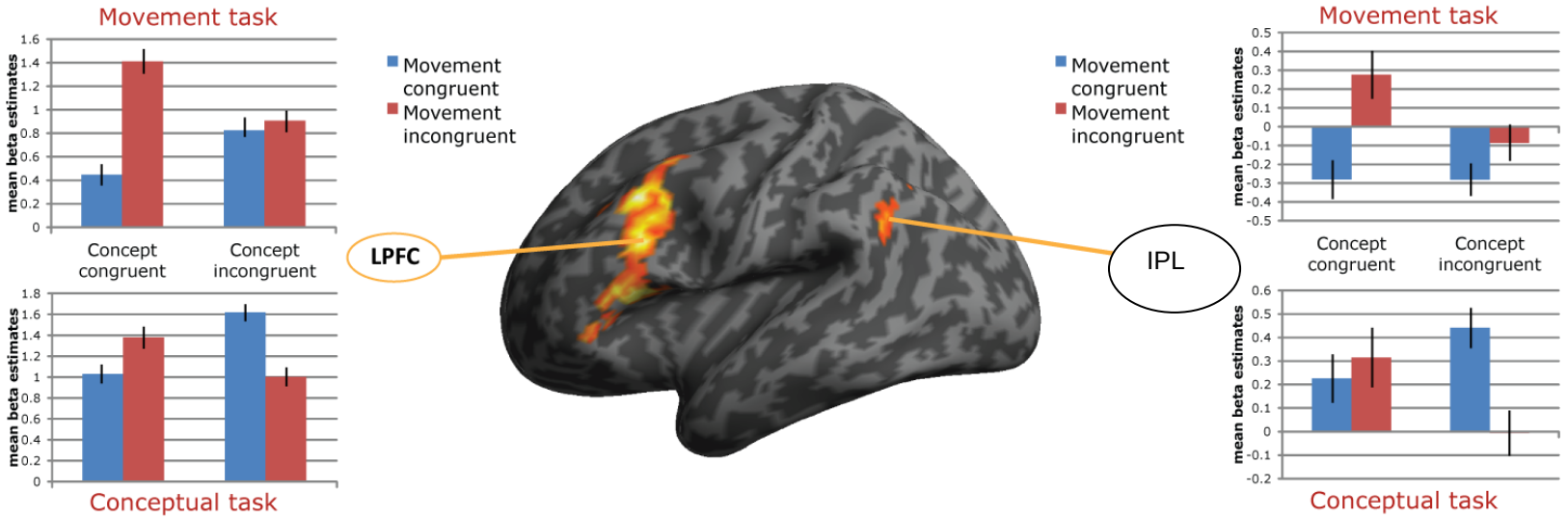


movement task

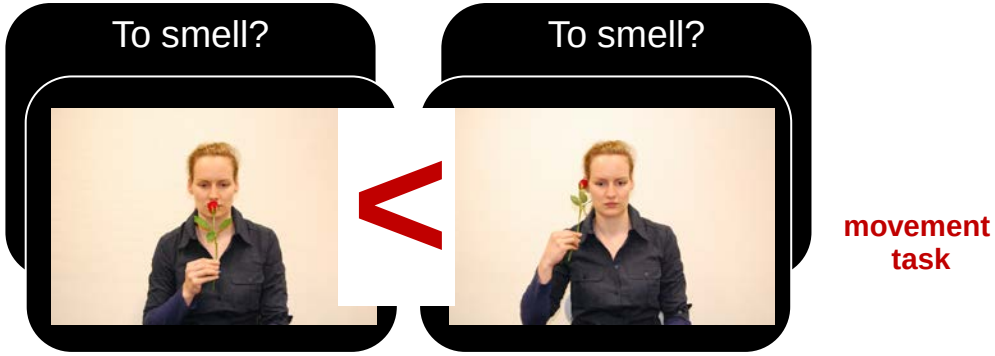
conceptual task

Ondobaka *et al.* (Cereb. Cortex, 2014)

Movement incongruent > congruent (for conceptually congruent)



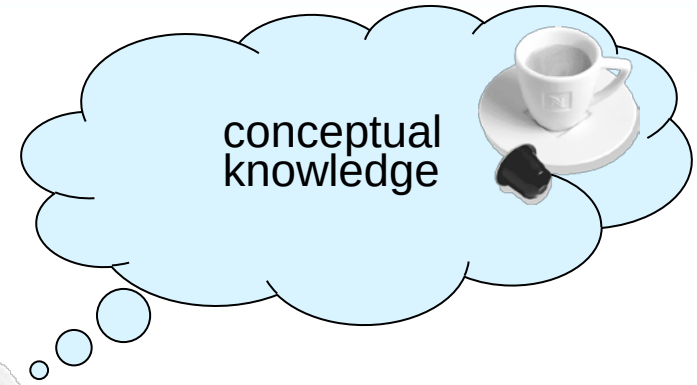
All results are thresholded voxel-wise at $p < .001$ and corrected for multiple comparisons using family-wise error correction with the threshold of $p < .05$



movement task

Ondobaka *et al.* (Cereb. Cortex, 2014)

Combining conceptual and perceptual knowledge

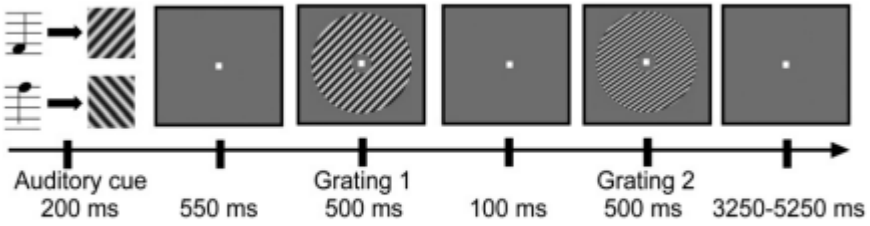


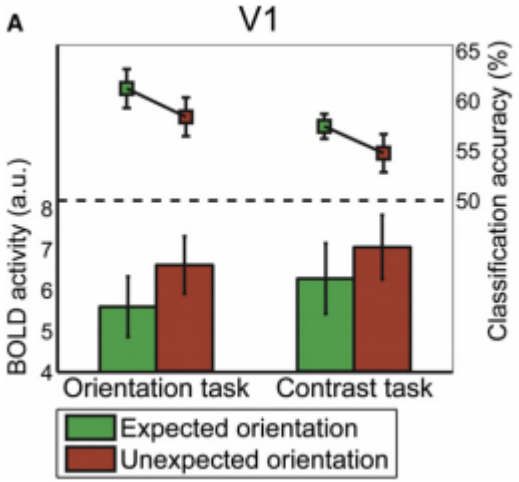
Action understanding relies on predictions from observer's conceptual knowledge, rather then pure direct perceptuo-motor information about concrete movements.

Perception of concrete movement goals is contingent on the observer's prior conceptual action knowledge.

Perceptuo-motor information

Future predictions





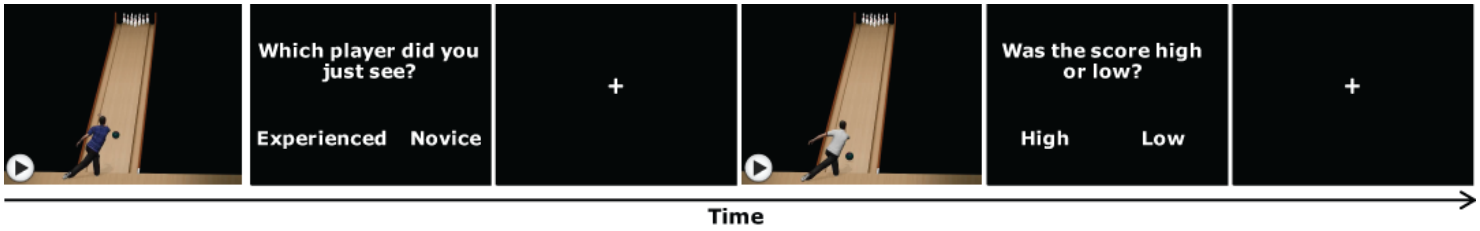
Kok et al., Neuron, 2012

Investigating internal models for higher perception

- Participants watch bowling animations with two different agents:
  - Experienced player: high score in 75% of trials
  - Novice player: low score in 75% of trials

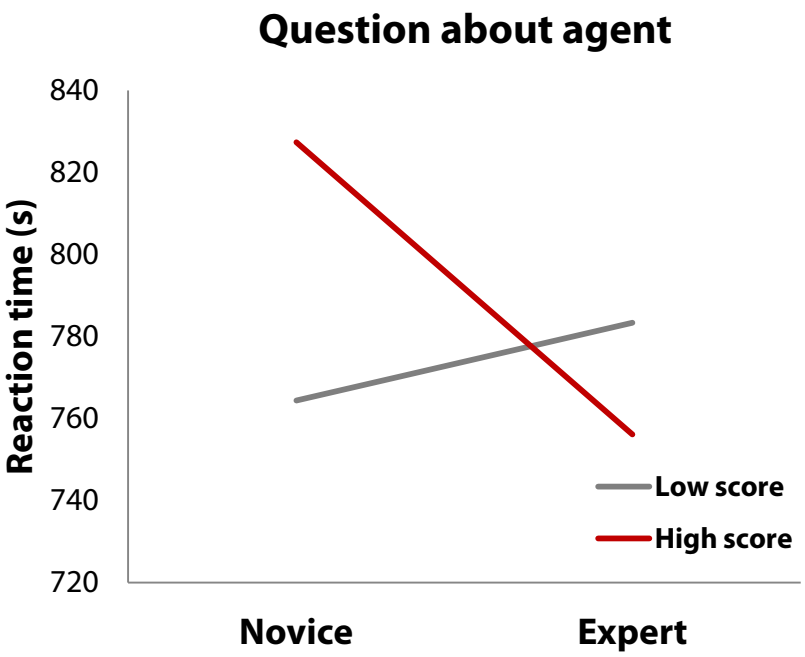
Experiment

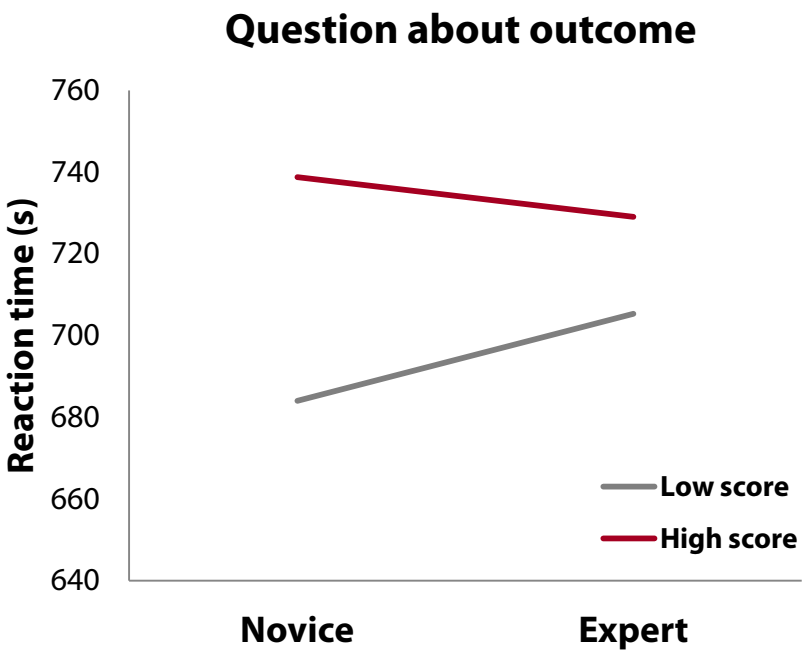
- Participants answer one out of two questions:
  - Which player did you just see?
  - Was the score high or low?



- Short training to induce expectations in subjects

- Subjects watch 288 bowling movies: 75% expected, 25% unexpected


Question about agent
Reaction time (s)
840
820
800
780
760
740
720
Low score
High score
Novice
Expert


Question about outcome
Reaction time (s)
760
740
720
700
680
660
640
Low score
High score
Novice
Expert

Longer reaction time for unexpected outcomes suggest that you integrate information about the performance of a certain agent over time to make predictions.

Current issues are:

Is there a hierarchy in the integration of information about agents and objects at the kinematic as well as outcome level (fMRI and MEG studies are performed)

Similarly, we have language prediction studies going on in which we investigate if and how language can facilitate perceptual predictions.

Sum up

- Natural development provides great opportunities to investigate action prediction and (social) learning in general.

- We can learn associations from others, but we are more accurate if we can simulate the actions with our own motor system, suggesting that we use motor predictions when observing others.

- Predictions in language are very comparable to predictions in action observation, more work is needed to understand the role of language in action prediction, particularly when it comes to conceptual knowledge.

- Intentions are about the relationship between objects and agents. The predictive hierarchy might start with knowledge about agents to predict at a lower level what goal-directed action to expect.

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Studies done with

BabyBRAIN Group

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Review

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One contribution of 19 to a Theme Issue 'Mirror neurons: fundamental discoveries, theoretical perspectives and clinical implications'.

What are you doing? How [illegible] observational experience shape infants' action understanding

Sabine Hunnius and Harold Bekkering

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From early in life, infants watch other people's actions. How do young infants come to make sense of actions they observe? Here, we review empirical findings on the development of action understanding in infancy. Based on this review, we argue that active action experience is crucial for infants' developing action understanding. When infants execute actions, they form associations between motor acts and the sensory consequences of these acts. When infants subsequently observe these actions in others, they can use their motor system to predict the outcome of the ongoing actions. Also, infants come to an understanding of others' actions through the repeated observation of actions and the effects associated with them. In their daily lives, infants have plenty of opportunities to form associations between observed events and learn about statistical regularities of others' behaviours. We argue that based on these two forms of experience—active action experience and observational experience—infants gradually develop more complex action understanding capabilities.

Action and Neurocognition group http://www.nici.ru.nl/anc

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GRANTS: NWO TOP, Brain-and-Cognition, Gravitation
Donders (TopTalent)
EU - ITN

Stan van Pelt

Lea Hald