Action Planning

1. form goal

e.g., read paper for class

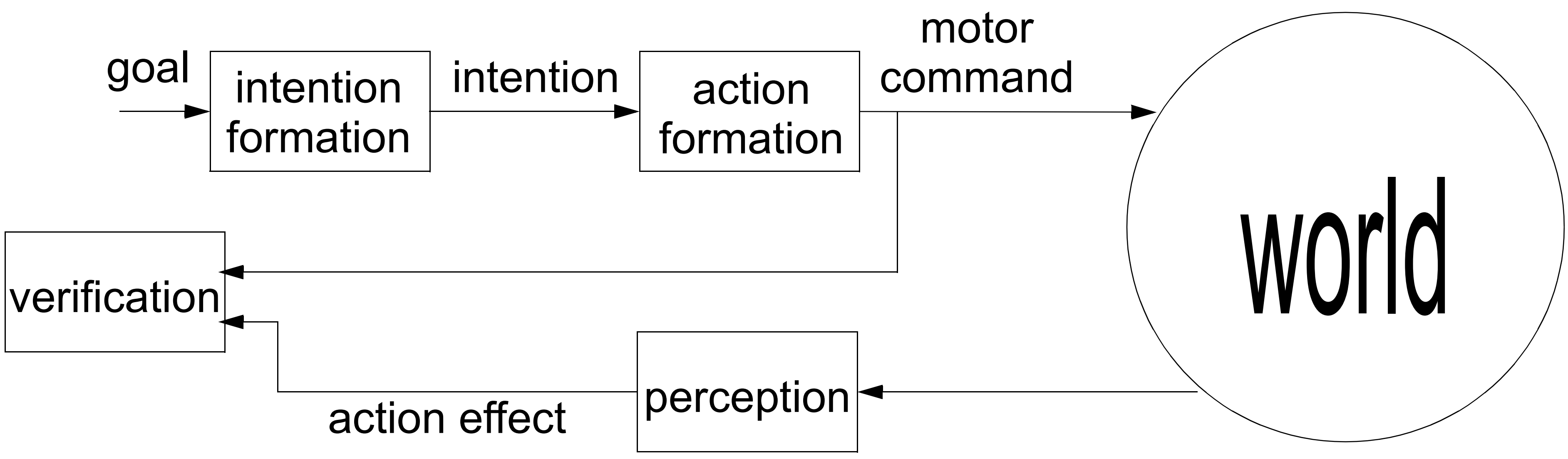
2. form intention

e.g., turn on desk lamp

3. initiate movement

4. verify that goal was achieved

compute difference between desired and actual outcome



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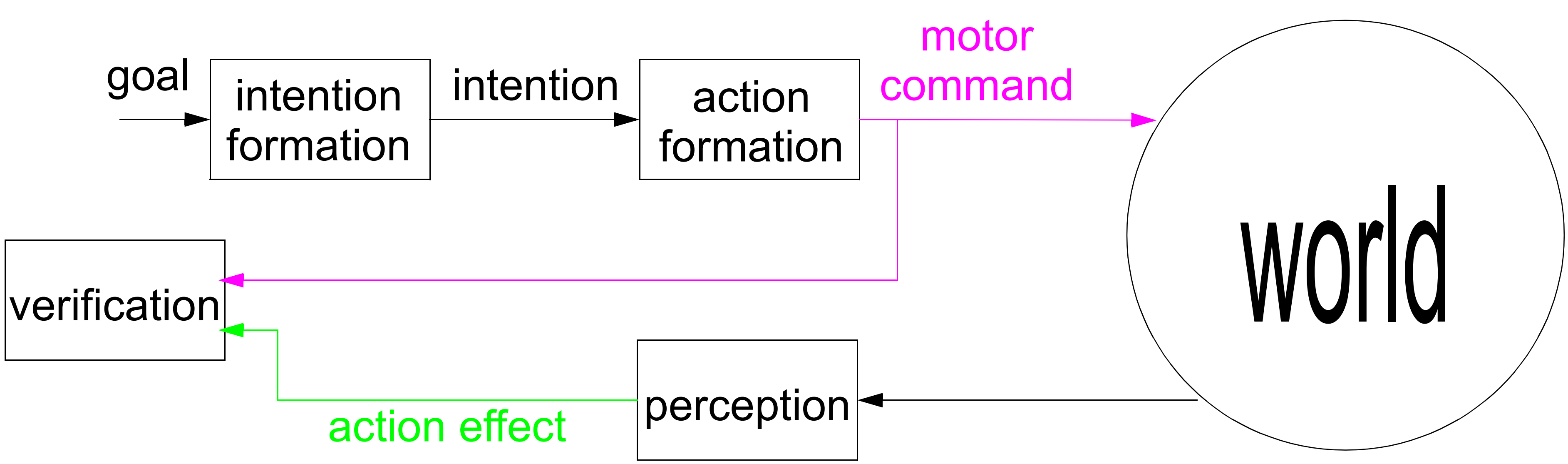

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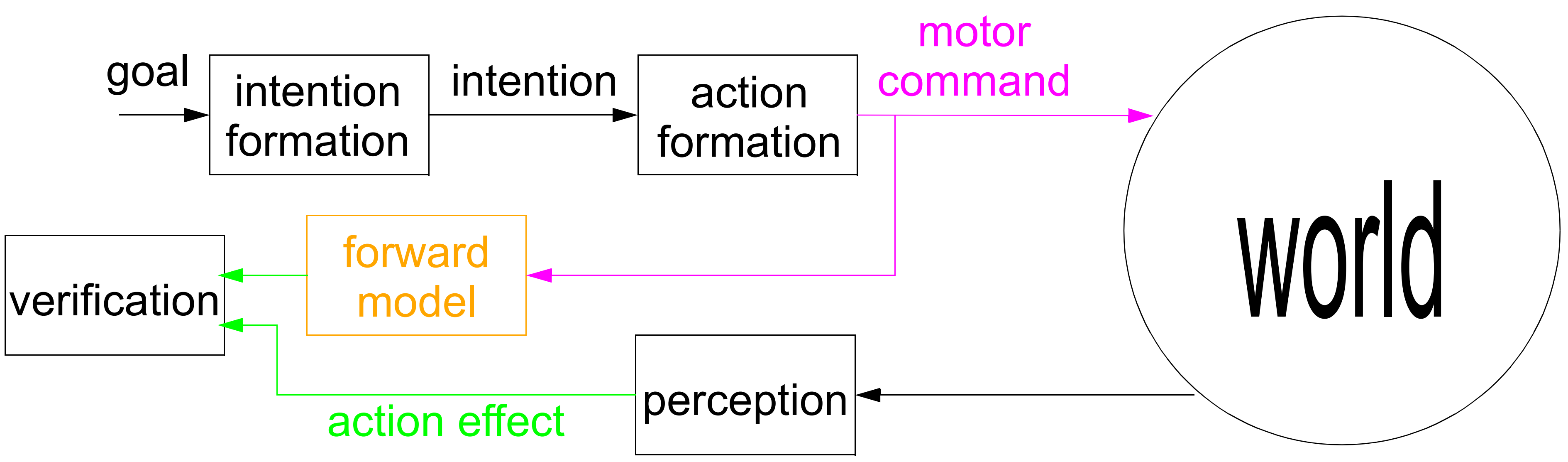


Questions

Where does feeling of control come from?

How does subjective experience correspond to neural events and motor acts?

Is free will an illusion?

Libet (1983)

Participants watch small clock

Voluntarily initiate action (flex wrist) at time of their choosing

Clock hand continues to rotate for a short while

Participants asked to report where clock was pointing when they first became aware of will to move.

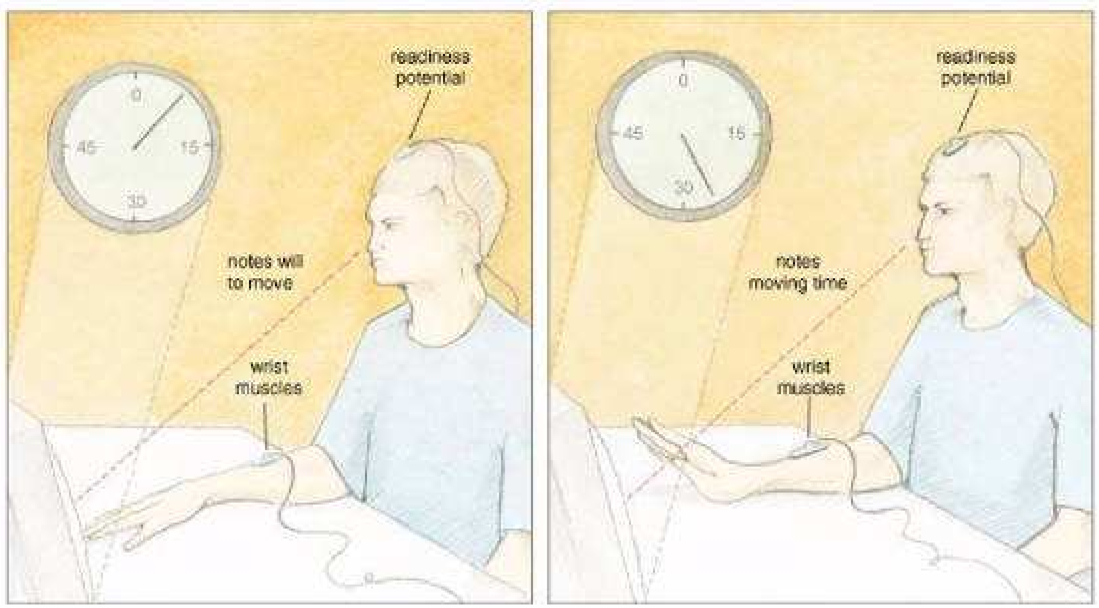
Libet (1983)

Measurements

1. subjective report of intention (W = will)
2. subjective report of when motion actually began (M = motion)
3. readiness potential

   scalp EEG recording over motor cortex
   ramplike buildup of electrical activity that precedes action by about 1 sec

4. electrical activity of the muscles

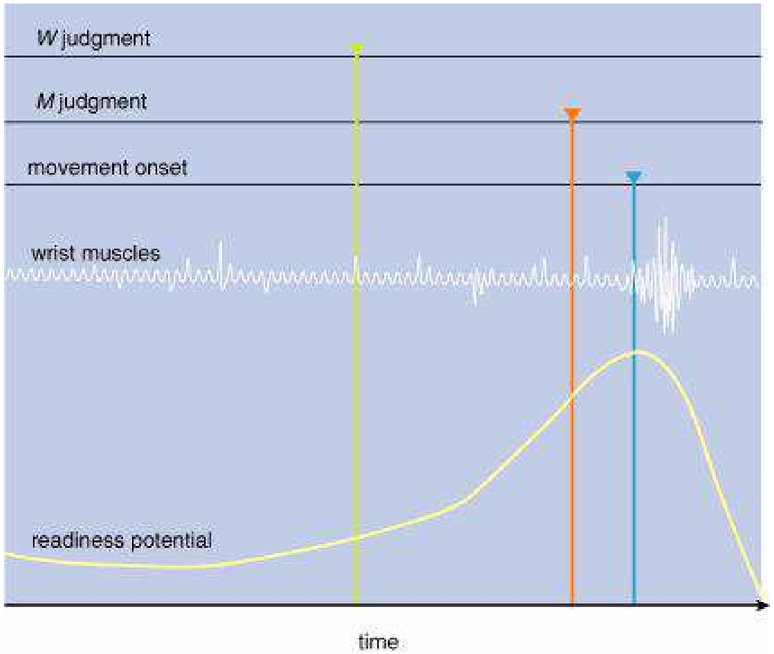


Libet (1983)

Results

Participants consciously perceived intention to move (W) as occurring before experience of actually moving (M)

Readiness potential (RP) preceded intention (W) by 300-500 ms.



Later studies showed that LRP is a better correlate of intention, but still precedes W.

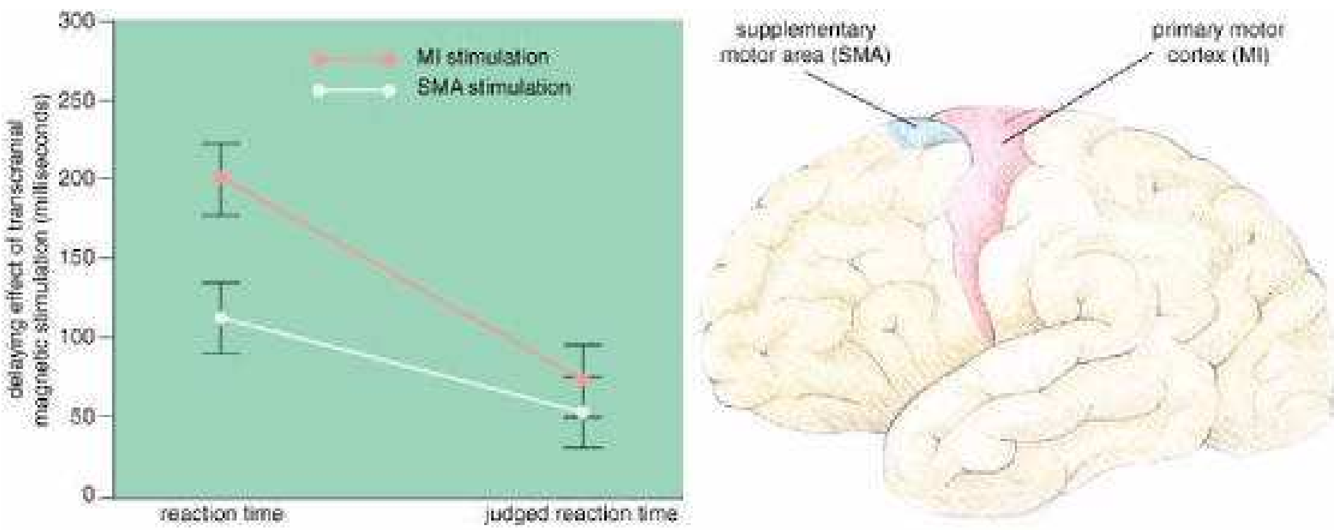
Haggard and Magno (1999)

Participants press key when hear sound

Measure

- objective reaction time
- subjective reaction time (according to hand on clock)

TMS pulse either to primary motor cortex (MI) or supplementary motor area (SMA, movement planning)



Some awareness arises between SMA and MI

Three Principles of Free Will (Wegner, 2003)

1. Intentions must be perceived to precede actions.

2. Intentions must be consistent with those actions.

3. There must be no other perceptible cause of the action.

If these principles are upheld, then people believe that their intention caused the action.

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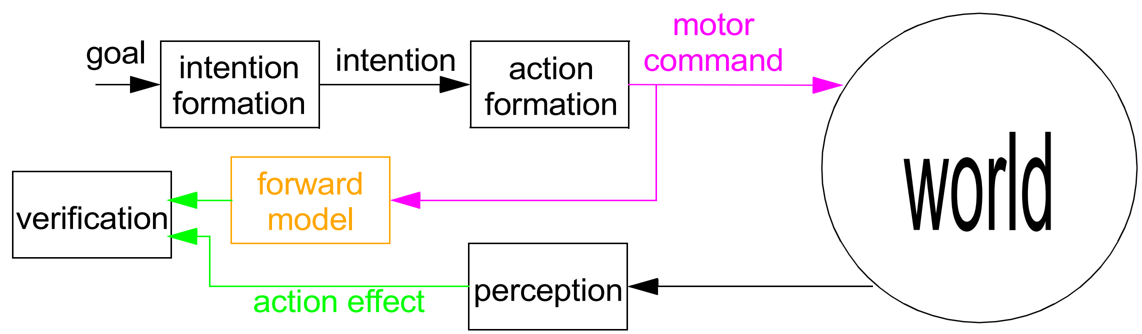
If these principles are upheld, then people believe that their intention caused the action.

Link between intentions and actions is not directly perceived, but is *inferred* from observation.

No direct introspection...sound familiar?



People can be tricked into believing they caused events via these three principles.

Wegner and Wheatley (1999)

Task

Working together with another participant, move a cursor over objects on computer screen.

You'll hear words over headphones that refer to objects on screen.

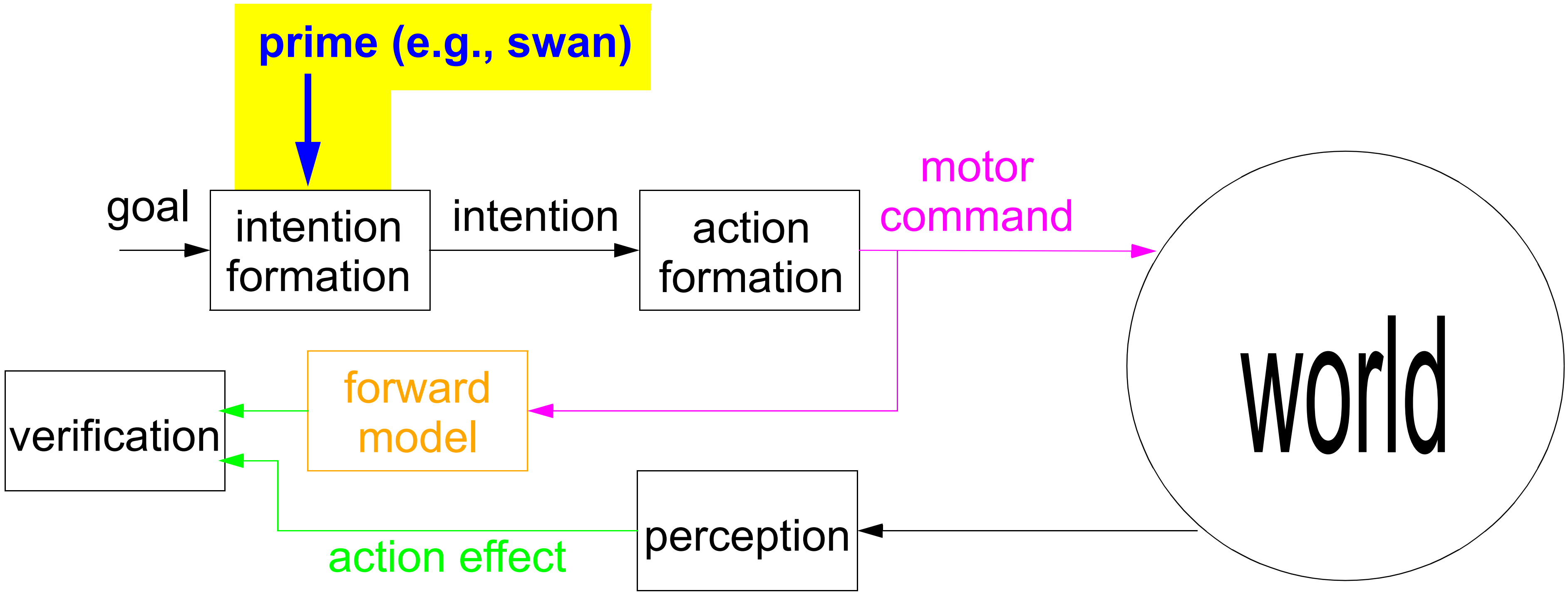
E.g., "swan" while moving cursor over picture of swan.

Result

If word presented 1-5 sec before action, participants felt they had acted intentionally to make the movement, but not if word presented 30 sec before or 1 sec after.

Trick

All movement of the cursor came from the other participant, a confederate.



1. Intention must be perceived to precede action.

prime precedes action

2. Intention must be consistent with action.

prime cannot occur long before action

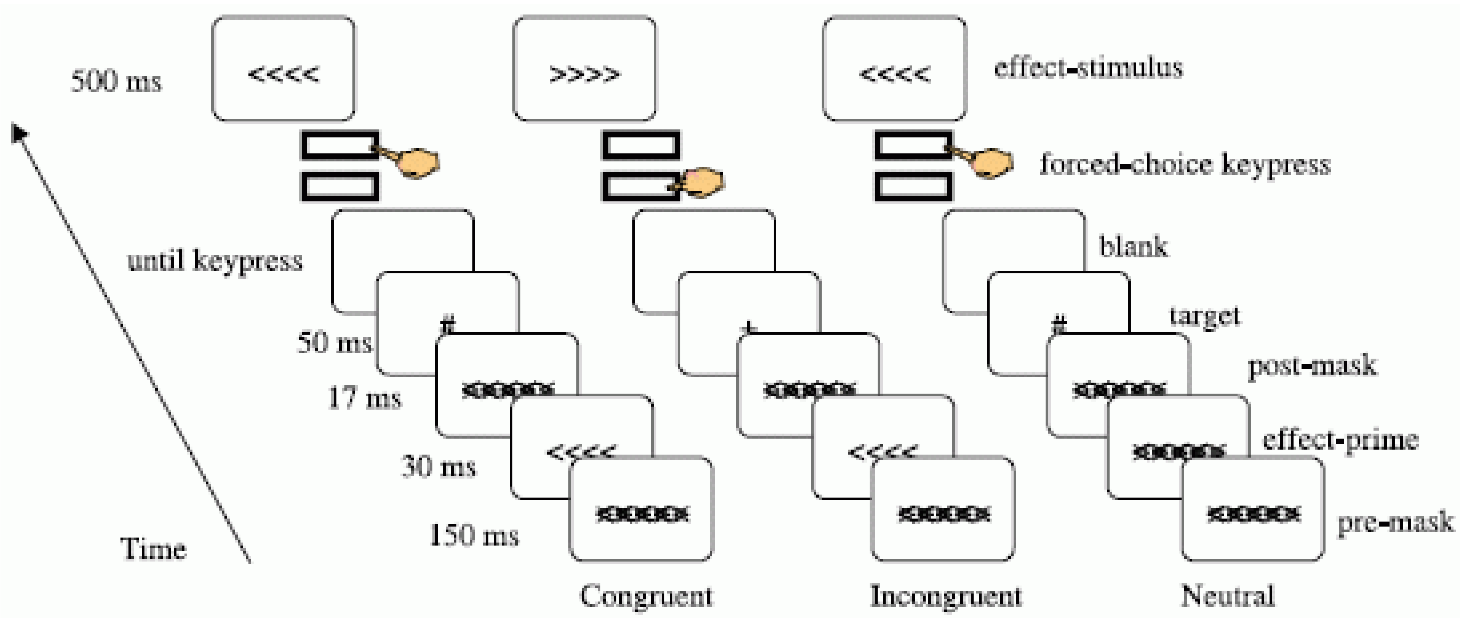
3. There must be no other perceptible cause of the action.

Linser and Goschke (2007), Experiment 1

Like Wegner & Wheatley, they *prime* representation of action-effect, but priming is *subliminal*.

Task: respond upper button to “#” target, lower button to “+” target

On 75% of trials, effect-stimulus corresponded to keypress (<<<< to upper, >>>> to lower)



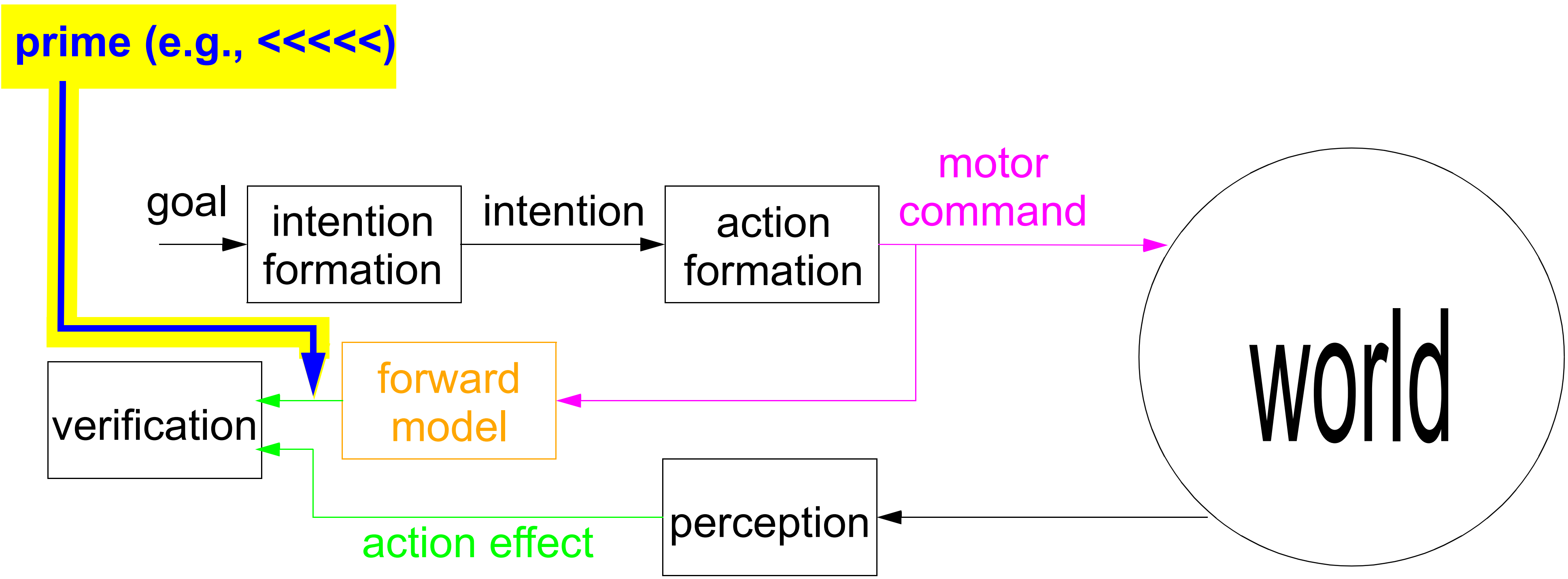
This correlation alone insufficient to induce strong sense of control.

Prime is subliminal: forced choice prime-identification task → 50.8% accuracy

Conditions are blocked with 40 trials/block

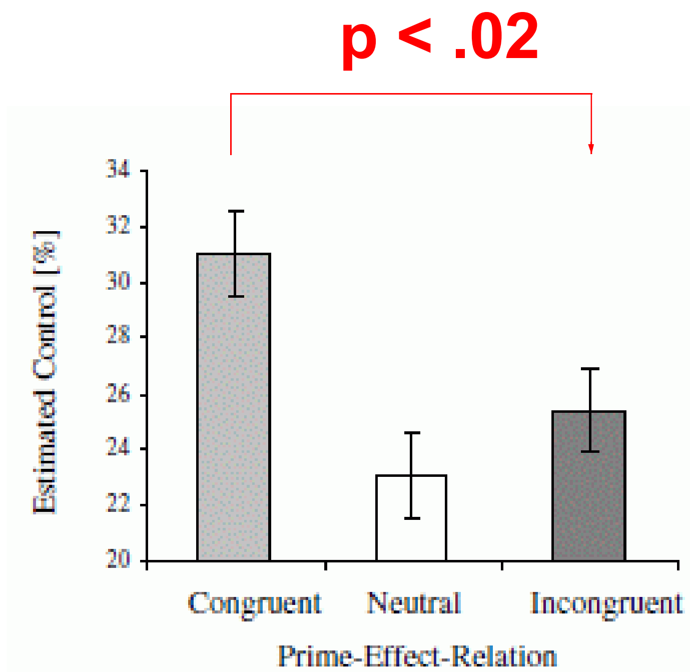
Following each block, subjects asked to report sense of control.

“...the mechanism that normally computes *internal* predictions of action effects may be ‘tricked’, when an *external* prime activates an ‘effect’ representation immediately prior to a voluntary action.”



Prime can’t affect intention, because it is subliminal.

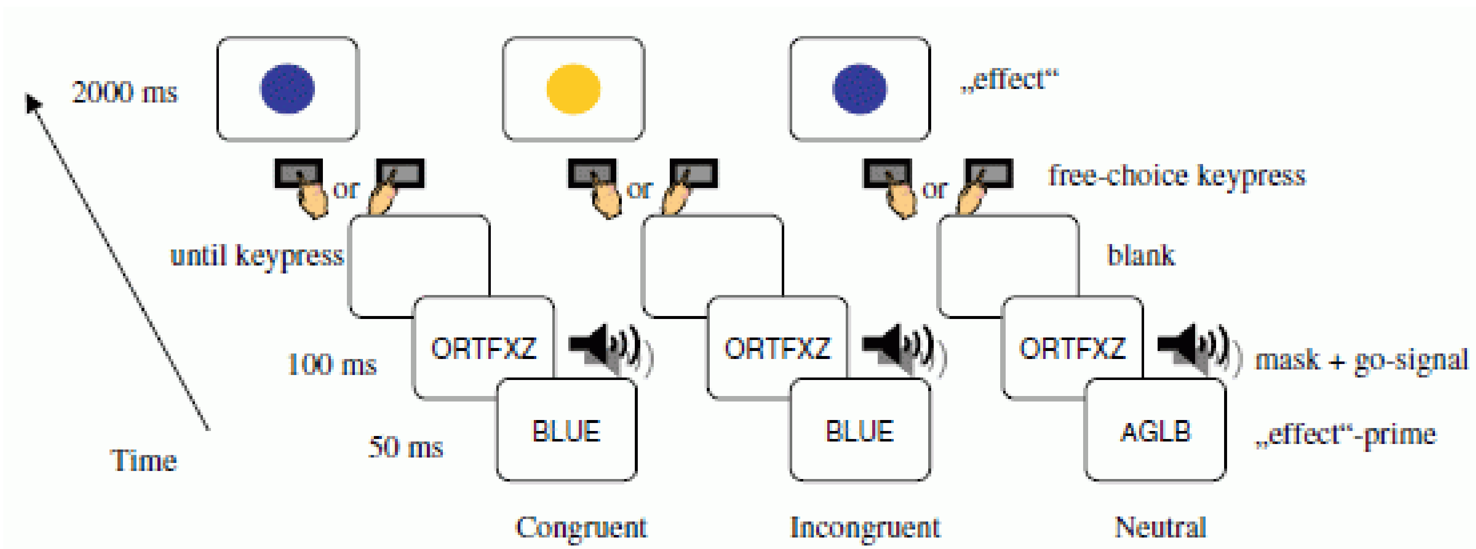
Experiment 1 Result



Experiment 2

Three contrasts to Experiment 1

- **Participants freely choose action**
- **No systematic relation between action and subsequent stimulus**
- **Abstract (semantic) subliminal priming**



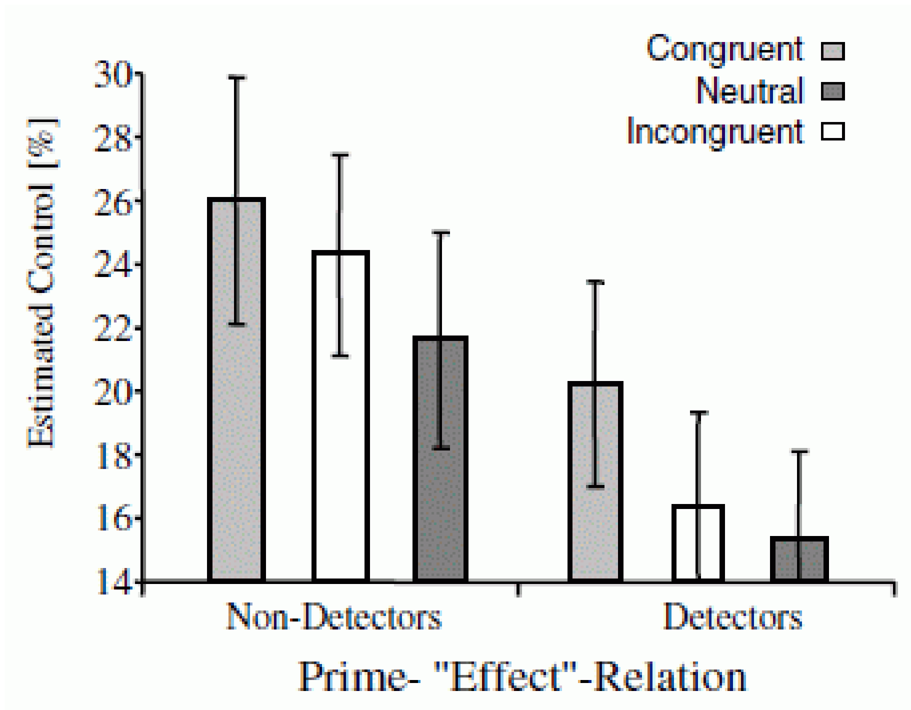
Experiment 2 Results

Some participants were conscious of primes ('detectors')

nondetectors: 37% correct identification (chance = 33%)

detectors: 67% correct identification

Same pattern of results for detectors and nondetectors



main effect of congruity, but not detection, and no interaction

Summary

Motor acts are initiated before people become aware of their intentions.

Awareness does arise until the final stages of action initiation.

People can be made to believe they exerted free will when in fact they did not.

> “The higher the congruence between anticipated and actual action-effects, the stronger is the tendency to experience the effect as caused by one’s own actions.” (Linser & Gaschke)

Is free will an illusion?

> Conscious processes could still exert some effect over actions by modifying brain processes already under way.
>
> But mostly conscious processes *inhibit* automatic/overlearned actions.
>
> Replace free will with free won’t?

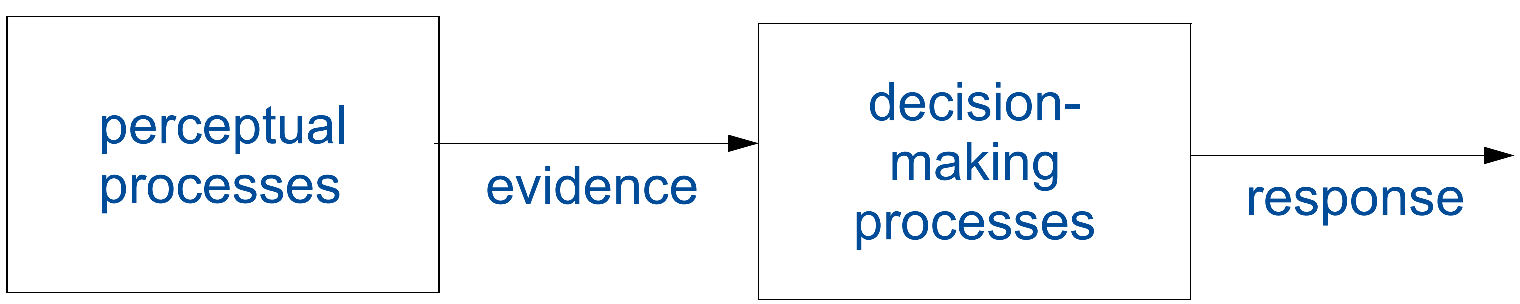
Neural Mechanisms of Decision Making

Diffusion model (a.k.a. random walk model)

Decision making takes time

Evidence toward one decision or another is provided by other brain systems

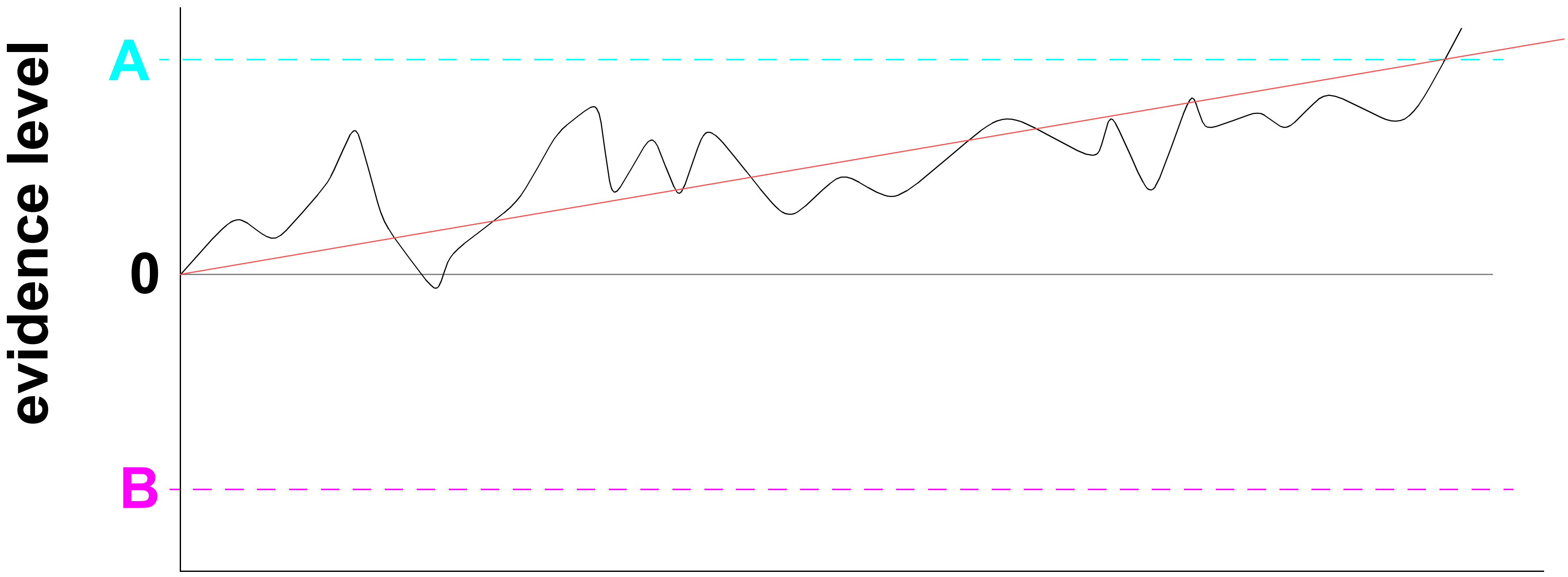
e.g., push left button if stimulus A, right button if stimulus B



sample evidence over time:

A, A, A, B, A, A, B, A, B, B, A, A

Decision making processes accumulate evidence toward one decision or another (A vs. B) over time



average drift is the bias (expected evidence) that comes from the perceptual system

Demo of Decision Making

Executive Control

A.k.a. cognitive control, executive function

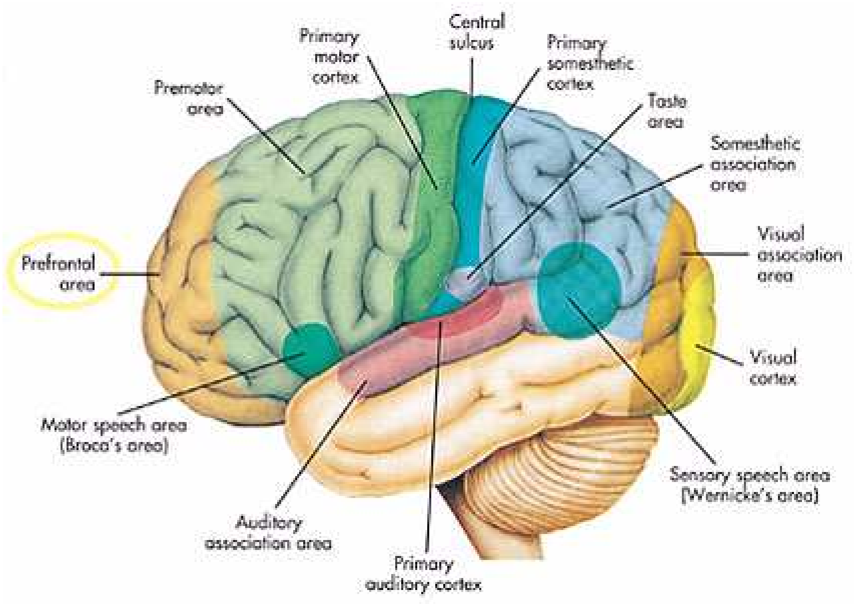
Operations that monitor and regulate ongoing processing in a goal-directed manner

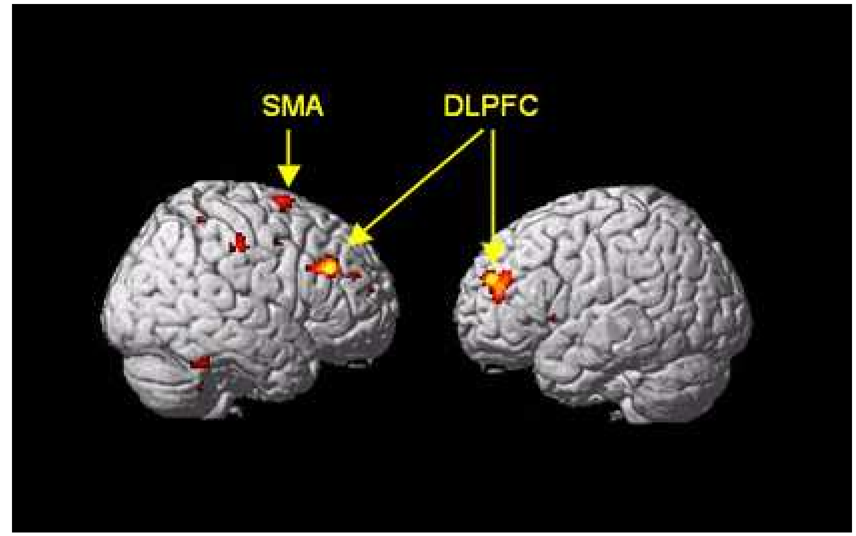
- following arbitrary directions
- processing aspects of the environment that interrupt routine action
  - e.g. ball rolling into street as you drive
- overriding default actions
  - e.g., driving to post office instead of home
- decision points
  - e.g., what to have for lunch
- maintaining information in working memory
  - e.g., phone number

When control is required, we usually become aware of the triggering events, both internal and external.

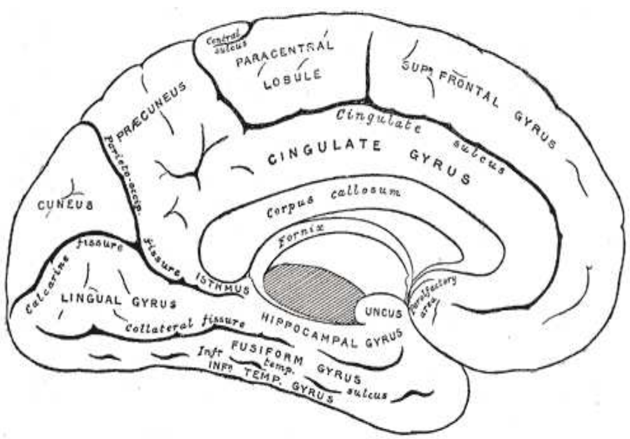
Brain Areas Involved in Executive Control

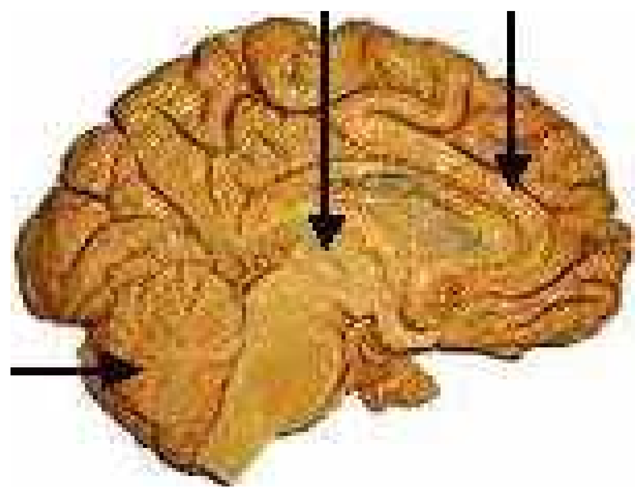
prefrontal cortex (DLPFC)





anterior cingulate cortex (ACC)





Experimental Tasks to Study Executive Control

Stroop task

Name the ink color

ORANGE BLUE GREEN

Overriding default response

Task switching

Add then subtract

9 2

4 1

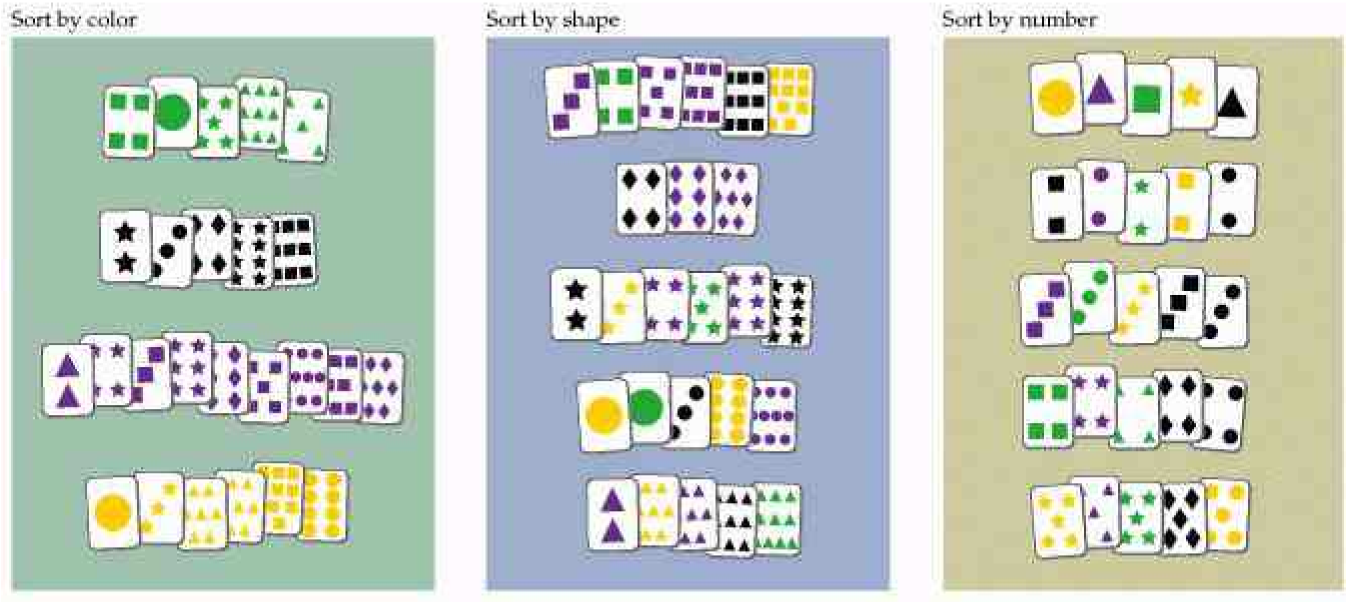
8 7

6 2

2 3

Experimental Tasks to Study Executive Control

Wisconsin Card Sorting Task



N-Back Task

Subjects view a long sequence of letters

For each letter, indicate whether it is a target or nontarget

Targets defined by condition

1-back: letter is a target if it matches the previous letter
2-back: letter is a target if it matches the letter before the previous one

What is the Relationship Between Executive Control and Awareness?

Routine, domain-specific operations do not require awareness

e.g., object recognition, motor control, reading, navigating environment

Executive control operations require awareness

Experiments presented in Mayr

- **examine neural and behavioral measures of control**
- **manipulate awareness**
- **manipulate integrity of cortical control network**

Dehaene et al. (2003)

Task

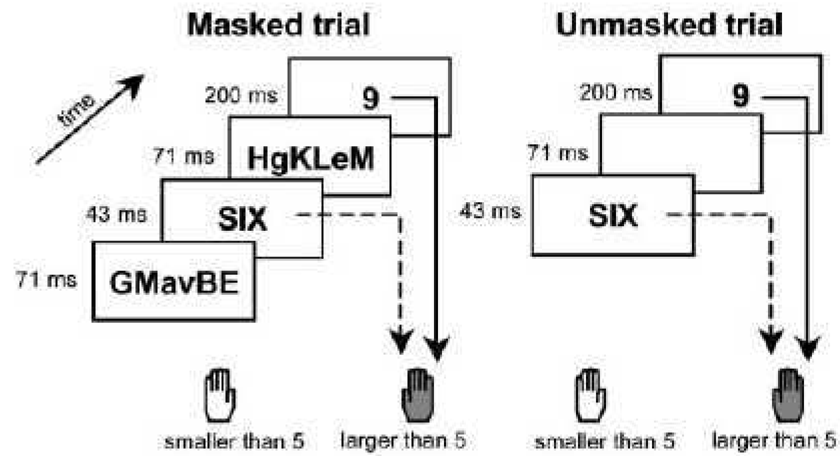
Indicate whether target digit is "less than 5" or "greater than 5"

Prime (spelled digit) precedes target

Prime can be congruent (e.g., "six - 9") or incongruent ("four - 9")

Prime can be masked (unconscious) or unmasked (conscious)

Unmasked primes demand cognitive control.

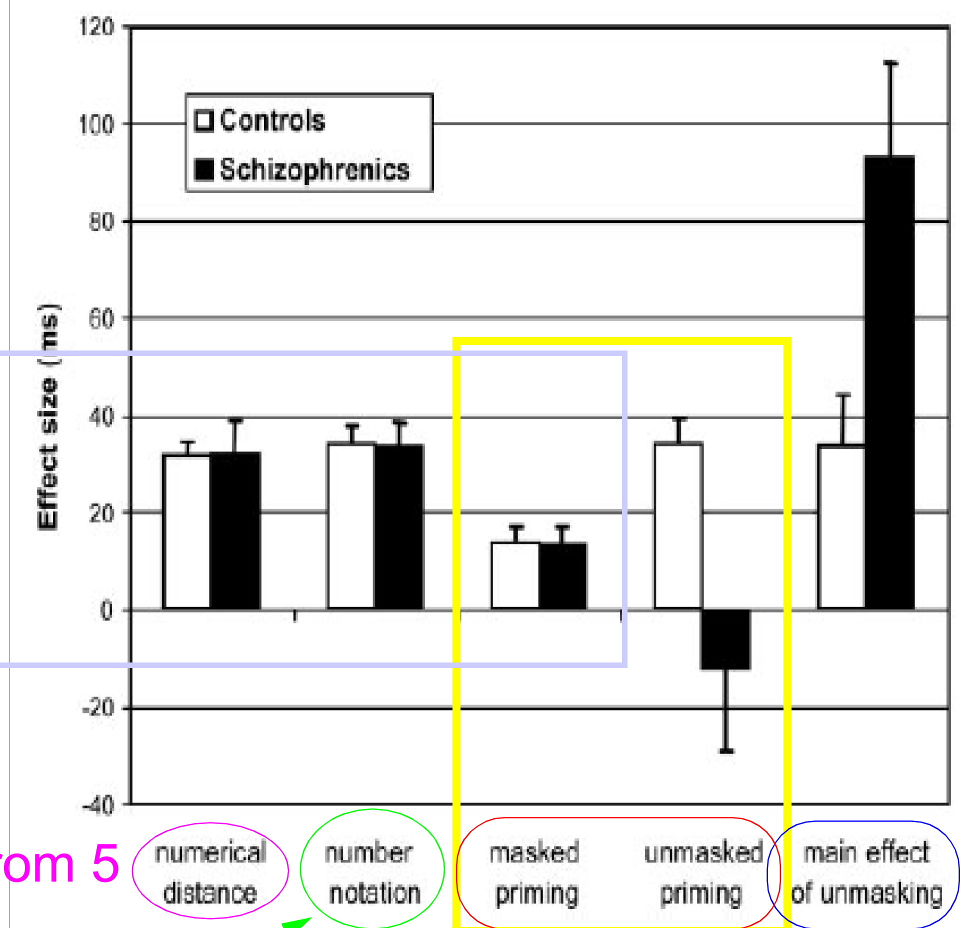


Subjects

Normals

Schizophrenics ("structural and functional abnormalities in ACC and related prefrontal areas")

Dehaene et al. (2003)



processing of numbers not affected

how far from 5

Arabic or spelled

unmasked - masked RT: operation of control to suppress potentially conflicting information

incongruent - congruent RT

Fig. 2. Behavioral performance in number comparison in control subjects and in patients with schizophrenia (mean effect size in milliseconds ± SE). Both groups show identical effects of numerical distance, number notation, and subliminal priming. However, they differed in the unmasked priming effect, which required conscious control of interference. Patients were also severely slowed in the unmasked condition compared with the masked condition.

Dehaene et al. (2003)

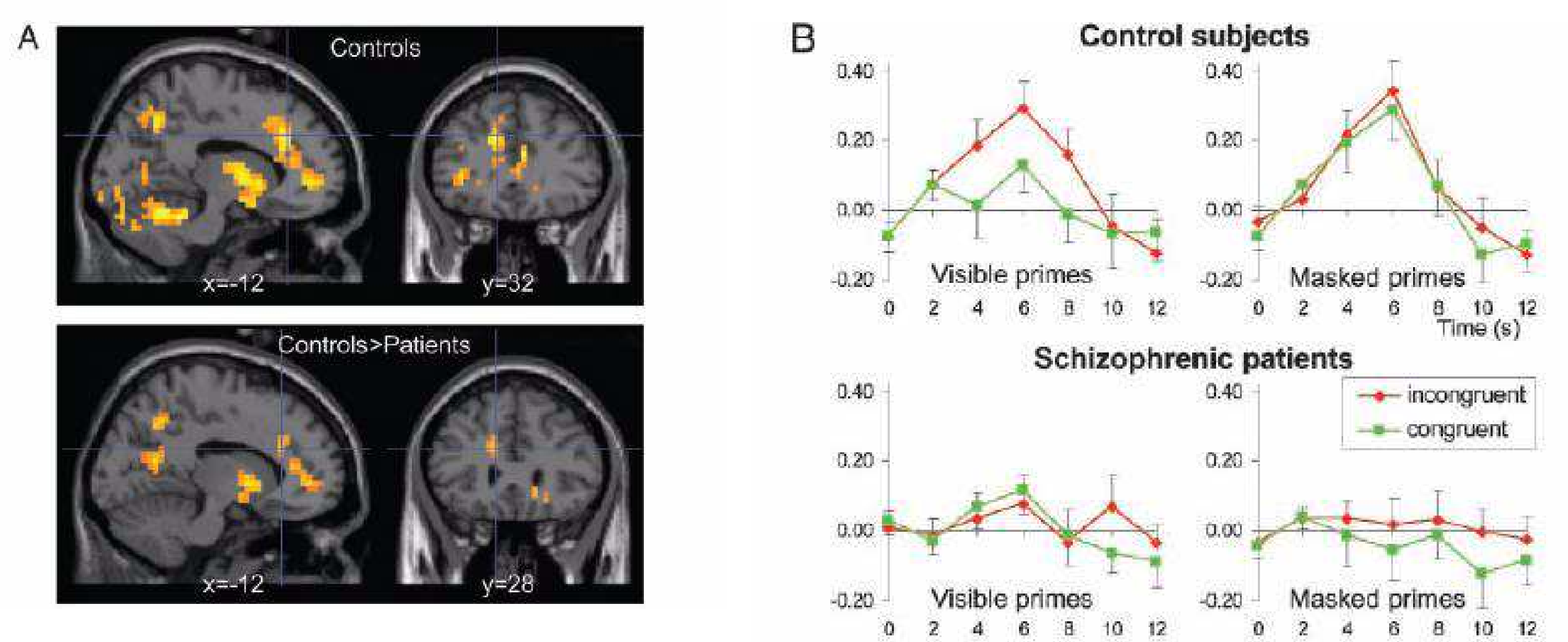


Fig. 4. Effect of conscious conflict in the anterior cingulate in controls and in patients. (*A Upper*) Congruity × visibility interaction in normal subjects showing greater activation in ACC and other brain regions on incongruent trials than on congruent trials, but only when the prime was unmasked. This effect was not found in patients, thus resulting in a triple-interaction group × congruity × visibility (*A Lower*). Curves show the mean percent signal change in the left ACC as a function of time (*B*), revealing a hypoactivation and an absence of conscious conflict effect in the patients.

Conflict regulation by ACC is possible only with awareness.

awareness -> conflict regulation ... or ... conflict regulation -> awareness

Relation Between Awareness and Control

Mayr mentions four other studies suggesting a link between the ability to control, activation of brain areas involved in control, and awareness.

E.g., Niewenhuis et al.

Target appears

Subject to make antisaccade

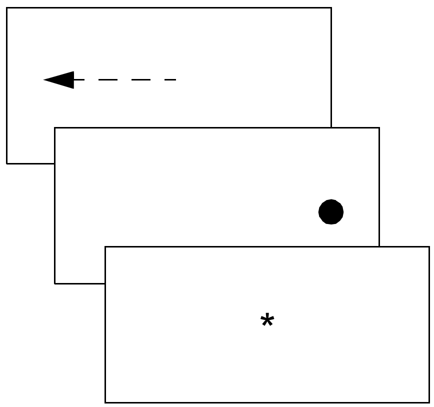
Posttrial assessment of error awareness

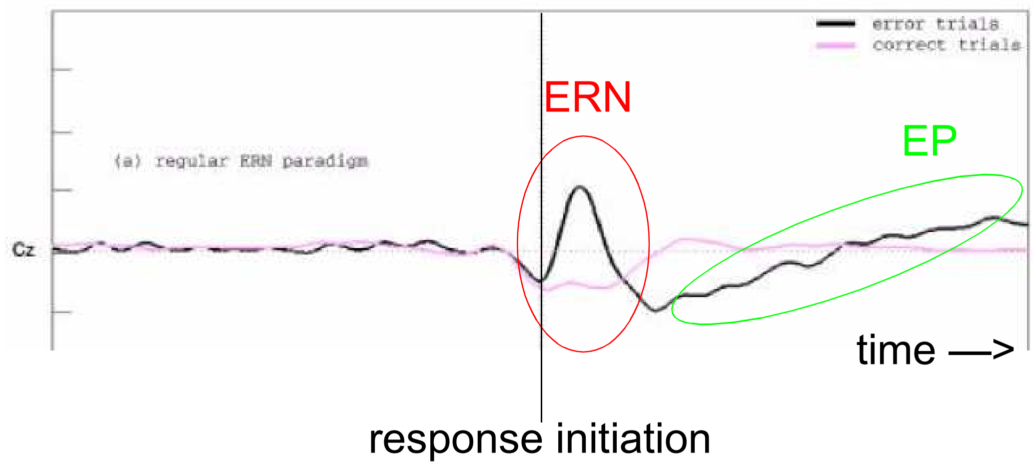
When subjects are aware:

- presence of ERN (assoc. w/ ACC!)
- presence of EP
- presence of post-correction slowing

When subjects aren't aware:

- presence of ERN
- absence of EP
- absence of post-correction slowing





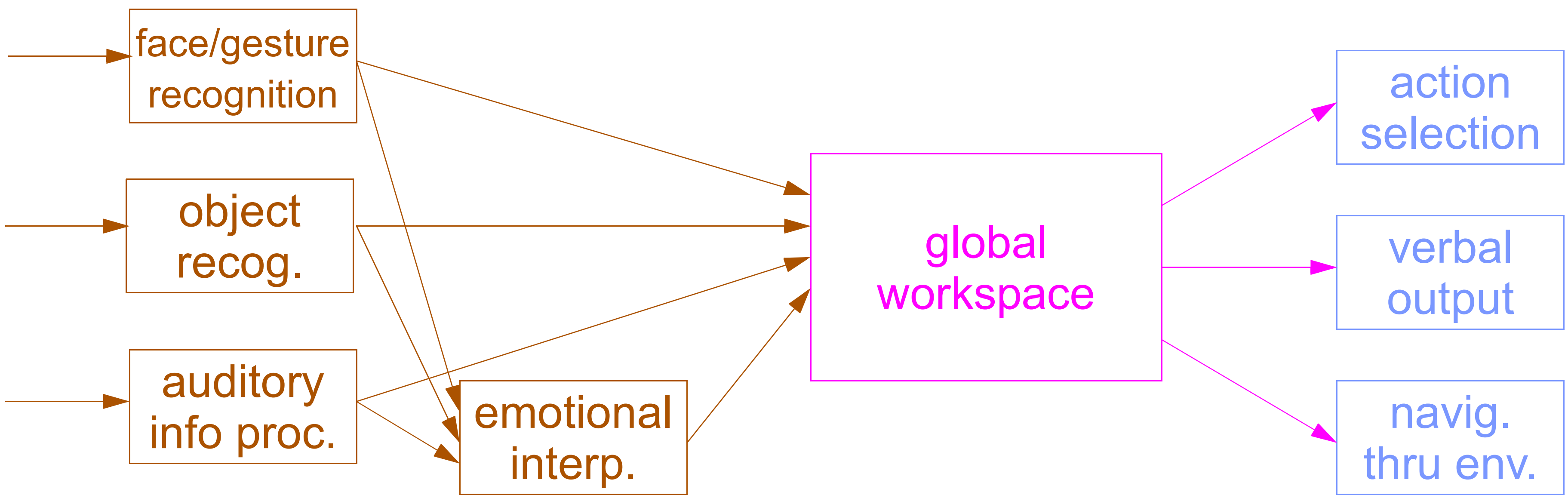
Global Workspace Theory

Global workspace facilitates widespread access (communication) between otherwise independent brain functions.

Many specialized perceptual processing systems

Many specialized response processing systems

Global workspace serves to connect them



Related to blackboard models in AI

Global Workspace Theory

Global workspace serves as a means of coordination and control.

Central information exchange

Related to notion of working memory

visual working memory: tracking visual objects, imagery

verbal working memory: inner speech

Data consistent with global workspace theory

- More activation when stimuli are conscious than unconscious (Fig in paper; binocular fusion study). [consistent with many theories]
- Activation of frontal-parietal circuits when stimuli are conscious (binocular rivalry studies)
- More powerful learning mechanisms come into play when information is conscious (implicit/explicit learning contrast)
- Executive control requires awareness.

Global Workspace Theory

Criticisms

- Explains how access can take place, but not how content is selected
- More of a framework than a theory
- Many other views are consistent with the above data
- Allows for many different neural implementations: some variants allow distributed neural representation of workspace, others place workspace in frontal regions.

Computational Modeling

Global workspace model (Dehaene et al.)

A state of *representational coherence* within a global workspace gives rise to both consciousness and cognitive control.

ACC and PFC are neural substrates of global workspace.

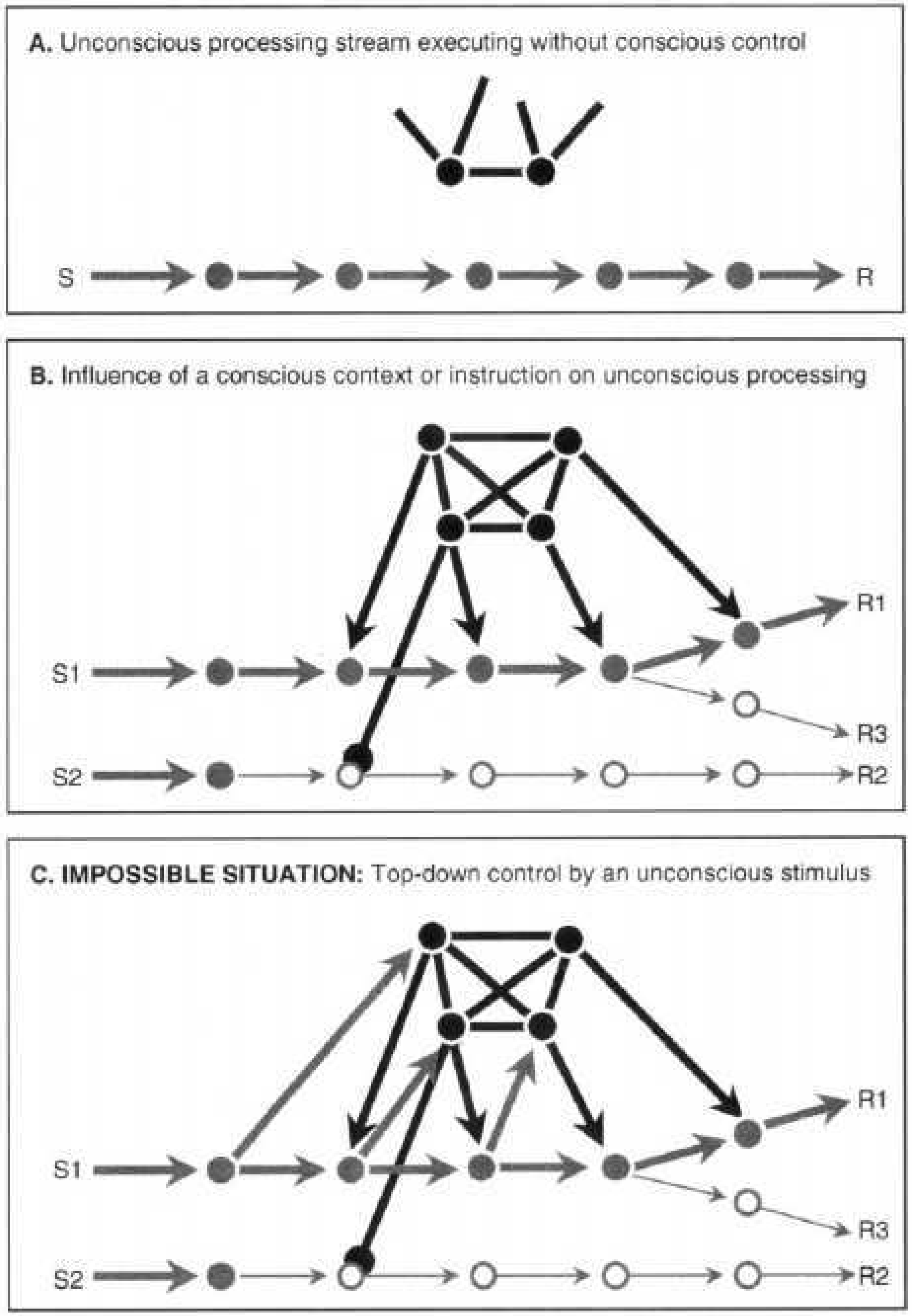
Conflict monitoring model (Botvinick et al.)

ACC detects conflict and “tightens control”, leading to a reduction in conflict.

Simple feedback mechanism does not require awareness of conflict, in contrast to global workspace model.

E.g., reinterpretation of ERN in Niewenhuis: conflict develops after response initiated due to continued processing of the stimulus

Global Workspace Model

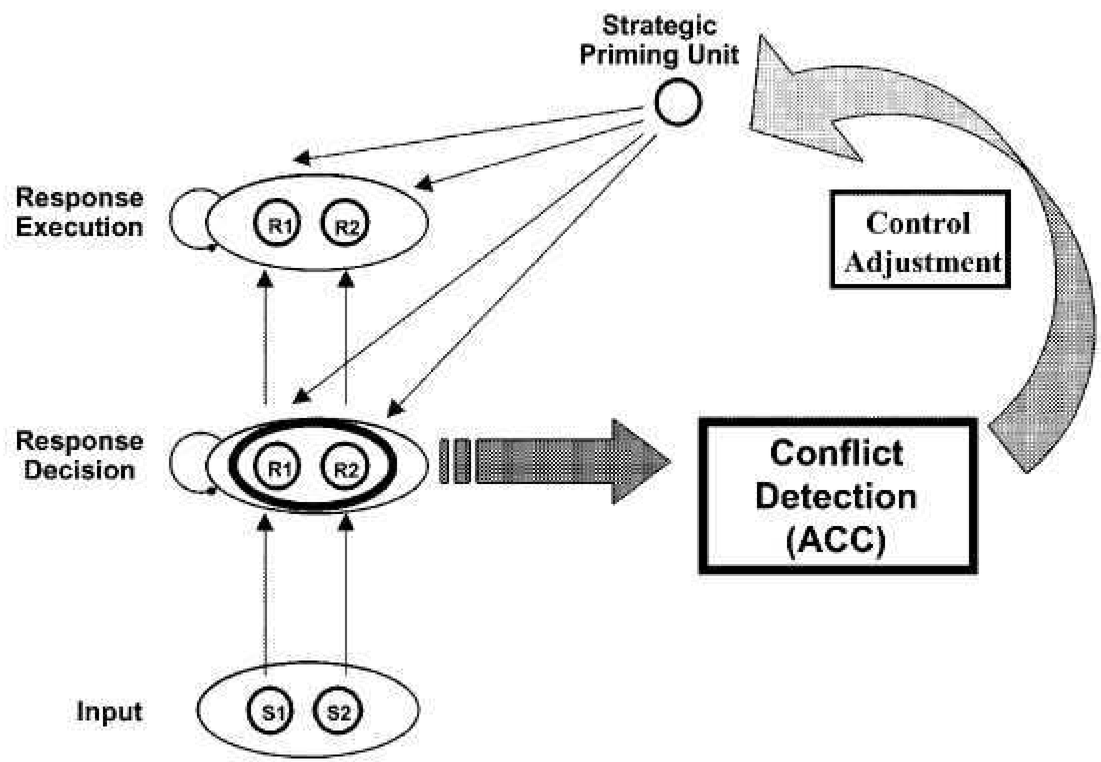


Conflict Monitoring Model

Task with S1->R1 and S2->R2

Low conflict sequences: S1 S2 S1 S2 S1 S2
High conflict sequences: S1 S1 S1 S1 S1 S2

Model



Functions of Consciousness

Flexible, adaptive control of action

Rapidly integrate information

Unified neural workspace through which many processes can communicate

frees organisms from acting out their intentions in the real world, relying instead on less hazardous simulation made possible by the neural workspace