1964 1975 1980 1990 2000

time

CNV, PINV
Grey Walter

O-wave
E-wave
Loveless & Sanford

SPN
MPN
Damen & Brunia

LRP (CMA)
Coles & Gratton; DeJong

ERN (Ne), Pe
Falkenstein; Gehring

BSP, RP
Kornhuber & Deecke
Vaughan et al.

CRN

P300
Chapman & Bragdon
Sutton et al.

Novelty P3
Courchesne et al.

N400
Kutas & Hillyard

P600 /SPS
LAN
Osterhout
Kluender
Neville

CPS
Steinhauer et al.

N200, P3a, P3b,
SW complex
Squires et al.

N2a, N2b
N2a=MMN
Naatanen

Dm
Paller et al.

Other components: Nd, PN, N2pc, nogoN200, ADAN, LDAN, CDA, etc.

The first psychological ERP effects…1964

CNV – contingent negative variation, Grey Walter et al.

BSP, RP – readiness potential, Kornhuber & Deecke, Vaughan et al.

P300 – Sutton et al.

SLOW (MOSTLY NEGATIVE) POTENTIALS
e.g., BSP/RP, CNV, SPN/MPN

Slowly rising negativities
- prior to voluntary movement (RP – readiness potential)
- prior to imperative stimulus   or between warning and imperative, i.e., foreperiod (CNV – contingent negative variation)
- prior to intake of information (SPN – stimulus preceding negativity)

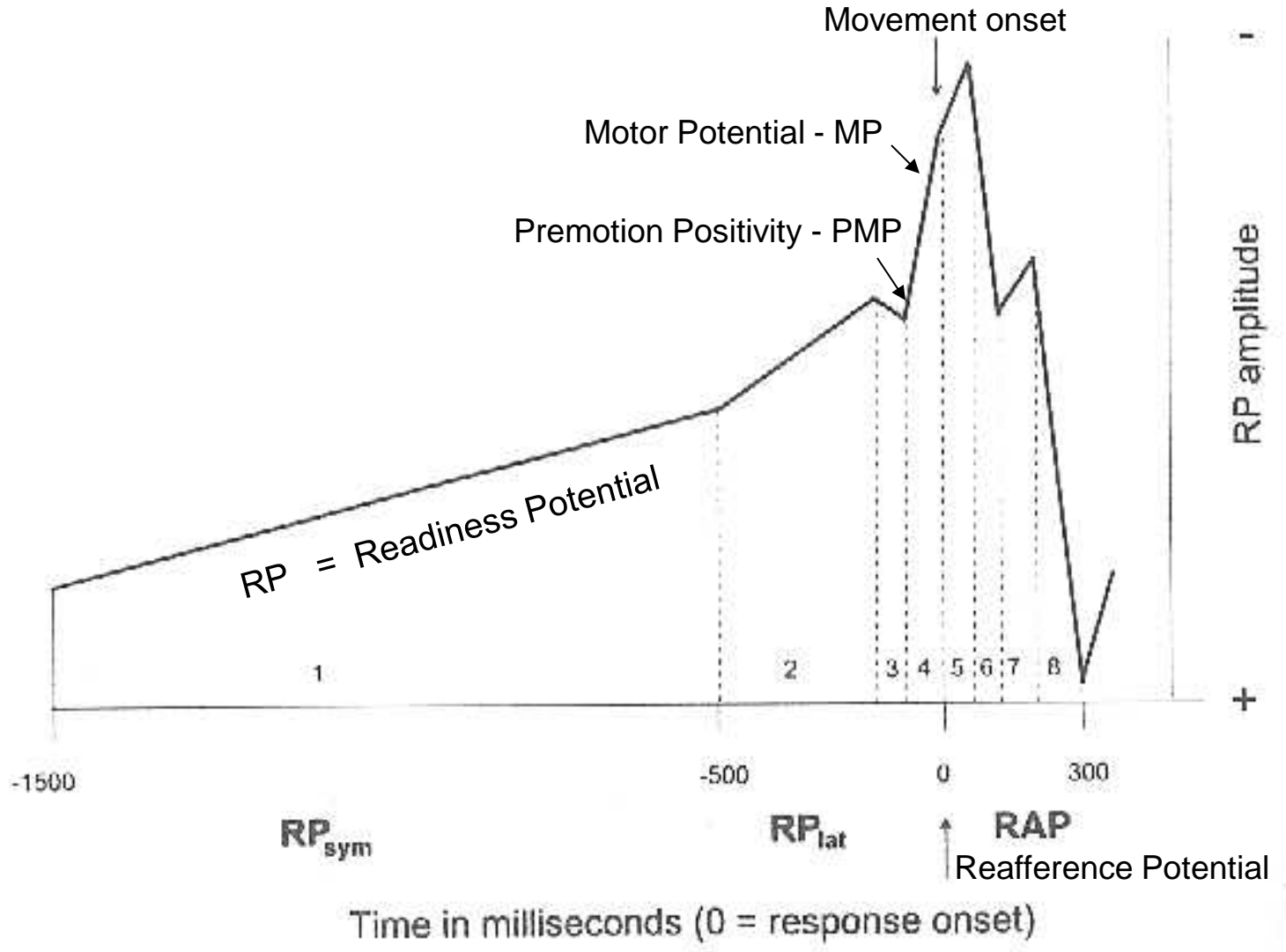# Bereitschaftspotential (BSP): aka Readiness Potential (RP)

L. motor

R. premotor

Mid-parietal

Bipolar L vs R
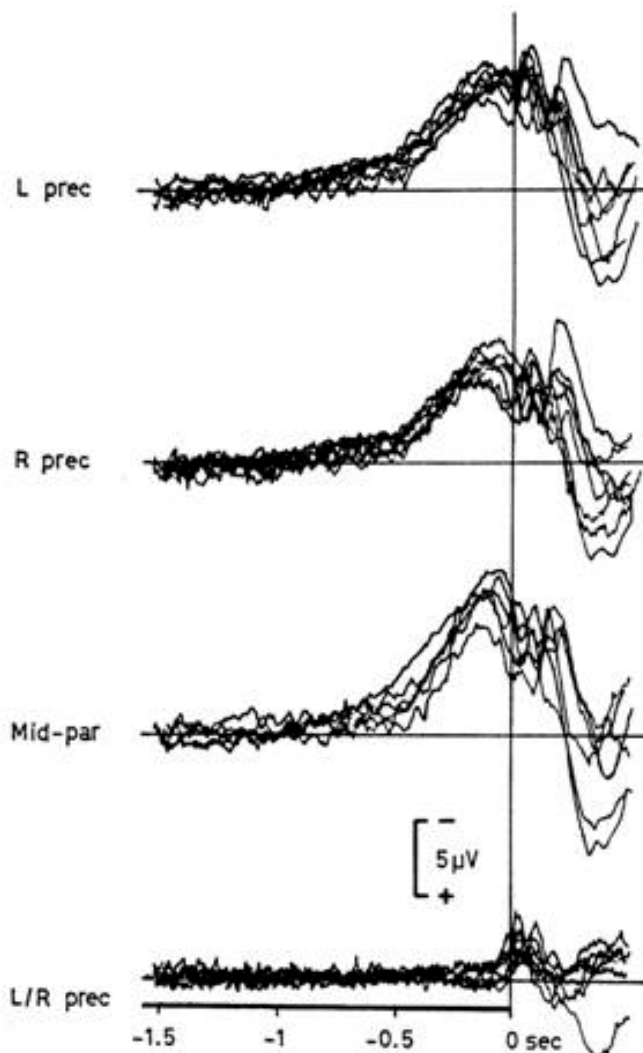
How might we test the hypothesis that RP related to voluntary movement?

Kornhuber & Deecke, 1964
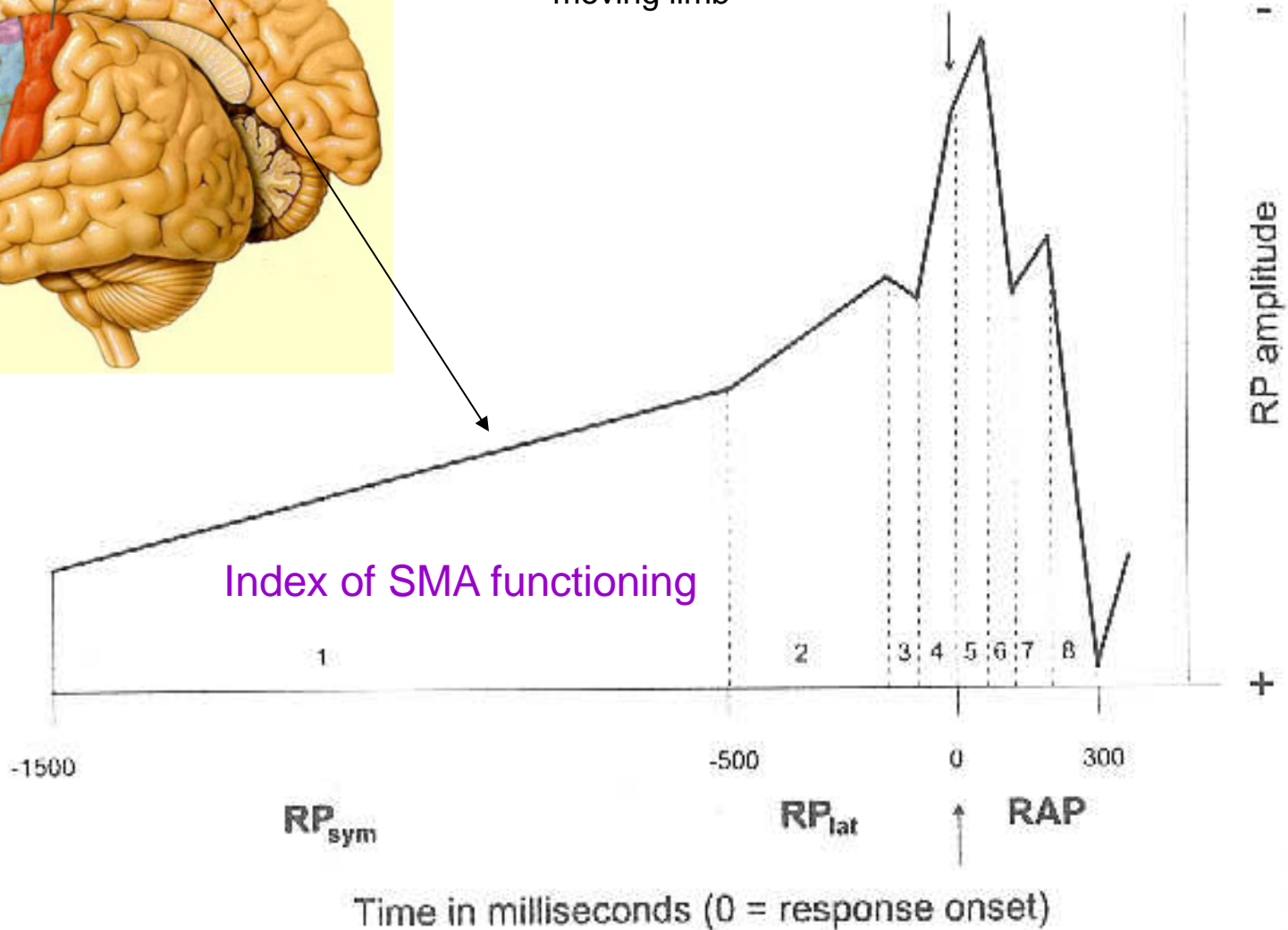
MOVEMENT-RELATED POTENTIALS

Movement onset

Motor Potential - MP

Premotion Positivity - PMP

RP = Readiness Potential

RP amplitude

1

2

3 4 5 6 7 8

-1500

-500

0

300

RP_sym

RP_lat

RAP

Reafference Potential

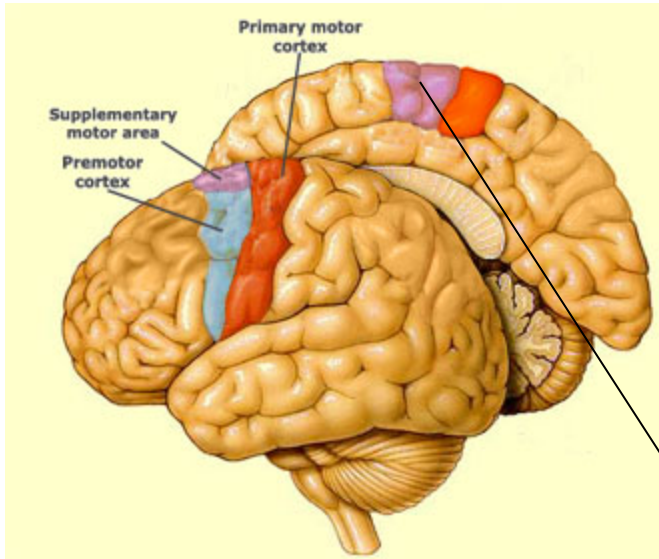Time in milliseconds (0 = response onset)

Pre-movement-related potentials

- RPsym - Readiness Potential symmetric

- RPlat - Readiness Potential lateralized
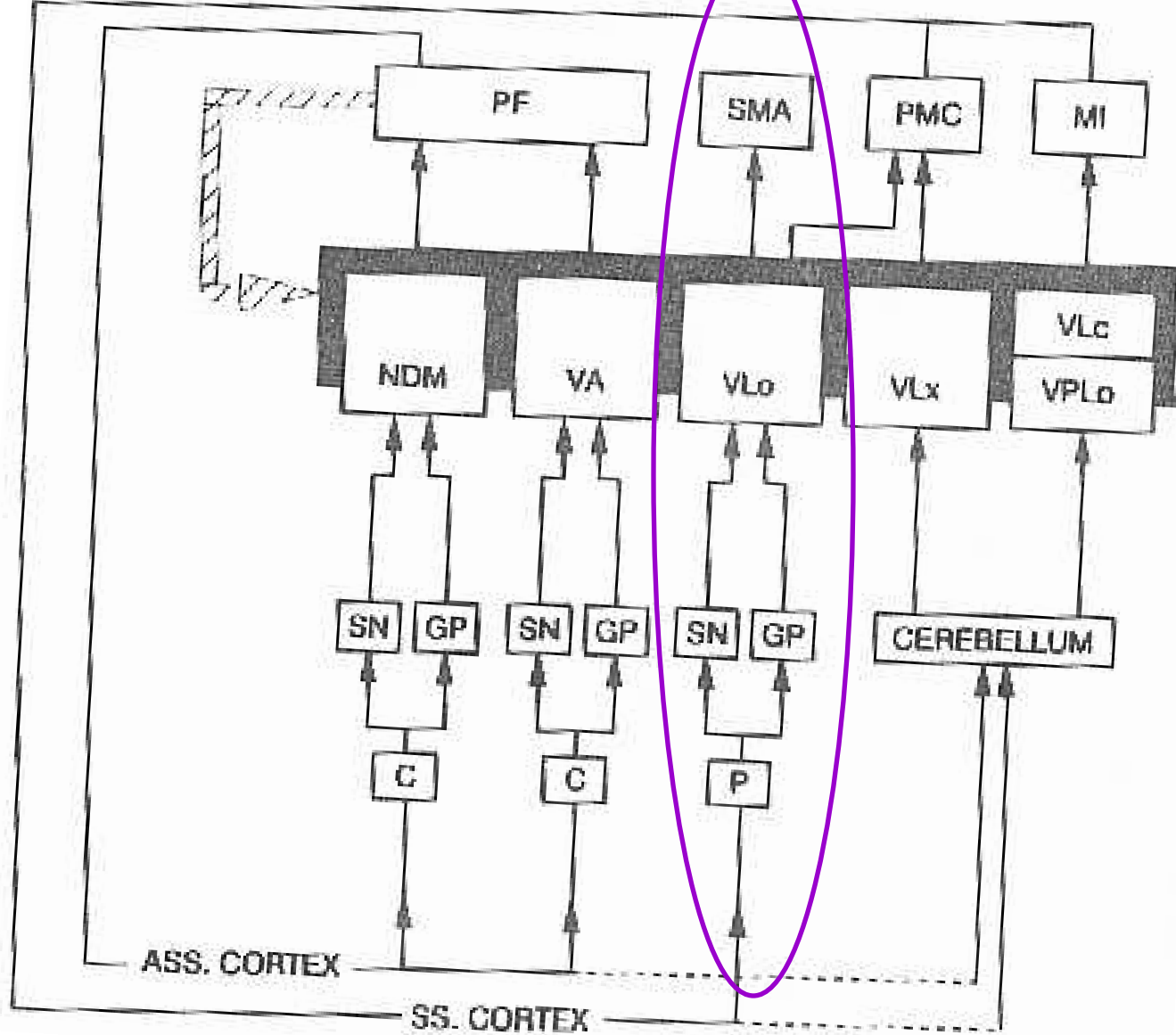
- PMP - Premotion Positivity

- MP - Motor Potential

RP - Readiness Potential symmetric
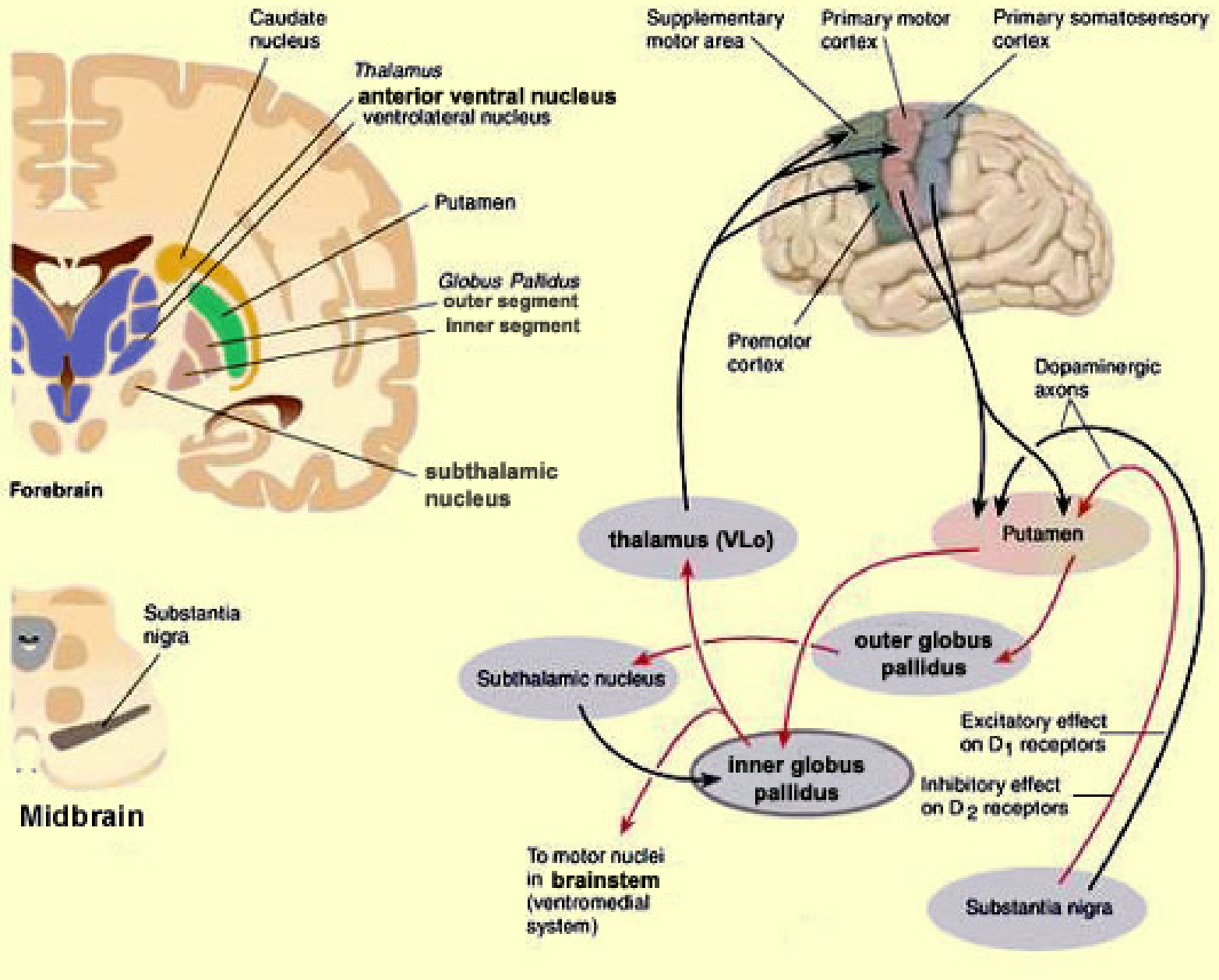1-1.5s prior to movement onset depending on
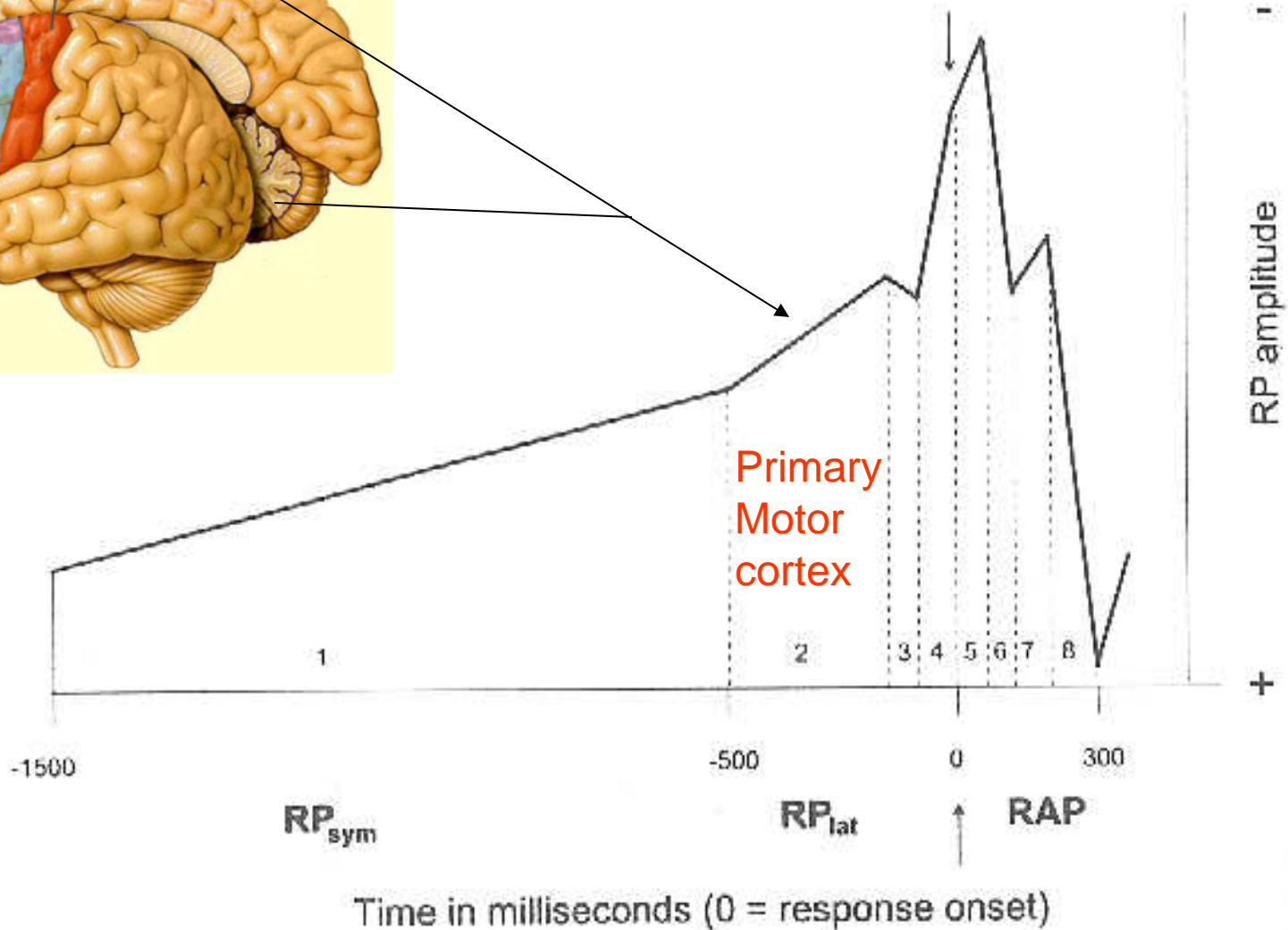- rate of movements
- complexity
- moving limb

Index of SMA functioning
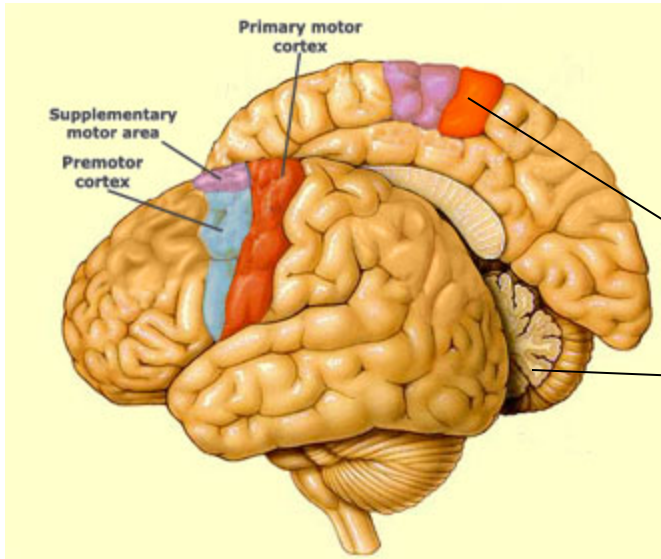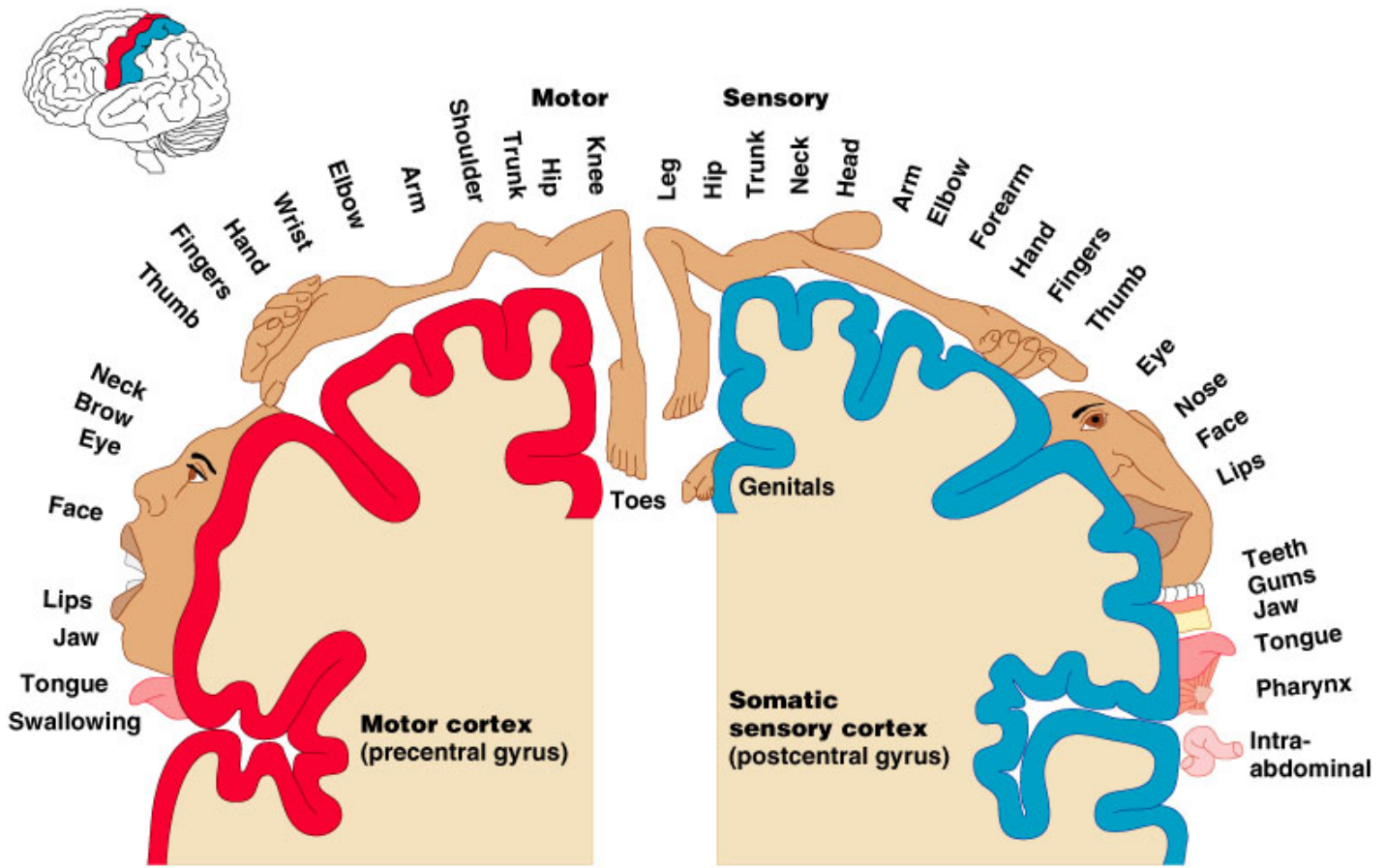
RP amplitude

−

+

1

2

3 4 5 6 7 8

−1500

−500

0

300

RP_{sym}

RP_{lat}

RAP

Time in milliseconds (0 = response onset)

RPsym generation dependent on basal ganglia loop

Caudate nucleus

Thalamus
anterior ventral nucleus
ventrolateral nucleus

Putamen

Globus Pallidus
outer segment
inner segment

subthalamic nucleus

Forebrain

Substantia nigra

Midbrain

Supplementary motor area

Primary motor cortex

Primary somatosensory cortex

Premotor cortex

Dopaminergic axons

thalamus (VLo)

Putamen

Subthalamic nucleus

outer globus pallidus

Excitatory effect on D₁ receptors

Inhibitory effect on D₂ receptors

inner globus pallidus

To motor nuclei in **brainstem** (ventromedial system)

Substantia nigra

Readiness Potential lateralized, aka N1 of MP, NS'
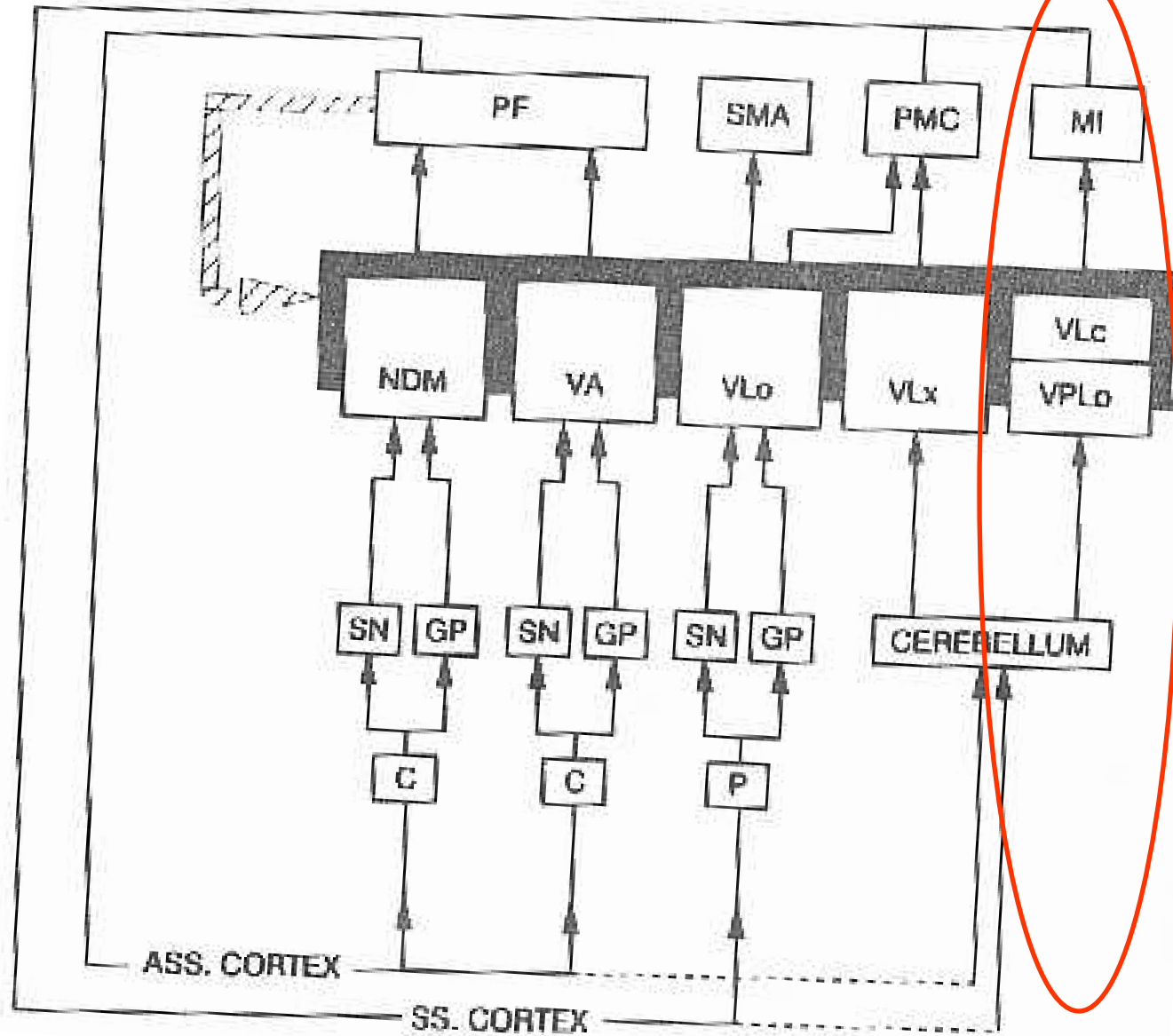 - begins 500 ms pre-movement, asymmetric
 - generated in primary motor cortex, depends on
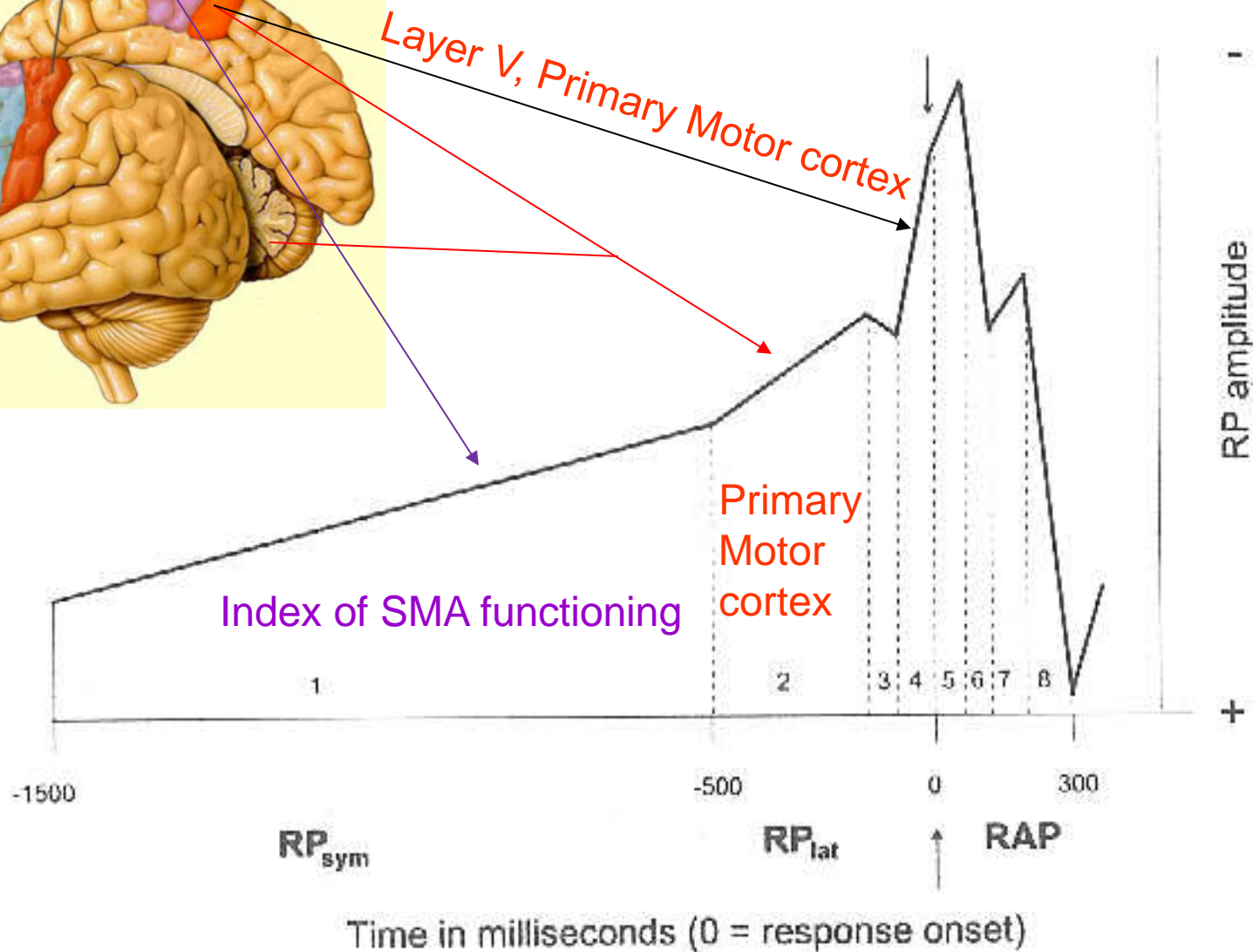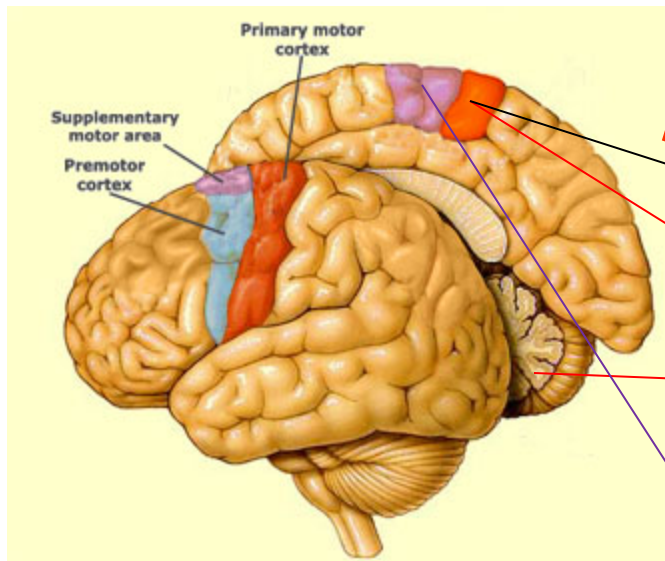   integrity of cerebello-thalamo-cortical loop

Primary Motor cortex

Primary motor cortex

Supplementary motor area

Premotor cortex

RP amplitude

−

+

1   2   3 4 5 6 7 8

−1500   −500   0   300

RP$_{sym}$ RP$_{lat}$ RAP

Time in milliseconds (0 = response onset)

Motor

Sensory

Shoulder · Trunk · Hip · Knee

Arm

Elbow

Wrist

Hand

Fingers

Thumb

Neck
Brow
Eye

Face

Lips

Jaw

Tongue

Swallowing

Leg · Hip · Trunk · Neck · Head

Arm

Elbow

Forearm

Hand

Fingers

Thumb

Eye

Nose

Face

Lips

Toes

Genitals

Teeth
Gums
Jaw

Tongue

Pharynx

Intra-
abdominal

Motor cortex
(precentral gyrus)

**Somatic
sensory cortex**
(postcentral gyrus)

Cerebello-thalamo-cortical loop necessary for RP$_{lat}$ generation

Pre-movement-related potentials

- **Pre motion positivity (PMP)**
  - 50-90 ms pre-movement onset
  - maximum at midline parietal (Pz)
  - bilaterally symmetric
- **Motor Potential**
  - 10-50 ms pre-movement onset
  - max at precentral sites contralateral to responding hand
  - command to move: discharge of pyramidal tract neurons (layer V) in MI

Primary motor cortex

Supplementary motor area

Premotor cortex

Layer V, Primary Motor cortex

Primary Motor cortex

Index of SMA functioning

RP amplitude

−

+

1

2

3 4 5 6 7 8

−1500

−500

0

300

RP_{sym}

RP_{lat}

RAP

Time in milliseconds (0 = response onset)

Voluntary Movement

1. Select motor strategy
   cortex → basal ganglia → SMA → reflected in RPsym

2. Set parameters for movement dependent on external context
   cortex→ cerebellum → motor cortex → reflected in RPlat

3. Command to move: discharge of pyramidal tract neurons in primary motor cortex → reflected in MP

CLINICAL USES OF READINESS POTENTIAL

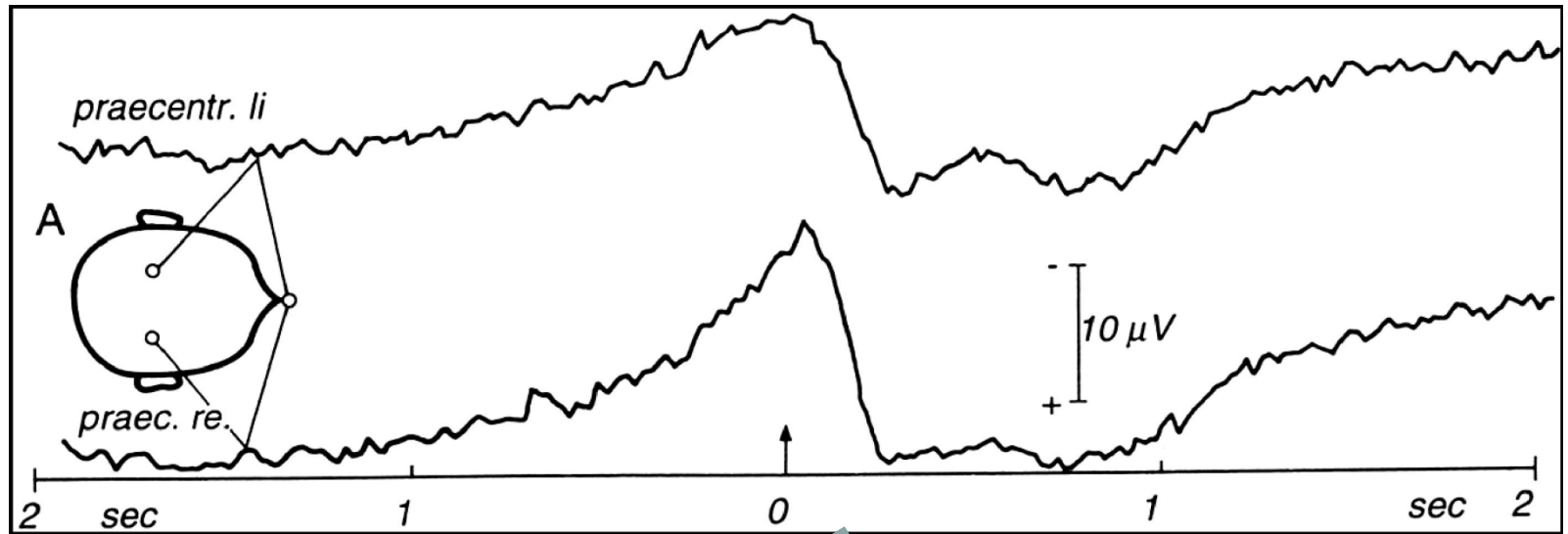UNDERSTANDING VOLUNTARY MOVEMENT

UNDERSTANDING DISORDERS OF MOVEMENT
 - TICS, REFLEXES, PARKINSON'S, HUNTINGTON'S
 - TOURETTE'S , RESTLESS LEG SYNDROME, TREMORS, ATAXIA

WAY TO TEST CONSEQUENCES OF STEM CELL IMPLANTS,
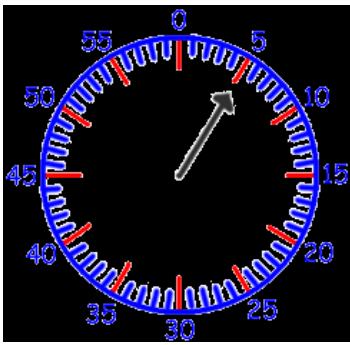INTEGRITY OF MOTOR SYSTEM

WAY TO ASSESS REHABILITATION PROCEDURES
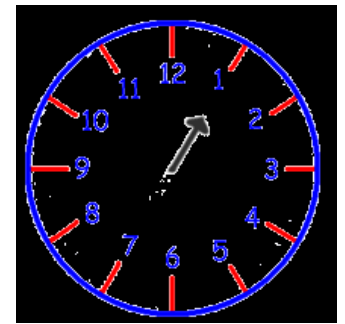
USEFUL TO UNDERSTAND ASPECT OF COGNITION

Voluntary movement initiated by hand

..can monitor preparation long before OVERT response (at time 0)!
Perhaps we can study intention, volition, will!

Libet's Protocol

- – Participants watched a clock hand that completed one revolution every 2.56 seconds.
- – While fixated on the clock, Ss voluntarily flexed a wrist at a time of their own choosing.
- – Participants reported the position of the clock hand at the time when they first became aware of their will, wish, desire to move (**W-awareness of their intent**)
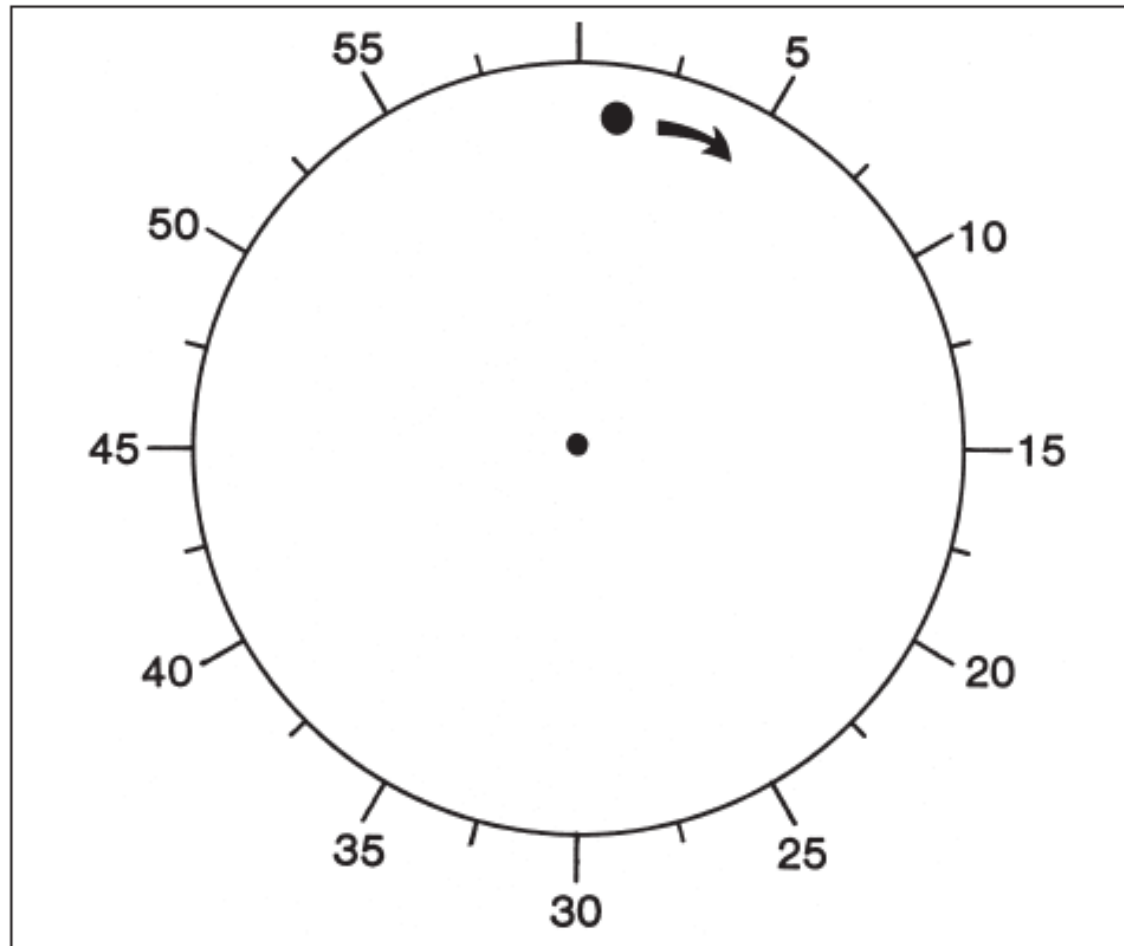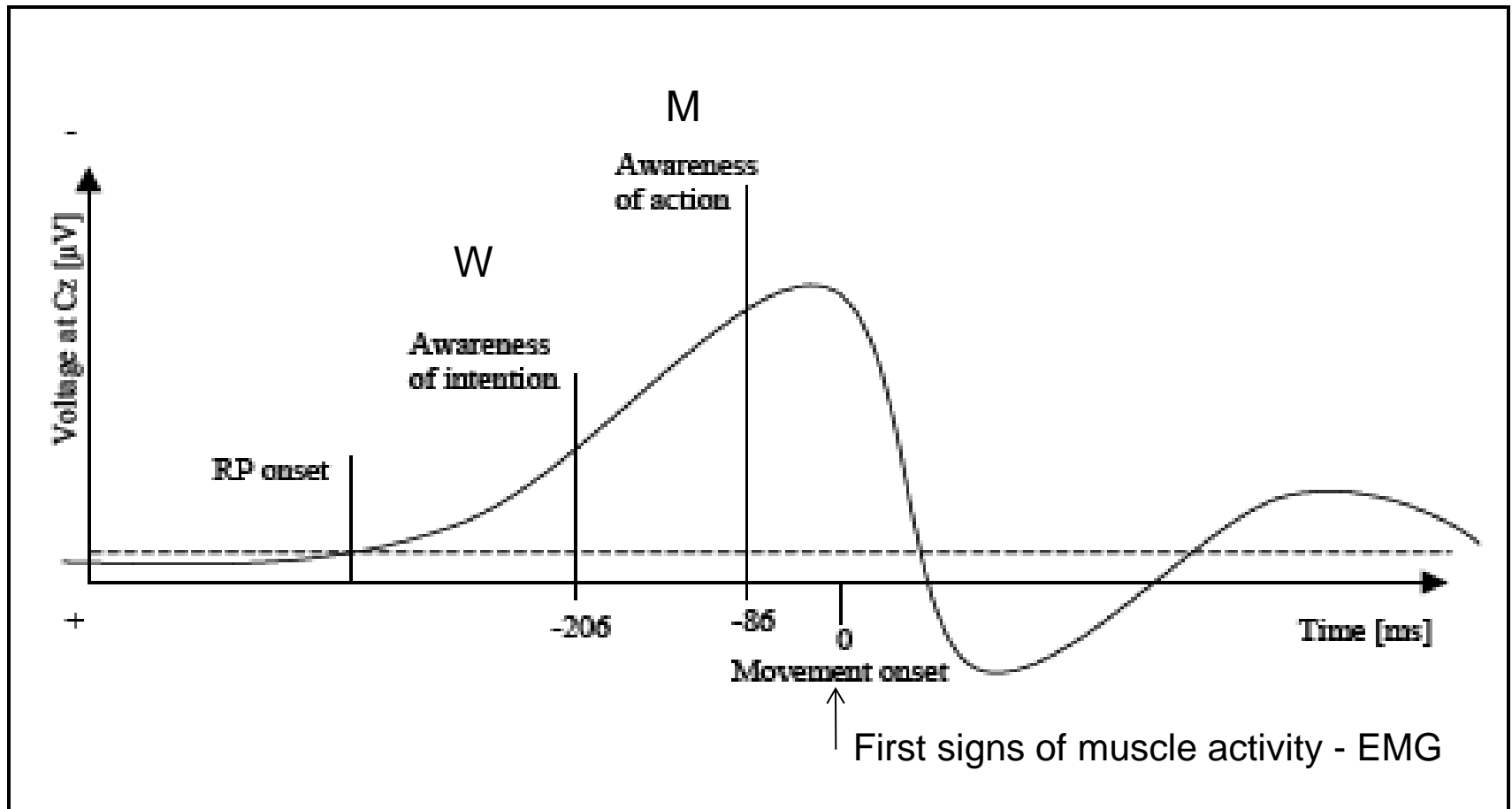- – In another condition judge **awareness of action (M)**.

Figure 2

Oscilloscope 'clock'. Spot of light revolves around periphery of screen, once in 2.56 sec. (instead of 60 sec. for a sweep-second hand of a regular clock). Each marked off 'second' (in the total of 60 markings) represents 43 msec. of actual time here. The subject holds his gaze to the centre of the screen. For each performed quick flexion of the wrist, at any freely chosen time, the subject was asked to note the position of the clock spot when he/she first became aware of the wish or intention to act. This associated clock time is reported by the subject later, after the trial is completed.
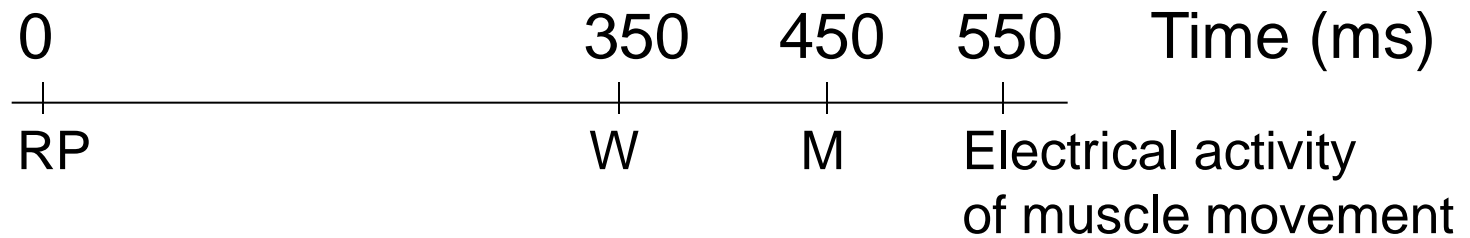
Spontaneous,
no plannning

pre-planned

Near threshold
skin stimulus
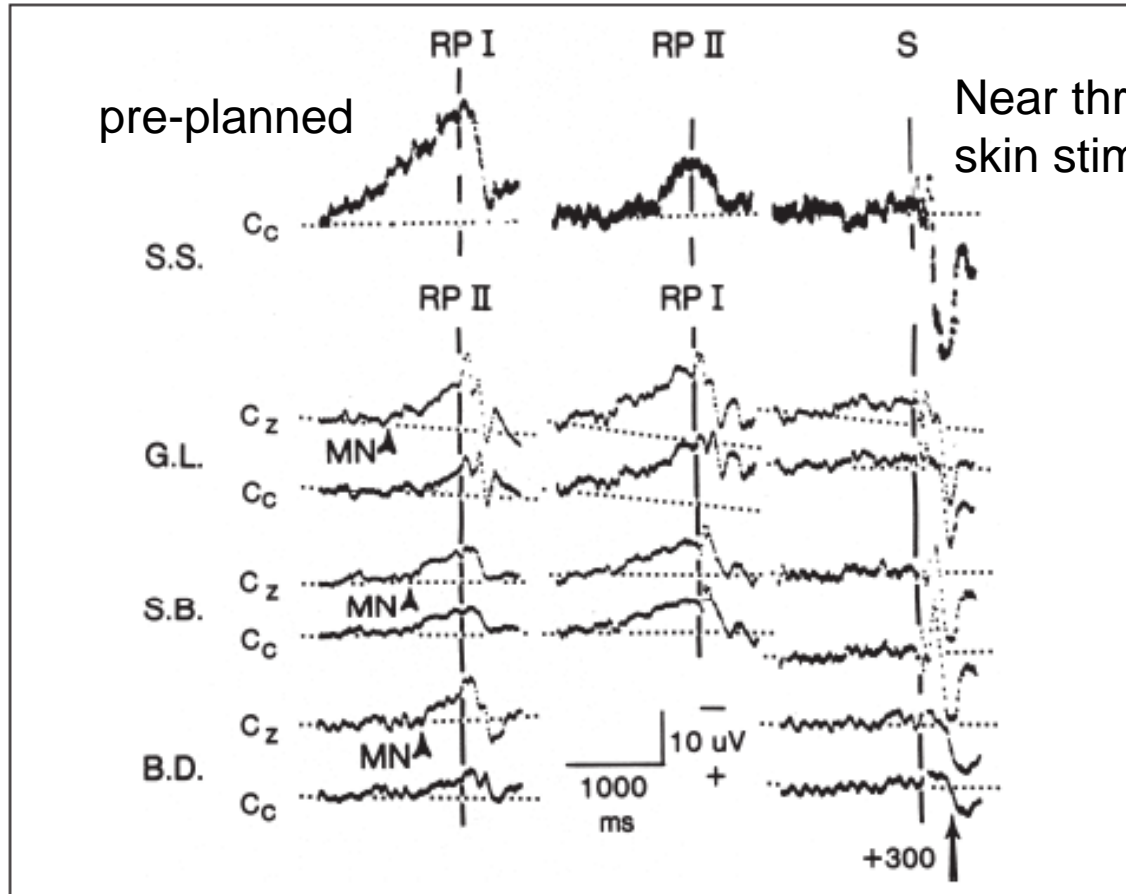
What free will ? Whoa…the RP begins before awareness of intent (W)!!

M
Awareness of action

W
Awareness of intention

RP onset

Voltage at Cz [μV]

-206   -86   0
                    Movement onset

Time [ms]

First signs of muscle activity - EMG

Neural time line for voluntary movement

```
0                        350    450   550    Time (ms)
├──────────────────────────┼──────┼─────┼──────
RP                         W      M     Electrical activity
                                         of muscle movement
```

RP = Onset of readiness potential

W = subject's judgment of will to move

M = subject's judgment of beginning of movement

Benjamin Libet

Do We Have Free Will?

*I have taken an experimental approach to this question. Freely voluntary acts are pre-
ceded by a specific electrical change in the brain (the 'readiness potential', RP) that
begins 550 ms before the act. Human subjects became aware of intention to act
350–400 ms after RP starts, but 200 ms. before the motor act. The volitional process
is therefore **initiated unconsciously.** But the conscious function could still control the
outcome; it can veto the act. Free will is therefore not excluded. These findings put
constraints on views of how free will may operate; it would not initiate a voluntary act
but it could **control performance of the act.** The findings also affect views of guilt and
responsibility.*

*But the deeper question still remains: Are freely voluntary acts subject to macro-
deterministic laws or can they appear without such constraints, non-determined by
natural laws and 'truly free'? I shall present an experimentalist view about these
fundamental philosophical opposites.*

UTILITY OF RP IN INVESTIGATIONS OF COGNITION

If RP generally or RPlat reflects preparation for intended movement, and is somatotopically related to relevant members (contralateral for hand/finger movements), then it can be used to investigate motor preparatory processes even when movement is **never** actualized!

This is a way to externalize a covert mental process, in all sorts of situations where people respond or plan to respond to a stimulus, even if they don't actually do so
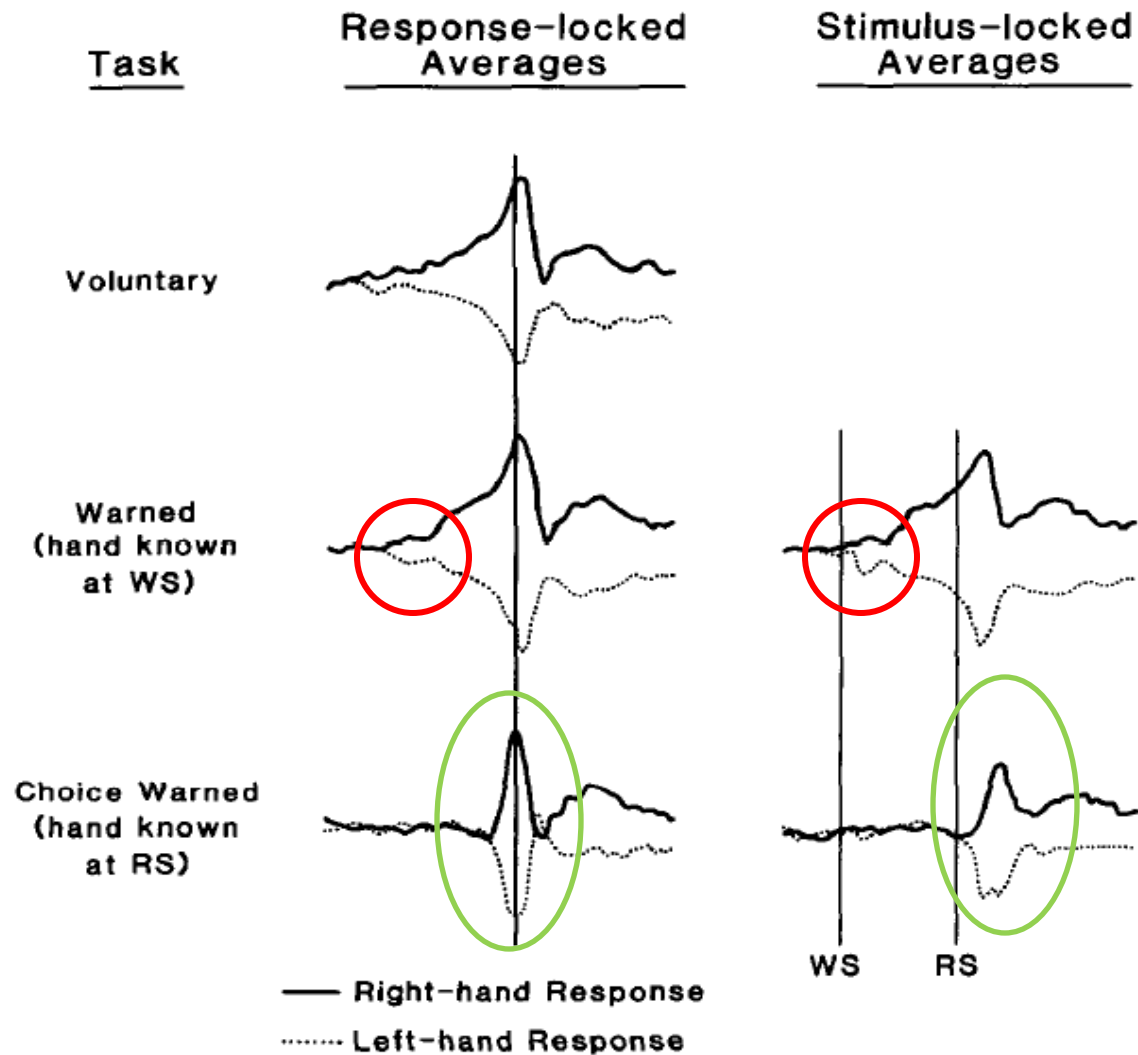
Fig. 2. Lateralized readiness potentials time-locked to the motor response, or to the respond stimulus, for three different conditions. Voluntary: the subject produced self-paced squeezes. Warned: the subject responded to the respond stimulus (RS) in a choice reaction time task when the warning stimulus (WS) provided information about the hand to be used. Choice Warned: the subject responded to the respond stimulus (RS) in a choice reaction time task when the warning stimulus (WS) did not provide information about the hand to be used. (Copyright 1980, Elsevier Science Publishers. Adapted with permission from the author and publisher from Kutas & Donchin, 1980.)