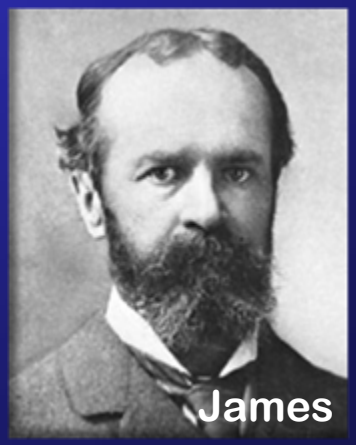
Becoming an intentional agent: The emergence of voluntary action

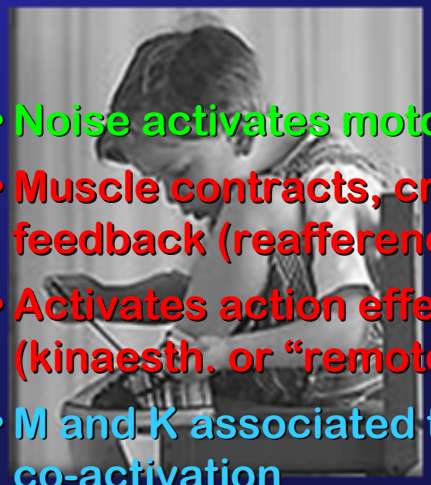
Bernhard Hommel

Leiden University Institute for Psychological Research
& Leiden Institute for Brain and Cognition
The Netherlands

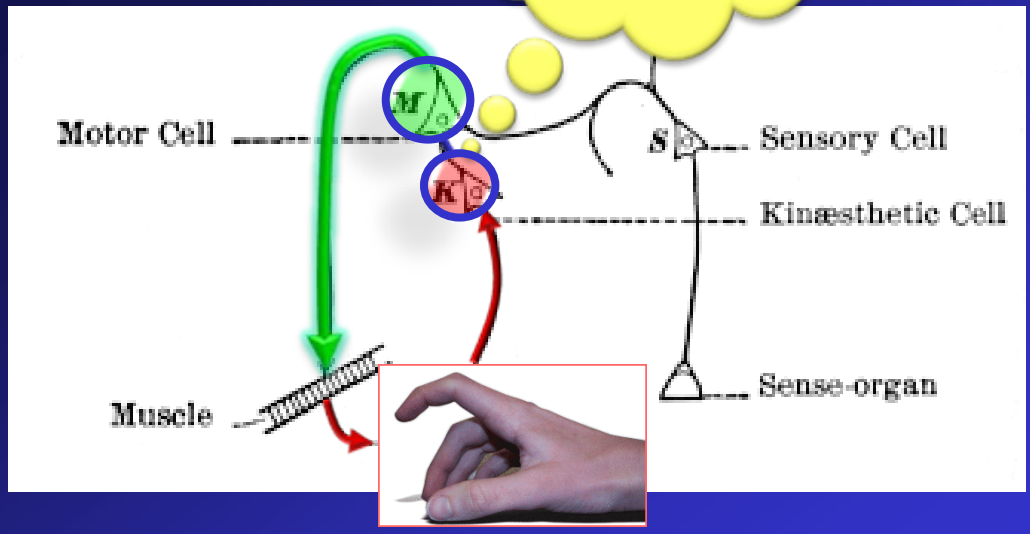
How do you tie your shoe?



…every representation of a movement awakens in some degree the actual movement which is its object… (James, 1890)

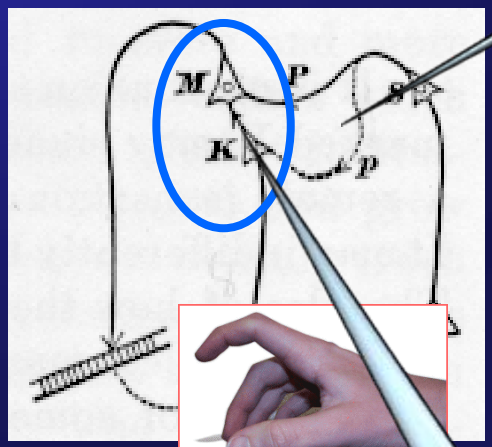


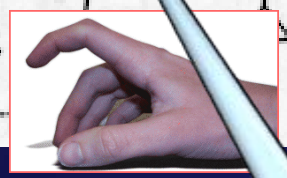
- Noise activates motor pattern M
- Muscle contracts, creates sensory feedback (reafference)
- Activates action effect code K (kinaesth. or "remote")
- M and K associated through repeated co-activation
- "Imaging/anticipating" K (effect) can now trigger M → intentional action



Acquiring action effects (means-ends associations)

Experimental rationale





- introduce novel action effect (R→E)
- its code should become associated with movement (r←→e)
- activating effect code should prime motor pattern (e→r)

Hommel (1996). The cognitive representation of action: Automatic integration of perceived action effects. *Psychological Research*.

Action-effect acquisition in adults

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L I B C

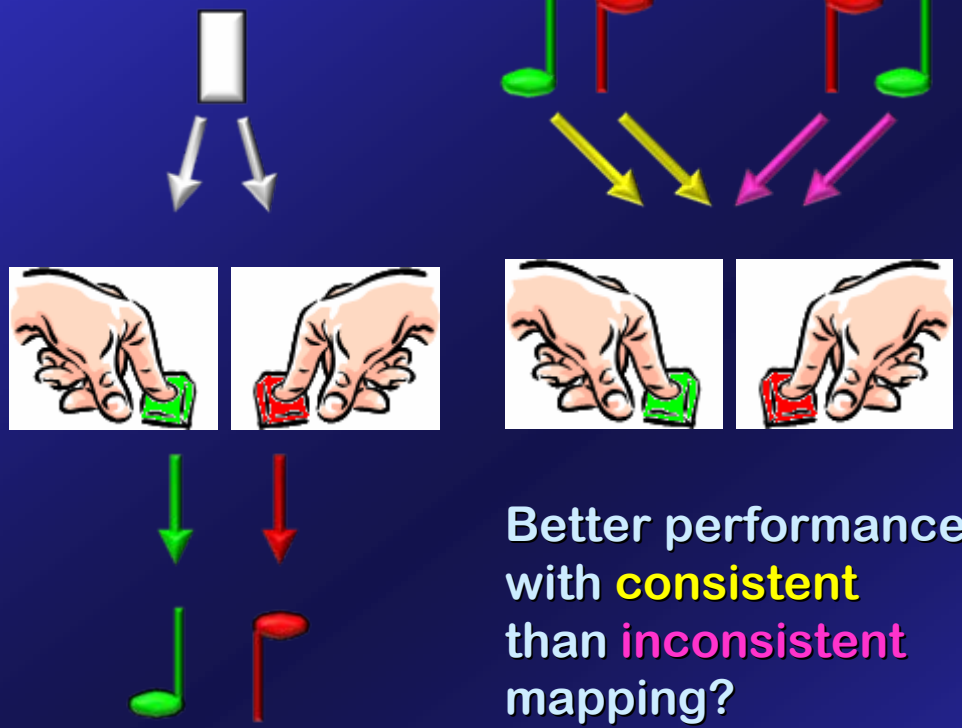
Acquisition Phase
(free choice)

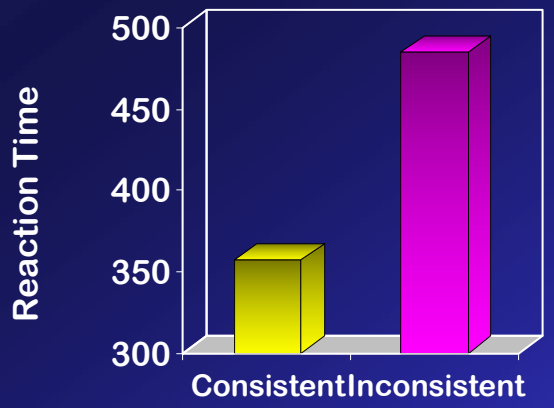
Transfer Phase
(forced choice)

Stimuli

Responses

Effects





Better performance with **consistent** than **inconsistent** mapping?

Indeed, transfer shows better performance with **consistent** than **inconsistent** mapping

Elsner & Hommel (2001). Effect anticipation and action control. *Journal of Experimental Psychology: Human Perception and Performance.*

Action effects prime “free” choice

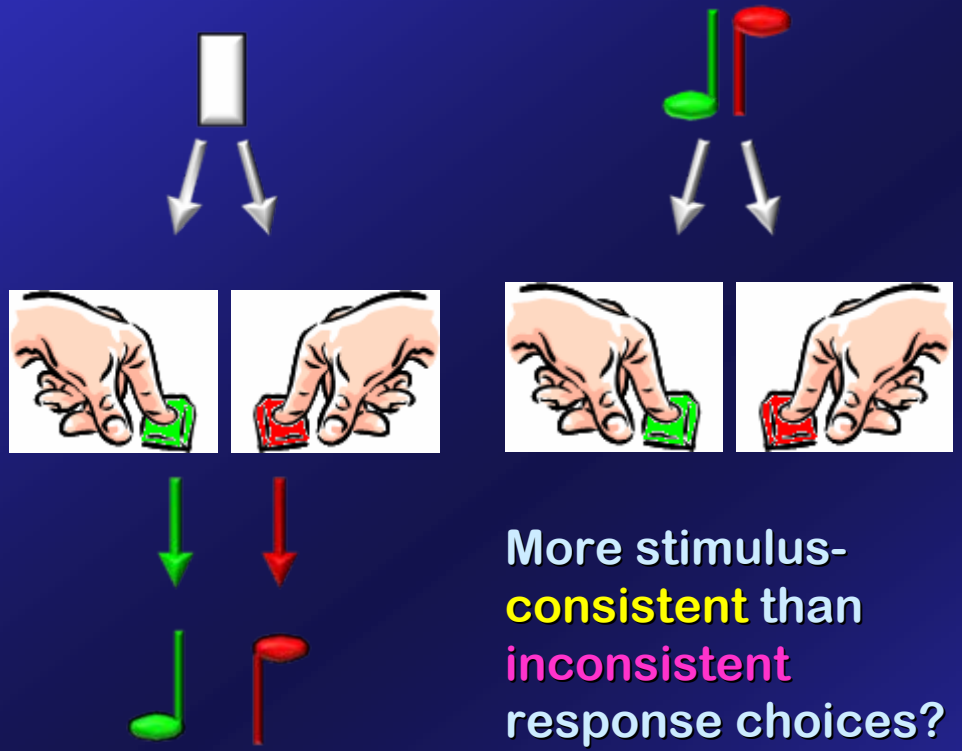
Acquisition Phase *(free choice)*

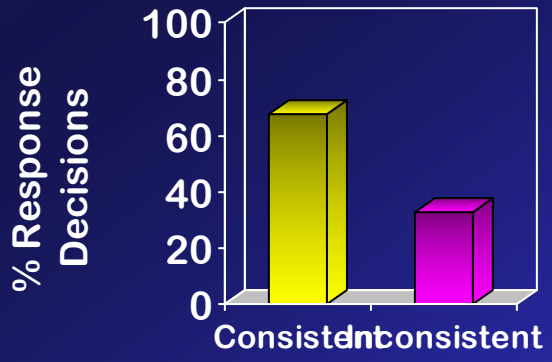
Transfer Phase *(free choice)*

Stimuli

Responses

Effects





More stimulus-**consistent** than **inconsistent** response choices?

Free choice shows more **consistent** than **inconsistent** response choices

Elsner & Hommel (2001). Effect anticipation and action control. *Journal of Experimental Psychology: Human Perception and Performance.*

Action-effect acquisition in children

Rena Eenshuistra

Maaike Weidema

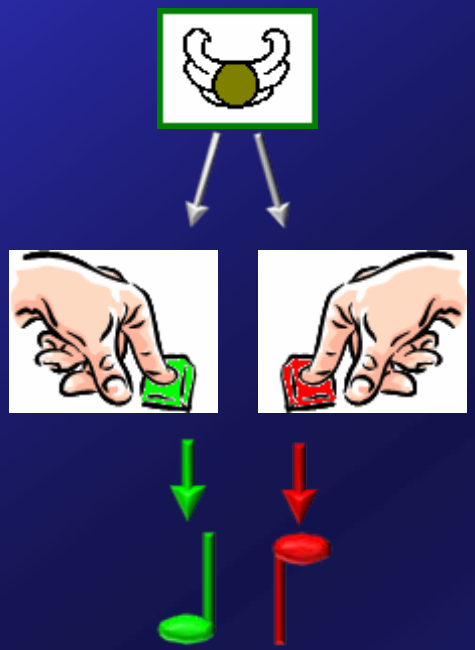
Acquisition Phase
(free choice)

Instruction: respond when snitch is caught

Stimulus

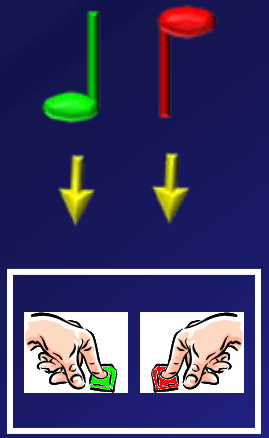
Responses

Effects



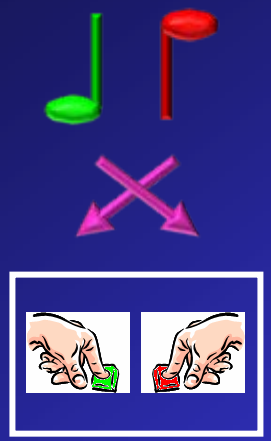
Transfer Phase
(forced choice)

Instruction: when magic hat talks:



consistent

or

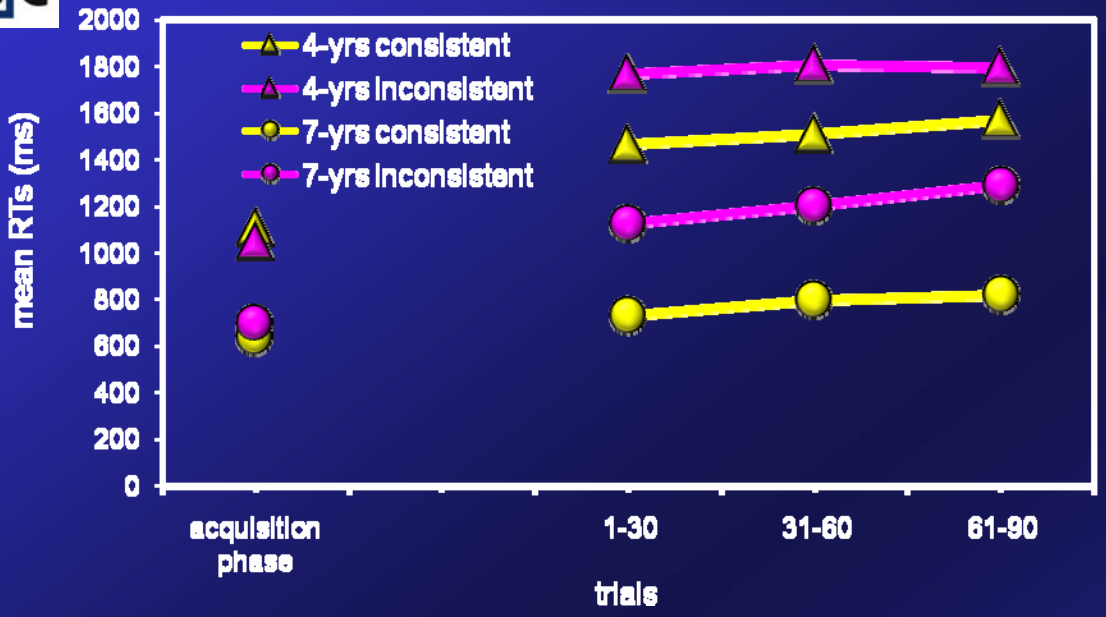


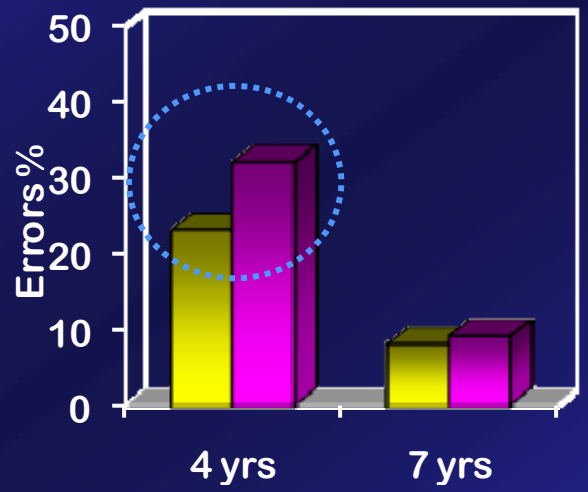
inconsistent

- Better performance with consistent than inconsistent mapping?

Eenshuistra, Weidema & Hommel (2004). Development of the acquisition and control of action-effect associations. *Acta Psychologica*.

Action-effect learning in (4-7y old) children

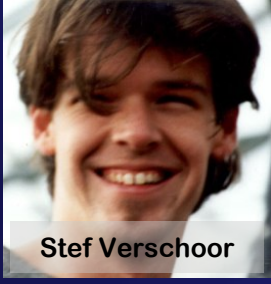




- Indeed, transfer yields better performance with **consistent** than **inconsistent** mapping
- Independent of age…?
- Larger consistency effect in 4-yr-olds
- due to "goal neglect" (➔frontal-lobe development)?

Eenshuistra, Weidema & Hommel (2004). Development of the acquisition and control of action-effect associations. *Acta Psychologica.*

Action-effect acquisition in infants



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L I B C

Acquisition

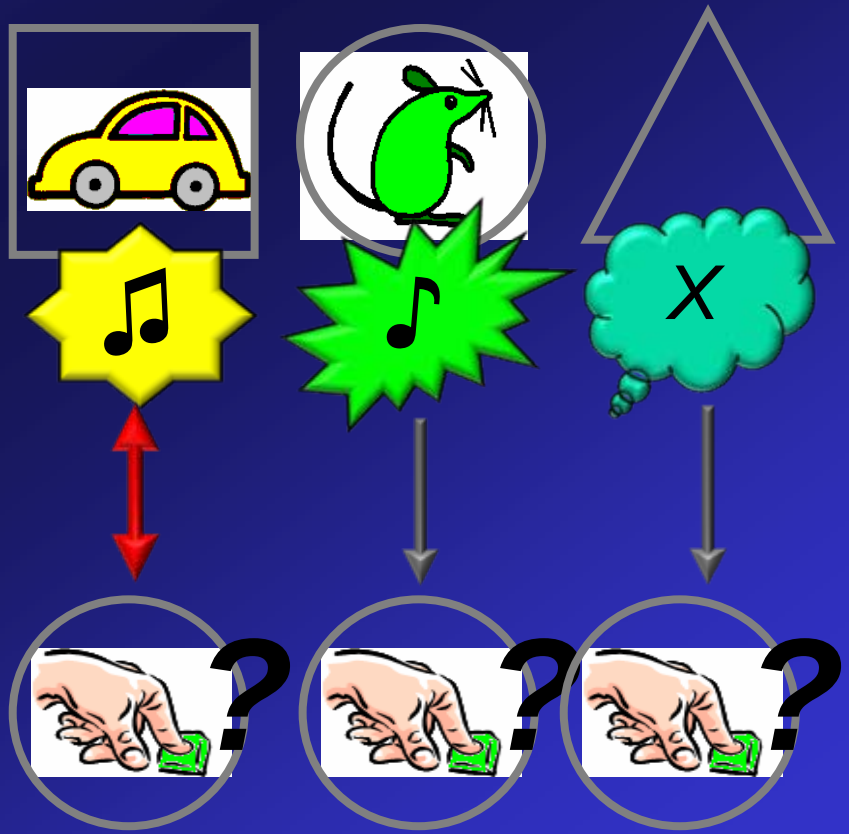
Baby watches (10 x)

Baby 'acts' (10 x)

B R E A K

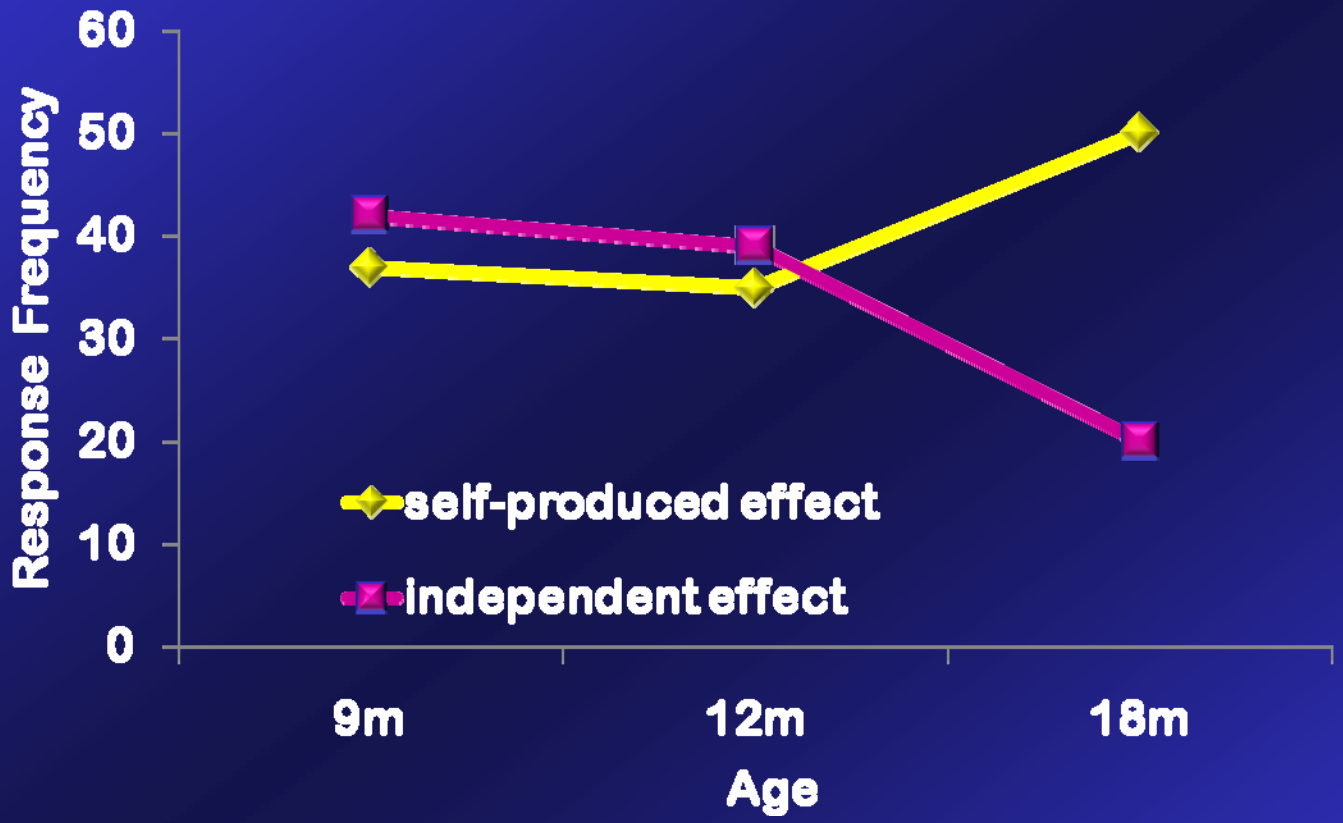
30 sec

Test (3 trials, order balanced)



Verschoor, Weidema, Biro & Hommel (submitted). Acquisition of action-effect associations in infancy.

Action-effect acquisition in infants

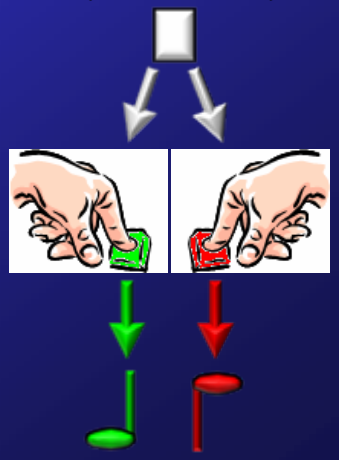


- No reliable transfer in 9-12 year-olds!?
- ≠ Rovee-Collier, Watson
- More difficult transfer (context)?
- Weak STM?

Verschoor, Weidema, Biro & Hommel (submitted). Acquisition of action-effect associations in infancy.

Locating action effects in the human brain

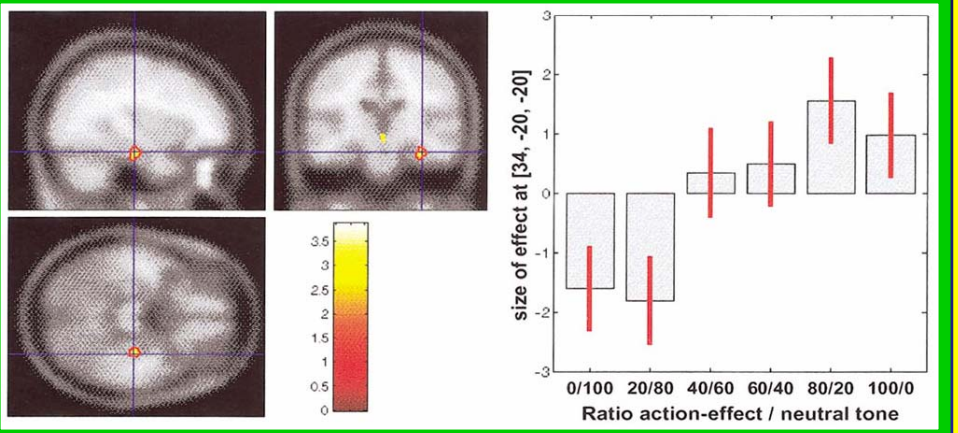
Acquisition Phase
(free choice)



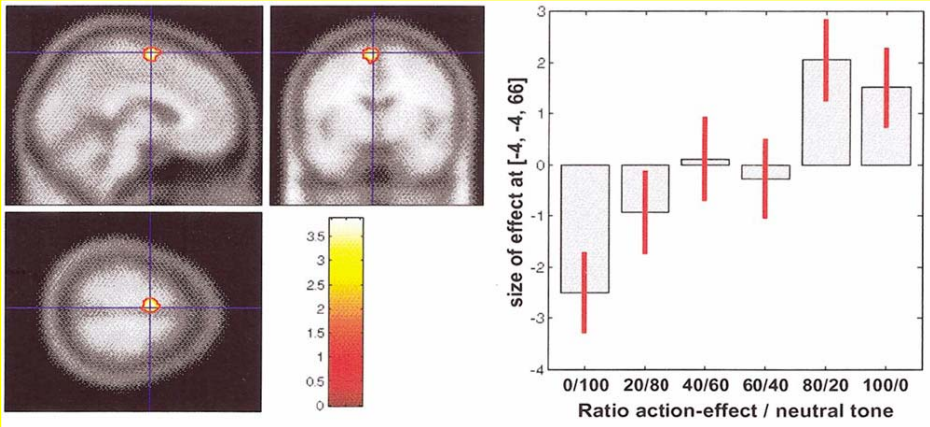
Transfer Phase
(tone monitoring)

12 PET scans, parametric design: 0%, 20%, 40%, 60%, 80%, 100% effect tones

- **Hippocampus: storing action-effect associations**



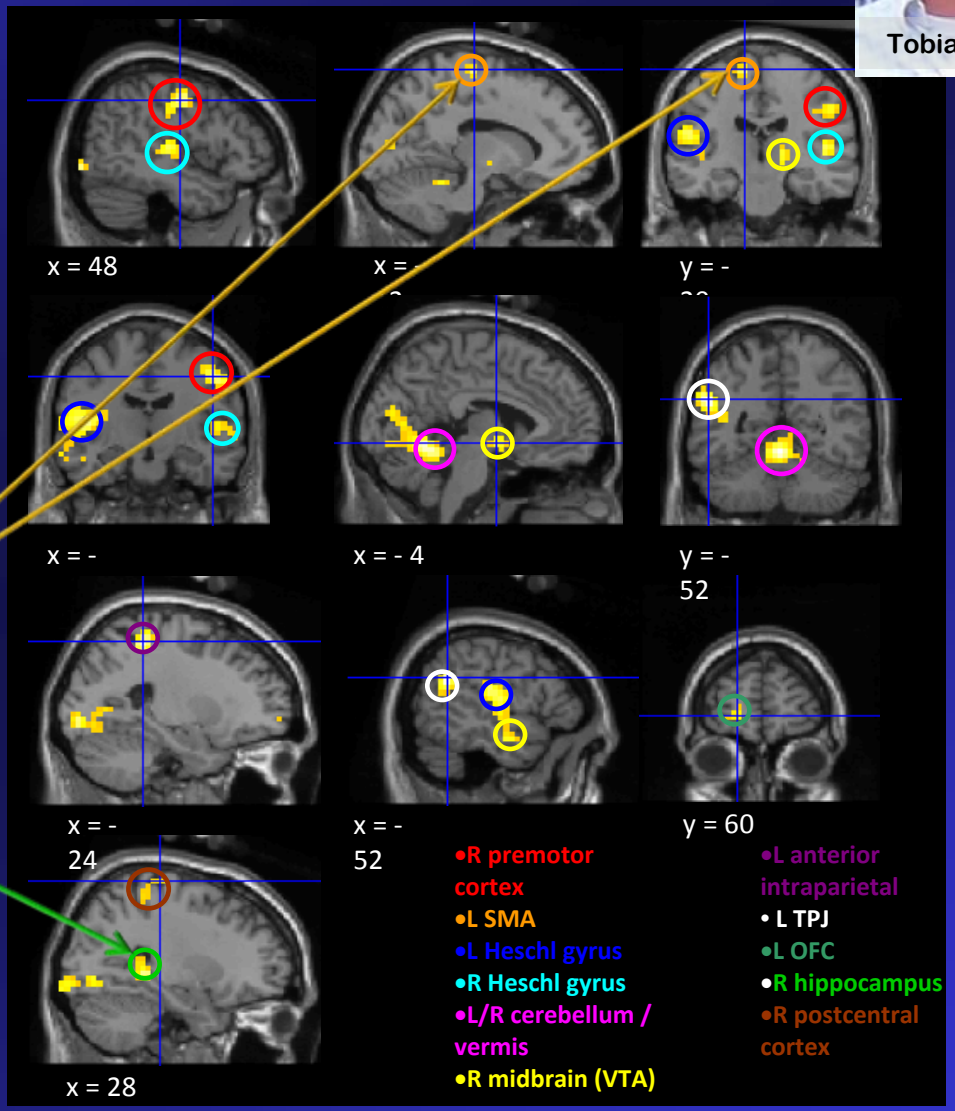
- **Rostral Supplementary Motor Area (SMA) proper: housing plans for voluntary actions**



Elsner, Hommel, Mentschel, Drzezga, Prinz, Conrad, & Siebner, H. (2002). Linking actions and their perceivable consequences in the human brain. *NeuroImage*.

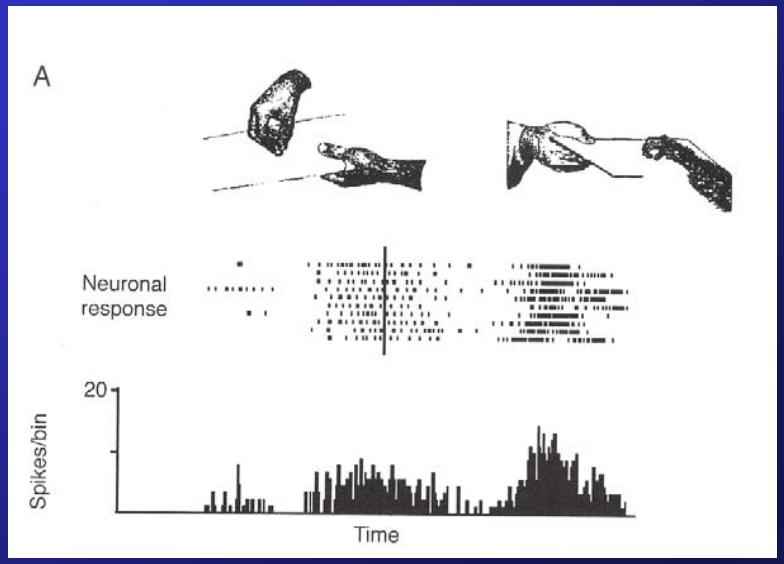
Locating action effects in the human brain

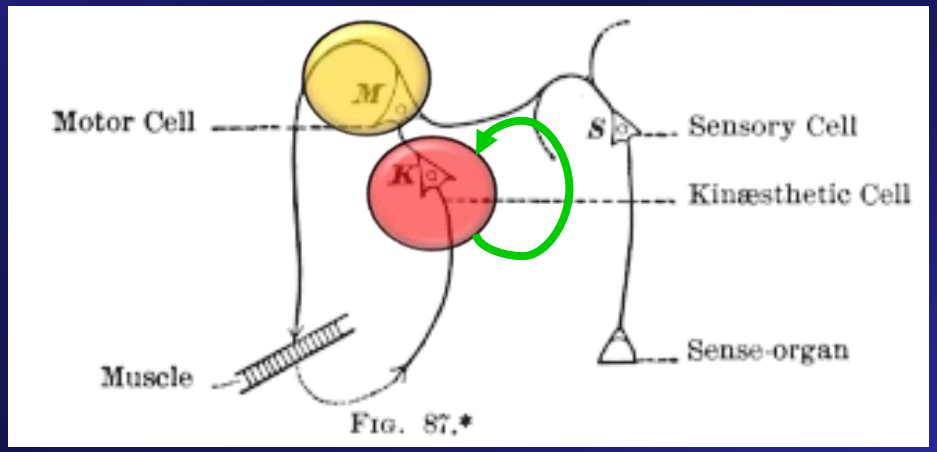
- SMA: houses plans for voluntary actions
- Hippocampus: storing action-effect associations



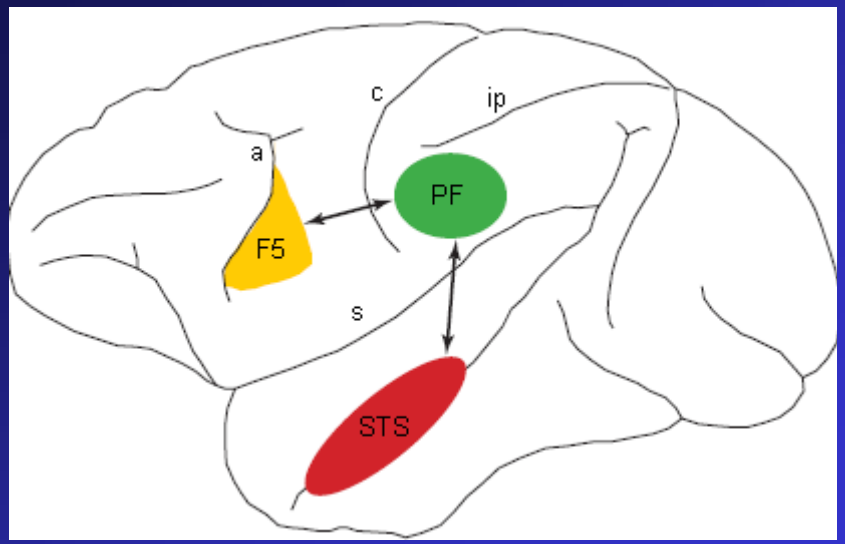
Melcher, Weidema, Eenshuistra, Hommel & Gruber (2007). The neural substrate of the ideomotor principle: An event-related fMRI analysis. *NeuroImage.*

Mirror neurons or mirror system?

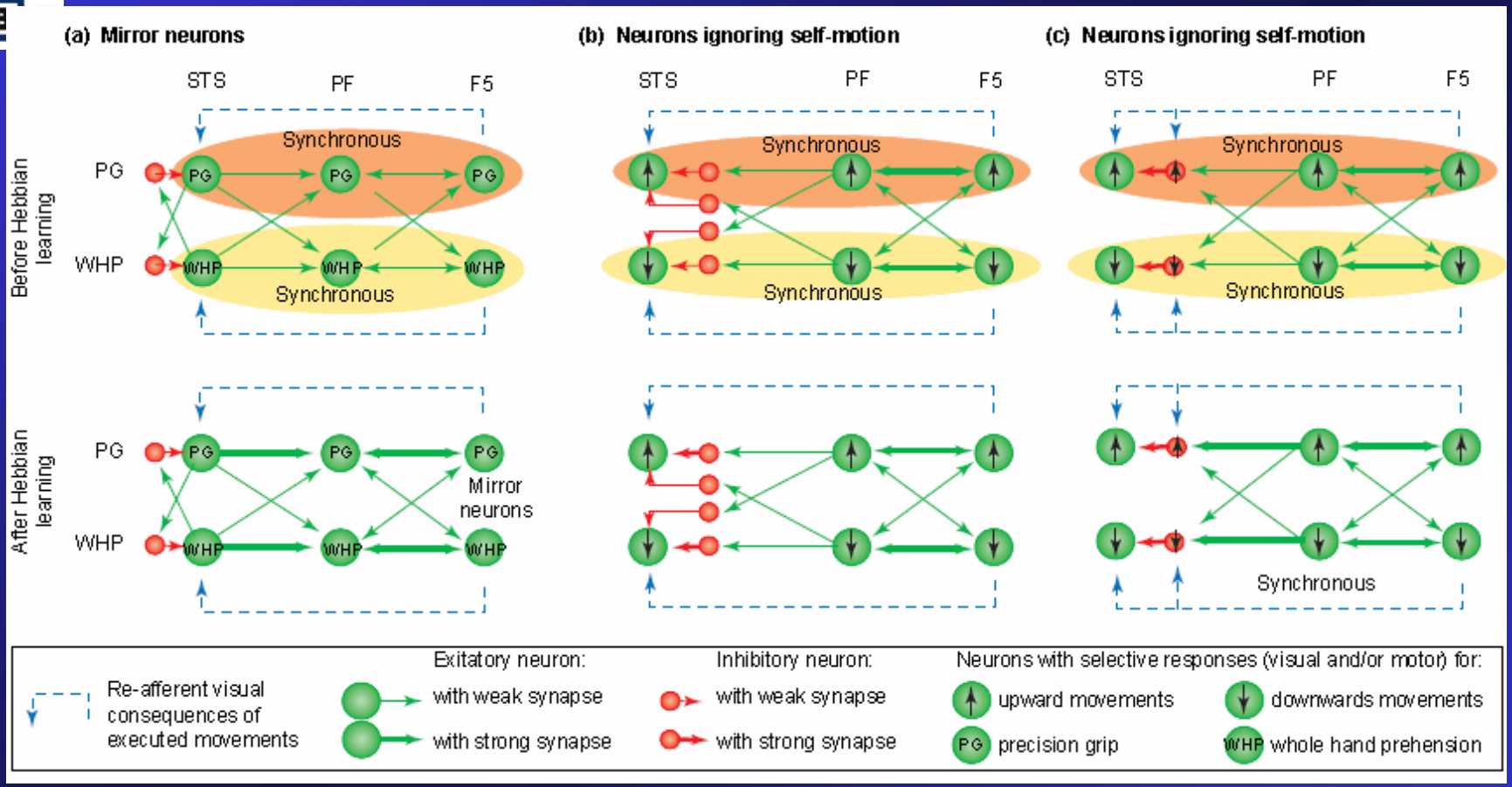




F5/SMA: action program
PF (inferior parietal cortex):
differentiating self from other
STS (superior temporal sulcus):
integration of action effects



Keysers & Perrett (2004): Acquiring mirror neurons



- Perceiving oneself while acting associates action and effect
- Action-effect integration produces mirror neurons (James!)
- Intermodal integration!

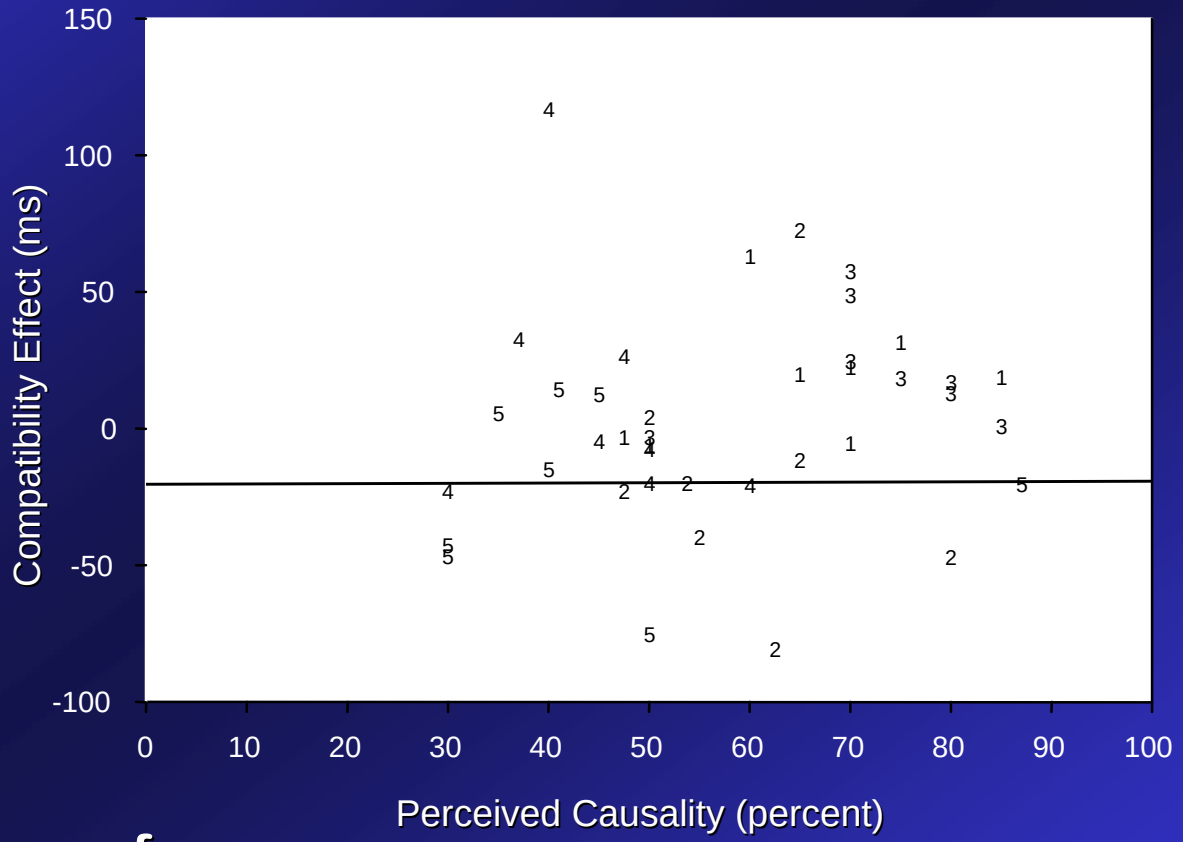
Preconditions for action-effect acquisition

Acquisition as by-product of acting and exploration

Acquisition as result of intentional search for means to an end

AE learning does not depend on causal perception

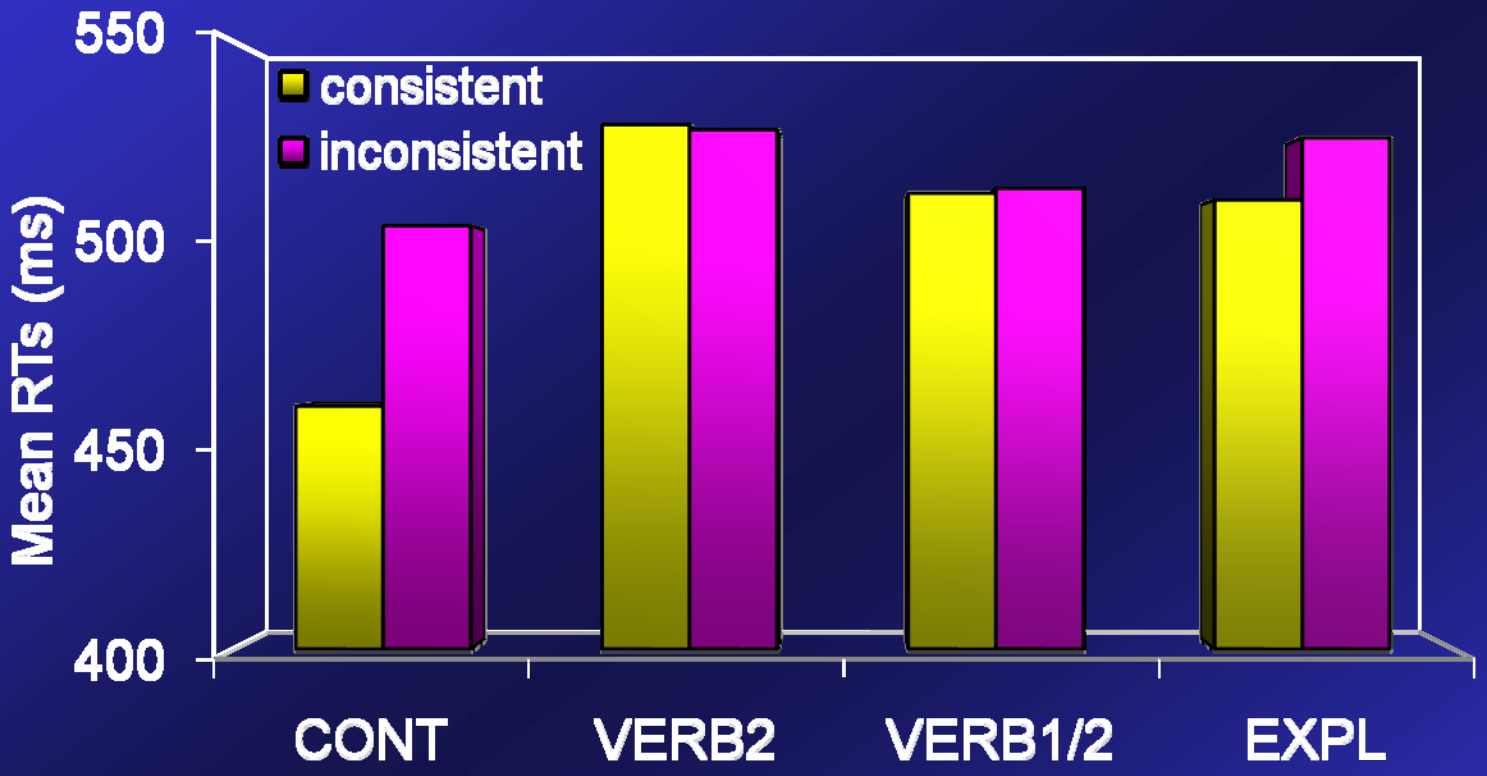
No correlation between learning and causal perception



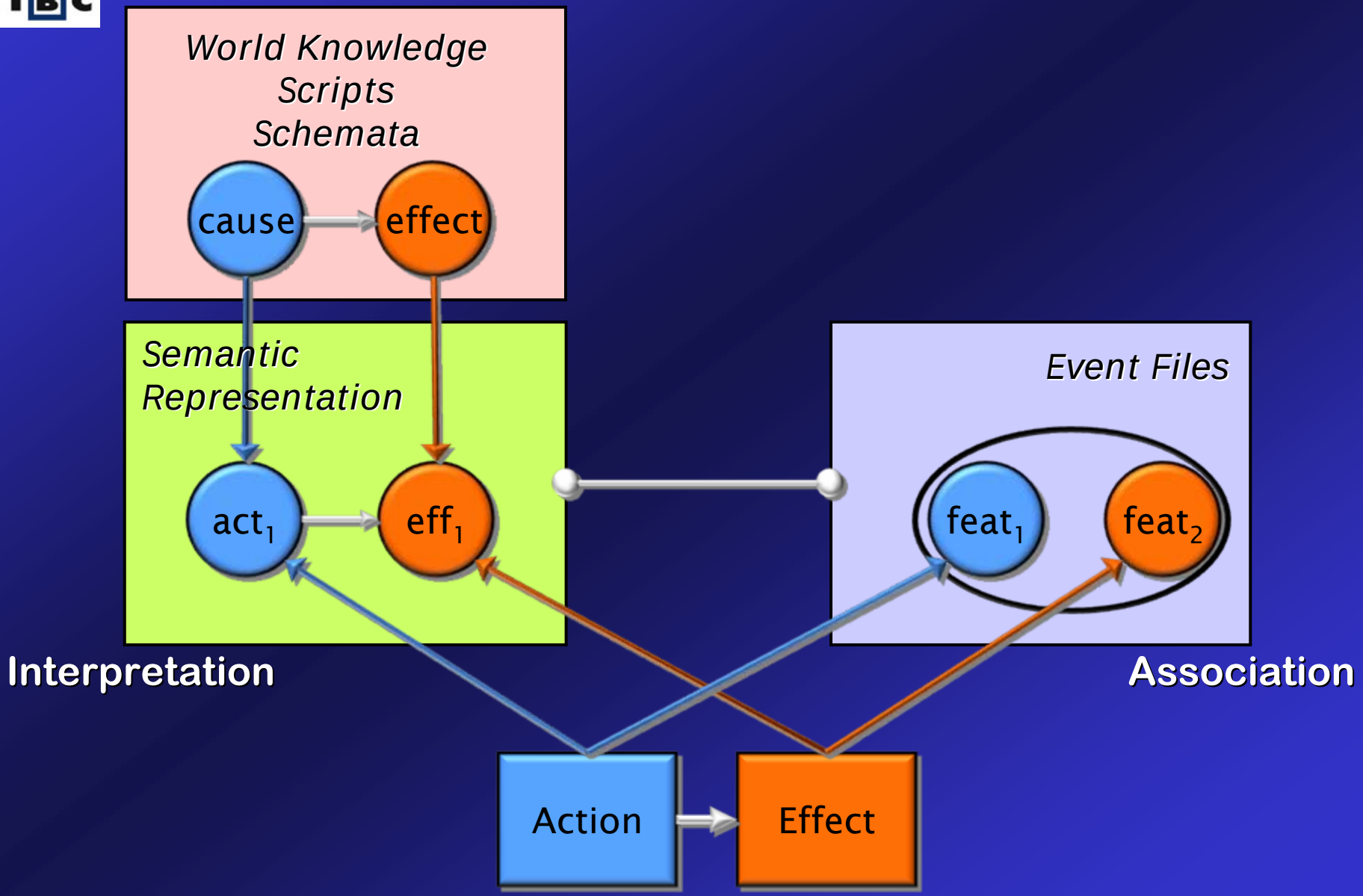
Learning even in absence of insight into systematic relationship (Hommel, Alonso & Fuentes, 2003)

Elsner & Hommel (2004). Contiguity and contingency in the acquisition of action effects. *Psychological Research*.
Hommel, Alonso & Fuentes (2003). Acquisition and generalization of action effects. *Visual Cognition*.

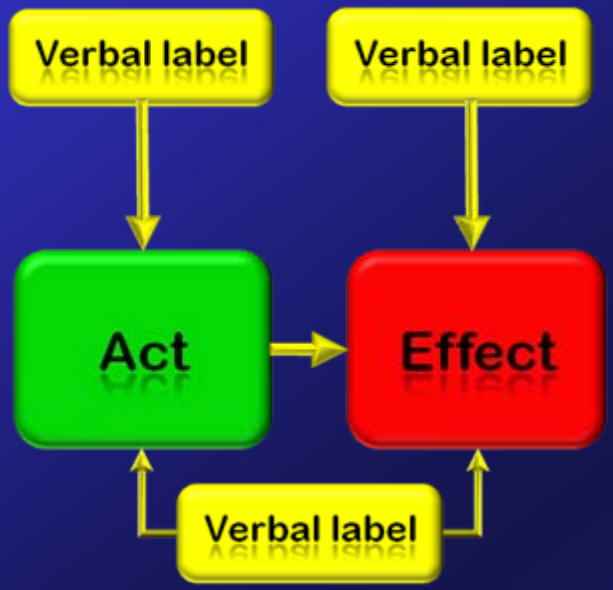
AE learning prevented by conscious representation

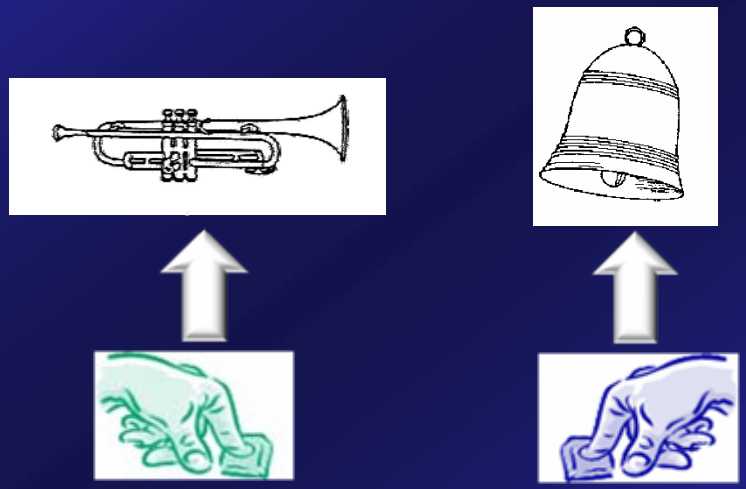


Dual integration model



Language as glue vs. pointer



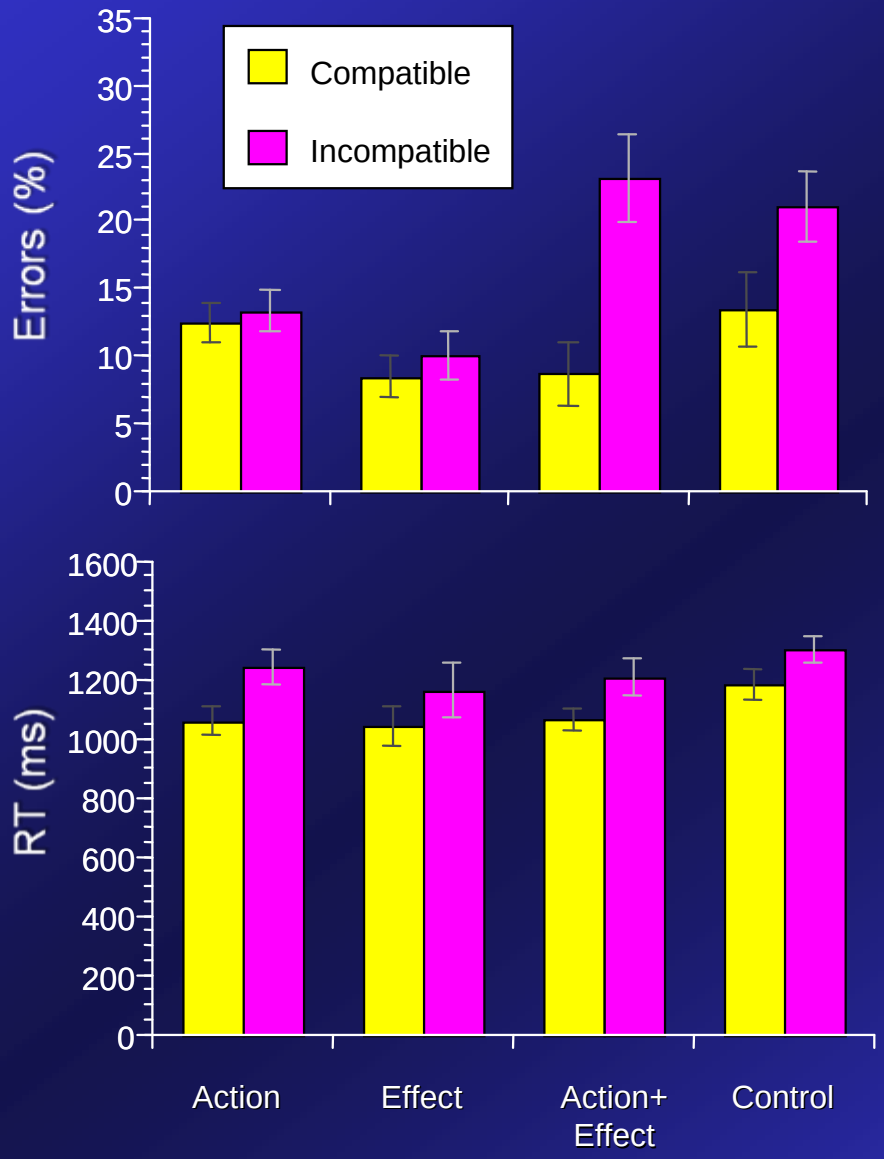


4-year-olds in 4 groups

- Action: “green key”
- Effect: “trumpet sound”
- Action+Effect: “green key to produce trumpet sound”
- Irrelevant word

Kray, Eenshuistra, Kerstner, Weidema & Hommel (2006). Language and action control: The acquisition of action goals in early childhood. *Psychological Science*.

Language as glue vs. pointer (4yrs)



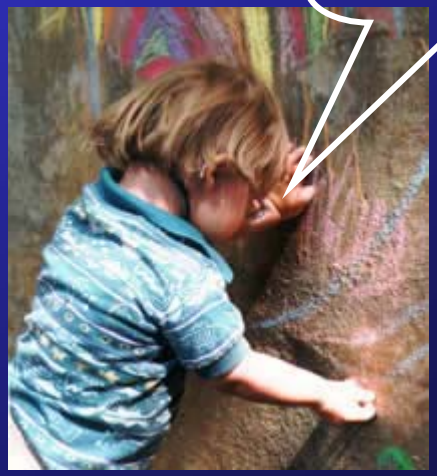
- No benefit from relational labels
- But interference from “single element” labels
- Labels as attentional pointers

Kray, Eenshuistra, Kerstner, Weidema & Hommel (2006). Language and action control: The acquisition of action goals in early childhood. *Psychological Science*.

Vygotsky: Language and action control

Lev Vygotsky

Look: I have painted something



I am painting something

I am going to paint something

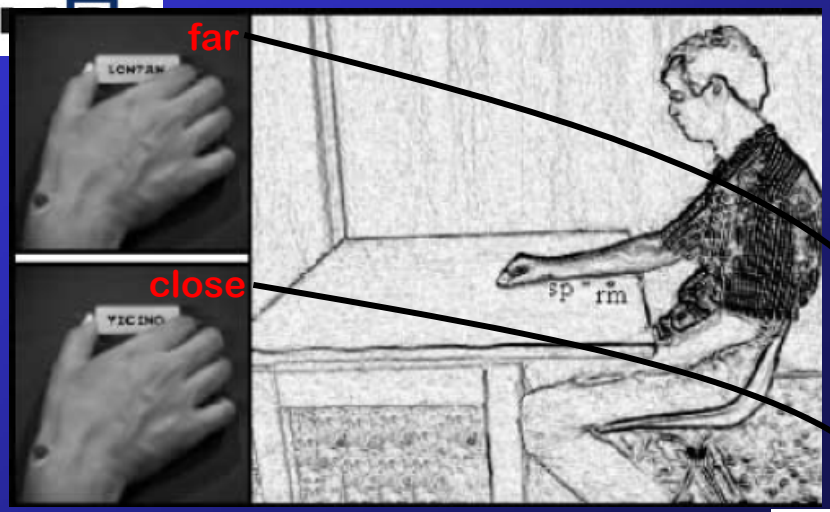
Age

Action → Labeling

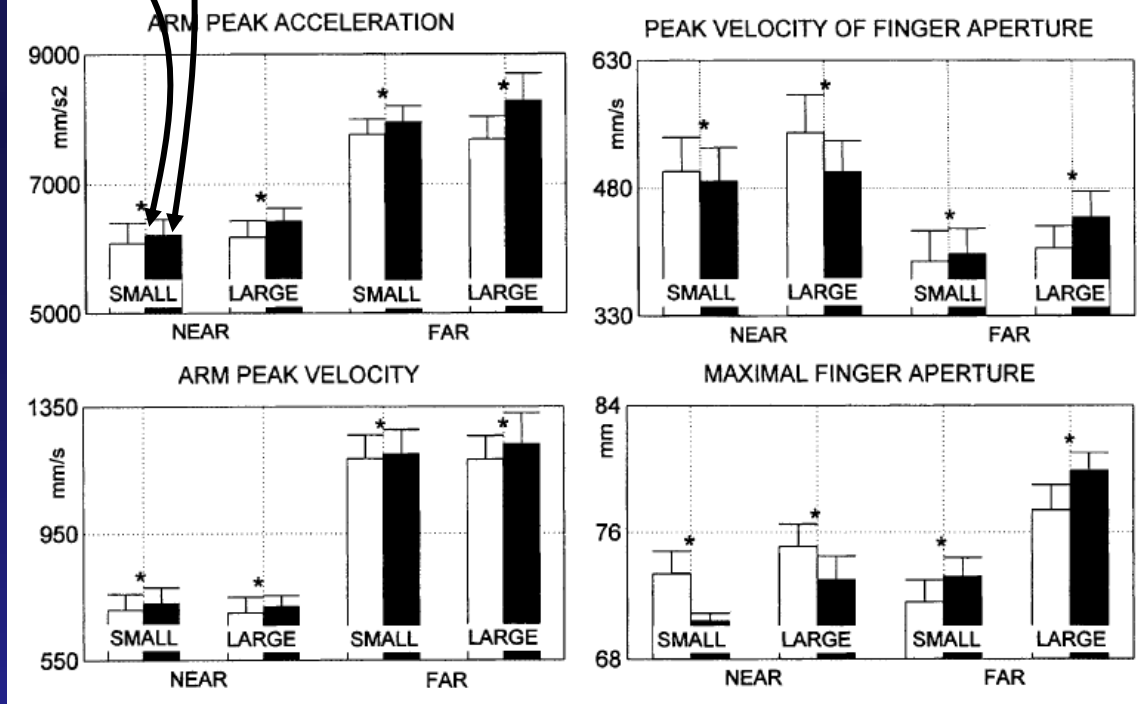
Action ↕ Labeling

Labeling → Action

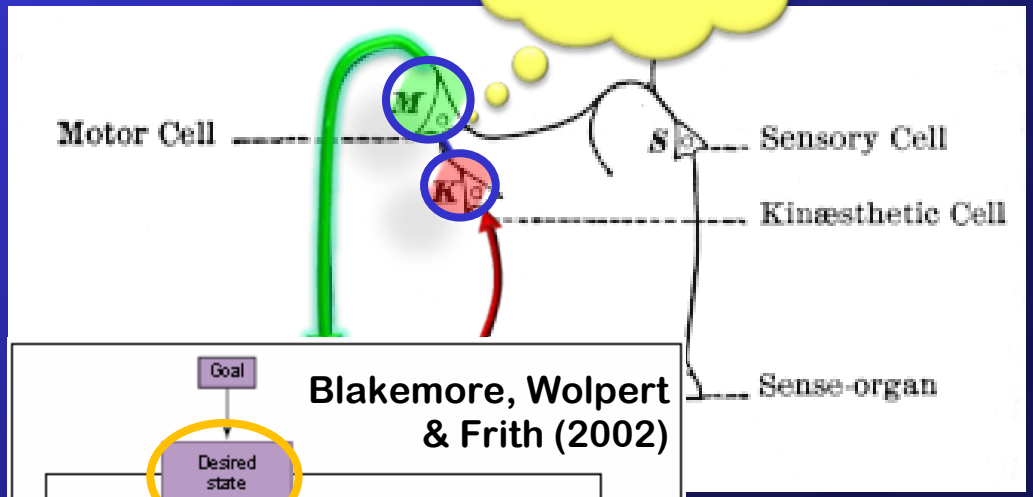
Verbal labels as action retrieval cues

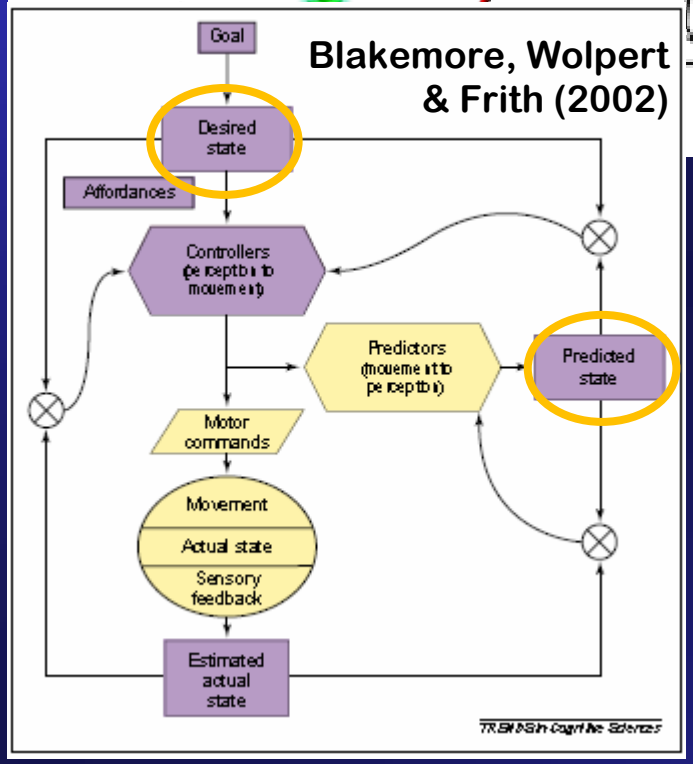


Gentilucci et al. (2000): Grasping objects with irrelevant labels



AEs in selection and prediction/evaluation





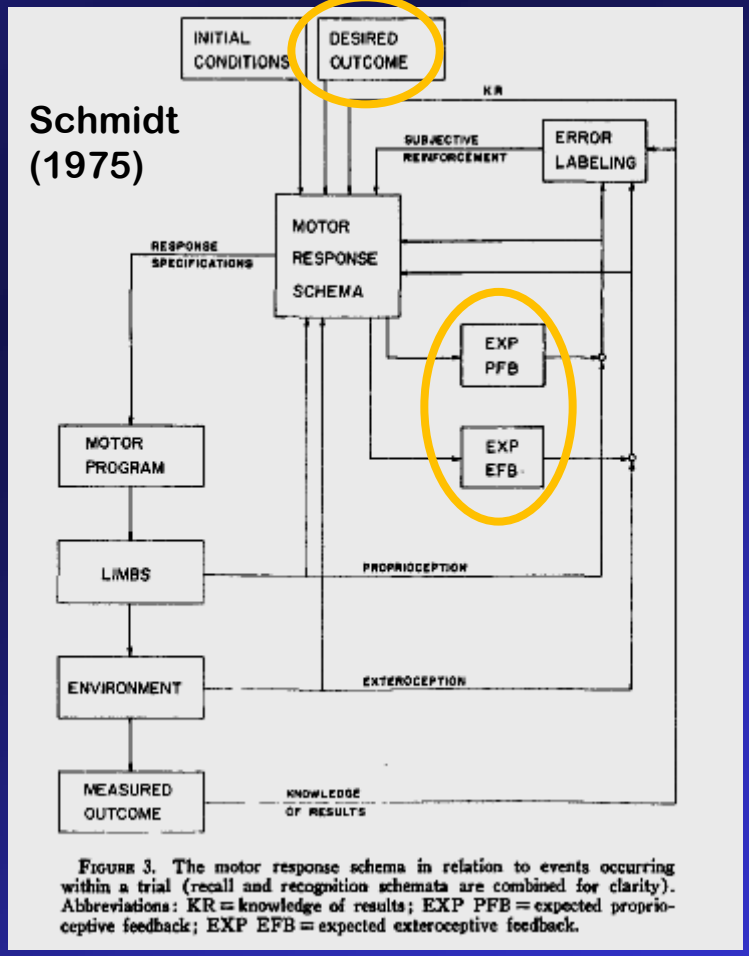
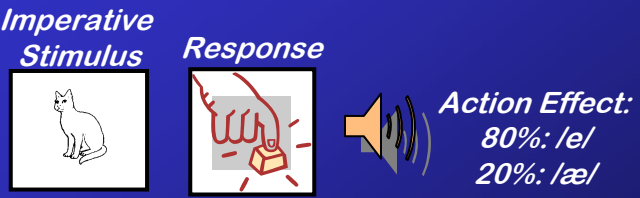
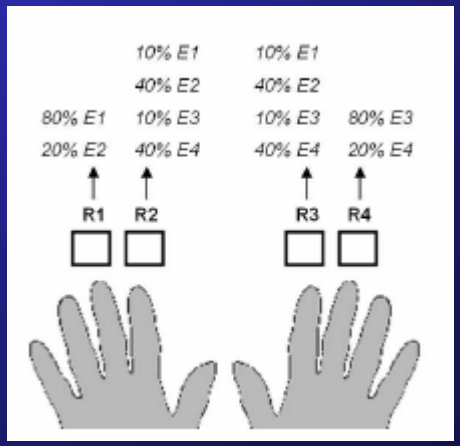


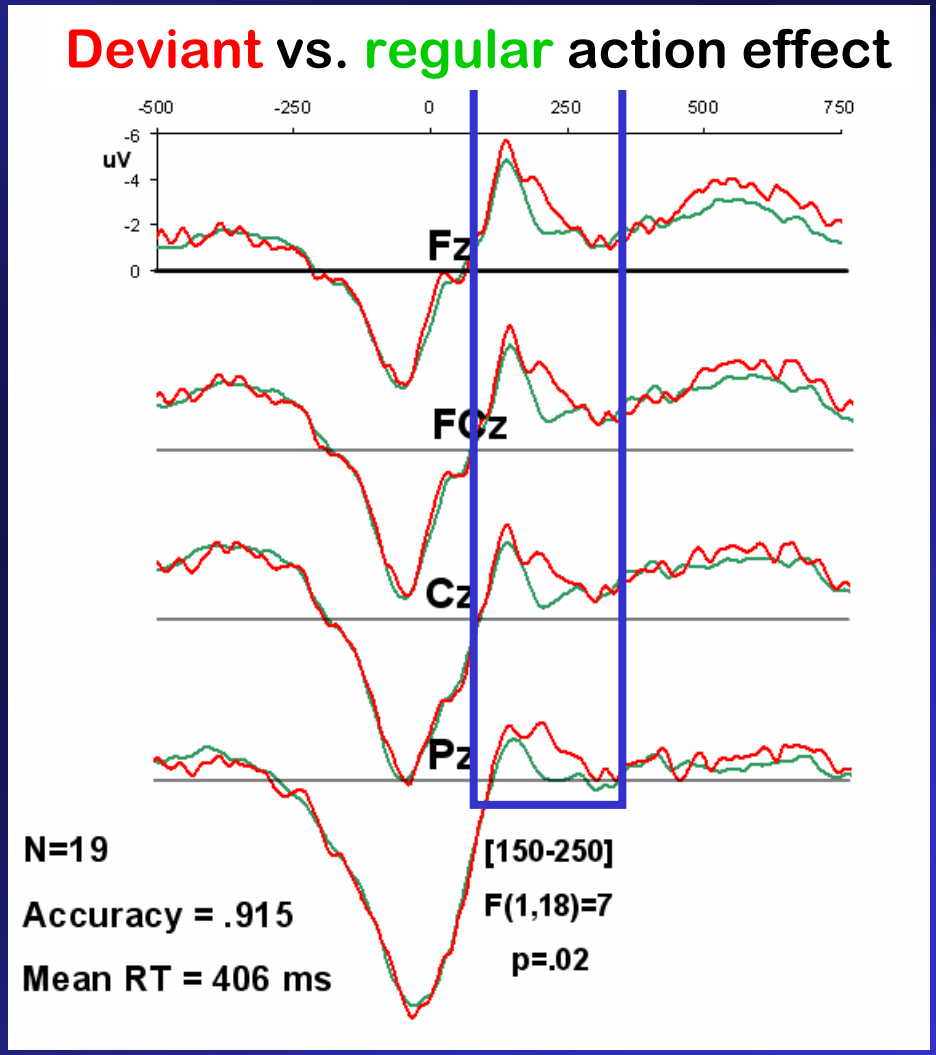
FIGURE 3. The motor response schema in relation to events occurring within a trial (recall and recognition schemata are combined for clarity). Abbreviations: KR = knowledge of results; EXP PFB = expected proprioceptive feedback; EXP EFB = expected exteroceptive feedback.

Automatic monitoring of action effects





Deviant action effects evoke feedback-ERN-type negativity, but smaller and shorter in duration



Summing Up

- Novel, action-contingent events are registered and automatically associated with the accompanying action (hippocampus)
  - From early on (>1 yr)
- Action-effect codes mediate selection of intended action (SMA)
  - Depending on developing frontal cortex
- Language acts as pointer/action-retrieval cue
- Strong support for the idea underlying ideomotor theory: we select and evaluate our actions by anticipating their perceivable consequences!

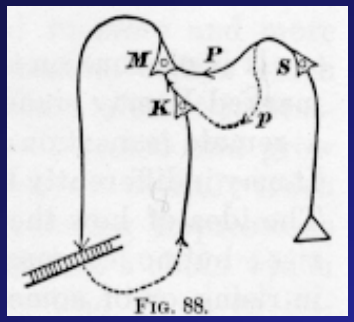


FIG. 88.

Thanks to:

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LIBC Leiden Institute for Brain and Cognition

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www.babylab.leidenuniv.nl