How we experience the passage of time: The body, feelings, and the self

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13th SYMPOSIUM OF BIAL FOUNDATION
BEHIND AND BEYOND THE BRAIN
The mystery of time, 9.4.2022

Agenda

- Cognitive model of time perception: research and application
- “10 researchers – 12 models“: the diversity of neural models of time perception
- My line of research on embodied time: current and historic evidence
  - How body signals inform us about the passage of time
- Timelessness & body-selflessness: altered states of consciousness
  - Meditation, Psychedelics, etc.

Two areas of ‘time perception’

(1) Temporal processes of the brain are involved in timing of actions: event synchronization

milliseconds to a few seconds

(2) Time is an experience: key to understanding cognitive processes and emotional states

multiple seconds

From the Wikipedia website on “Boredom”

Time Perspectives

Retrospective time perspective (looking back):

=> Memory contents / amount of changing experiences

Vacation/activities: subjective time expands

Everyday routine: subjective time seems shorter

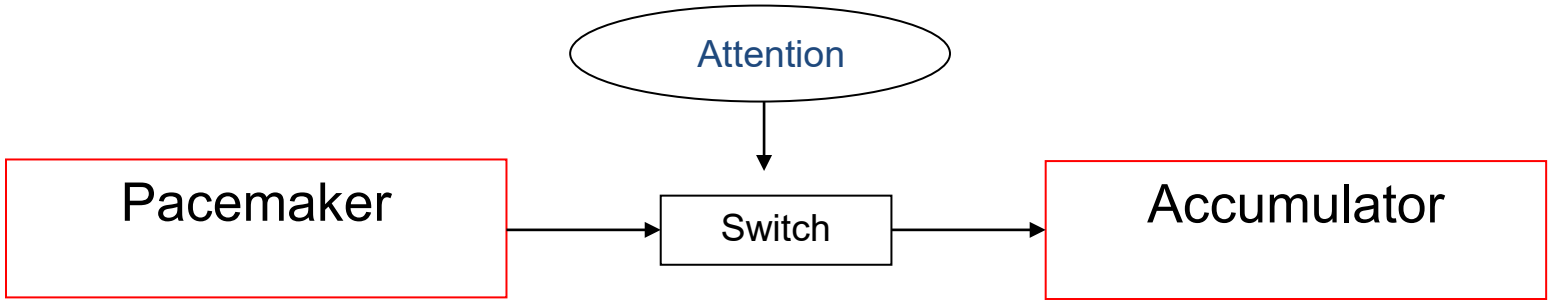
Prospective time perspective (experienced at the present moment):

=> Attention to time vs. distraction from time

Waiting time/boredom: time passes slowly

Distraction/pleasure: time passes quickly

Cognitive model of time perception

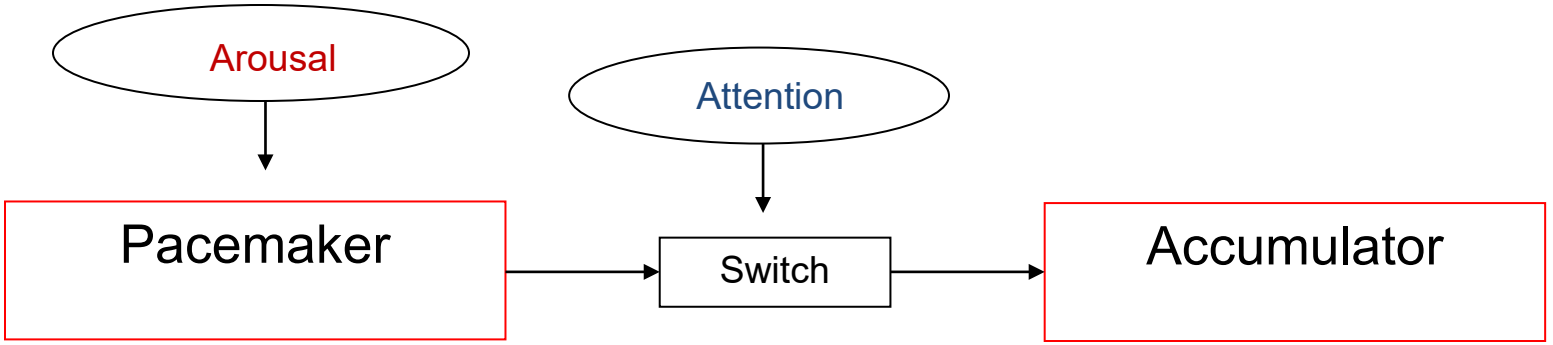


Amount of pacemaker impulses in accumulator = subjective duration

→ Subjective expansion of duration through

1. Attention

Cognitive model of time perception



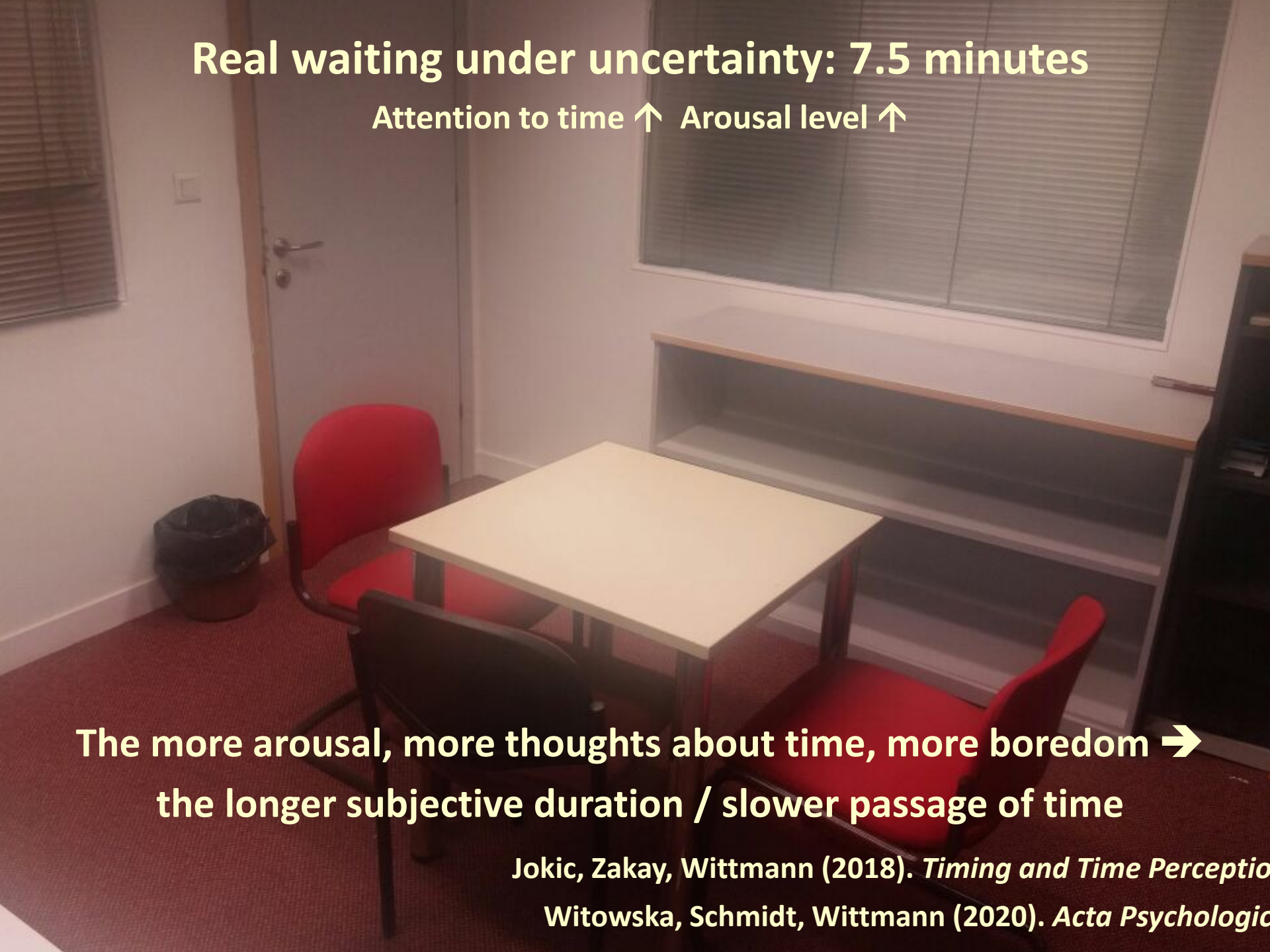
Amount of pacemaker impulses in accumulator = subjective duration

→ Subjective expansion of duration through

1. Attention

2. Arousal


Real waiting under uncertainty: 7.5 minutes
Attention to time ↑ Arousal level ↑


Real waiting under uncertainty: 7.5 minutes
Attention to time ↑ Arousal level ↑
The more arousal, more thoughts about time, more boredom ➔
the longer subjective duration / slower passage of time
Jokic, Zakay, Wittmann (2018). *Timing and Time Perceptio*
Witowska, Schmidt, Wittmann (2020). *Acta Psychologic*

Psychological and Neural Models of Time Perception

Functional principles:

- Pacemaker-accumulator model (Treisman, Church, Zakay)
- Memory decay (Staddon, Wackermann)
- Amount of energy expenditure when encoding time (Ernst Mach, Eagleman)
- Coincidence detection of oscillations (Meck)
- Short-term synaptic plasticity (Buonomano)

Brain locations:

- Striatum (Meck, Rammsayer)
- Right frontal lobe (Lewis & Miall, Harrington, Rubia)
- Right posterior parietal cortex (Bueti & Walsh)
- Cerebellum (Ivry)
- Anterior insula (Craig)
- Multiple sensory areas (Buonomano)
- …

⇒ No agreement on processing model

⇒ No agreement on neural substrates

Sources of difficulty in localizing brain areas for a time sense

- Several patient populations impaired in time perception:
  - Patients with lesions to cerebellum
  - Cerebral right-hemisphere (fronto-parietal)
  - Patients with Parkinson's disease
  - …

    But: Impairment ≠ brake down of performance

- Effects on different transmitter systems
  - **Dopamine** agonists/antagonists speed up/slow down "internal clock" (Meck, Balci)
  - **Serotonin** agonists impair temporal processes (Wittmann)
  - Resting-state **GABA** concentration levels (Terhune)

- Disruption of several brain areas through Transcranial Magnetic Stimulation (TMS) transiently impairs timing
  - Frontal cortex, cerebellum (G. Koch, C. Koch)

- Neuroimaging studies: always multiple brain areas activated

➔ Multiple parallel neural systems for processing time

Neuroimaging studies: multiple brain areas active

x	*y*	*z*	Z value	Functional region	Anatomical locus
(A) TIME > LENGTH 0.6 s					
Prefrontal cortex					
50	24	0	6.0	VLPFC (R)	Pars triangularis
48	39	24	5.1	DLPFC (R)	MFG, just dorsal to IFS
62	21	0	5.1	VLPFC (R)	Ventral ramus of lateral fissure
42	53	−6	5.0	Frontal pole (R)	MFG, just anterior to IFS
−45	50	12	5.0	Frontal pole (L)	Anterior MFG, just dorsal to IFS
−36	59	24	3.2	Frontal pole (L)	MFG, inferior bank of SFS
−48	39	36	3.2	DLPFC (L)	MFG
Insula					
36	24	−6	4.7	Insula (R)	Anterior insula
−42	21	0	4.8	Insula (L)	Anterior insula
Premotor cortex					
0	15	54	5.3	preSMA (R/L)	Medial wall of SFG
3	27	48	5.4	preSMA (R)	Medial wall of SFG
48	9	42	3.8	vPMC (R)	Posterior to VPCS-level with IFS
48	9	54	3.5	dPMC (R)	Posterior bank of DVPCS
−48	15	24	4.2	Frontal operculum (L)	Frontal operculum
−56	15	42	3.3	vPMC (L)	Posterior bank of DVPCS
Parietal cortex					
53	−45	60	4.1	IPS (R)	Inferior bank IPS
45	−45	42	3.9	Inferior parietal (R)	Angular gyrus
−39	−42	48	3.6	Inferior parietal (L)	Angular gyrus
Cerebellum					
−30	−65	−42	3.3	Cerebellar hemisphere (L)	Cerebellar hemisphere, Crus I/II
Temporal cortex					
−53	−42	18	3.4	STG (L)	Posterior superior temporal gyrus

Lewis & Miall 2003, Neurospychologia

Explaining the variety of models:
Duration-dependence of temporal processes

Working Memory

Millisecond timing < 500 ms

- **Modality-specific** processes

Timing between 500 ms – 2 to 3 seconds

- **Sensori-motor processing**: motor areas

Multiple-second time perception

- In humans: insular cortex activity related to interoception

Long-term memory for seconds and minutes intervals

- (para-) hippocampal structures (medial temporal lobe)

Where and how in the brain ?

… yet another (my) answer

for intervals with longer duration

Subjective time & the bodily self

THE KAVLI Institute for Brain and Mind at UCSD
University of California, San Diego

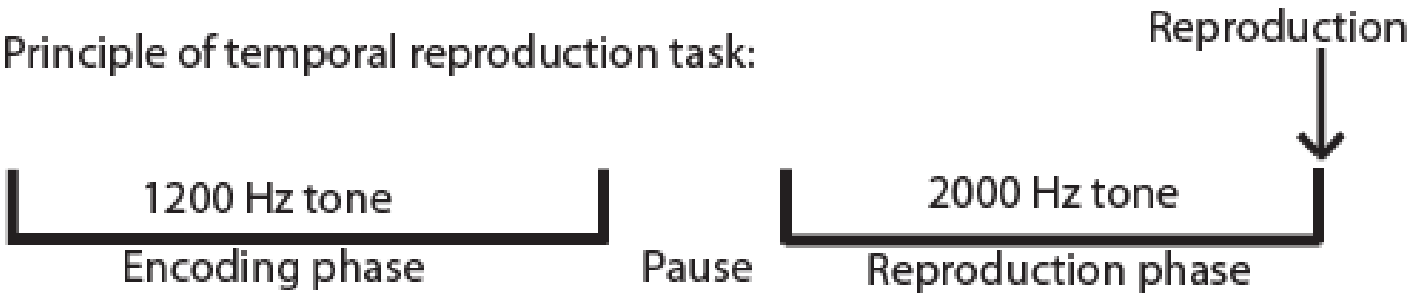
fMRI duration reproduction task

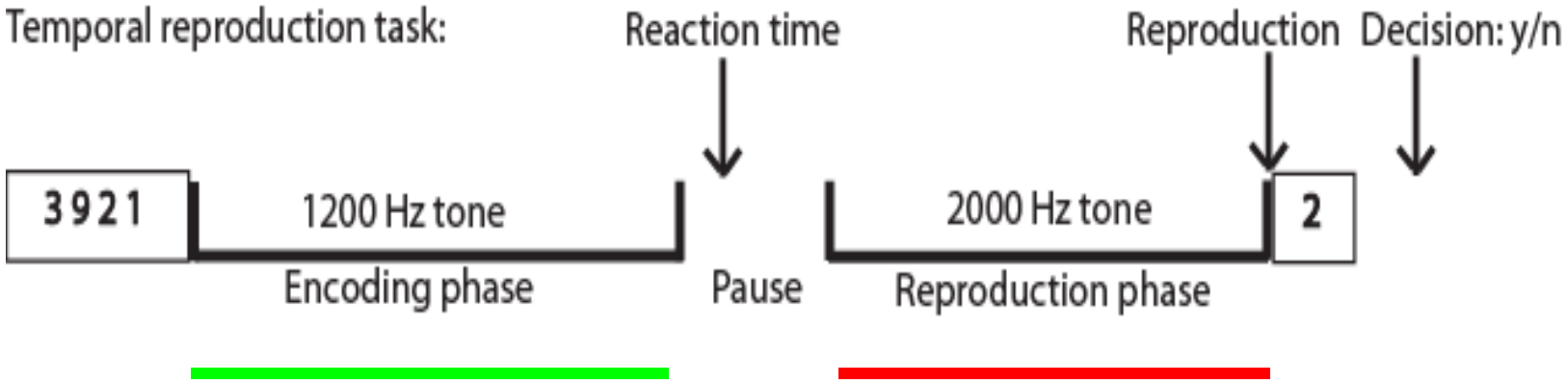
Which brain areas are involved in the perception of multiple-second duration?

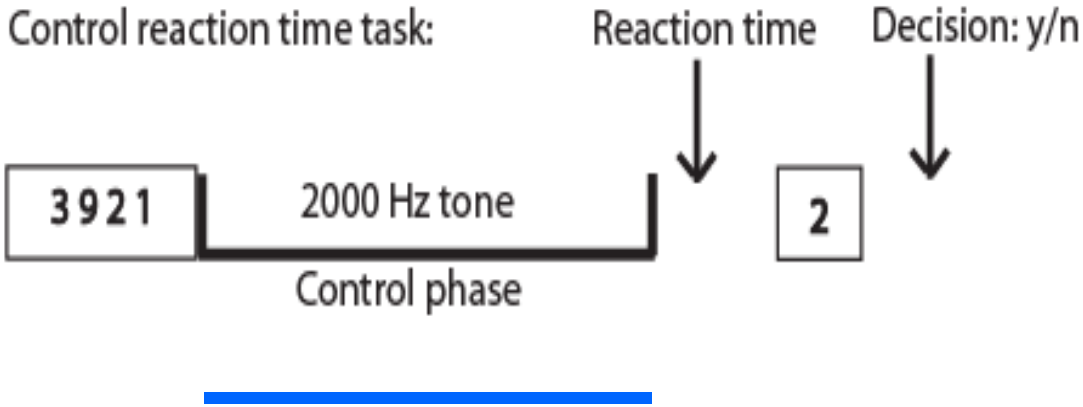
Duration of 3, 9, 18-s sinus tones

Counting prevented through a secondary memory task

Principle of temporal reproduction task:




Temporal reproduction task:
Reaction time
Reproduction
Decision: y/n
3921
1200 Hz tone
Encoding phase
Pause
2000 Hz tone
2
Reproduction phase


Control reaction time task:
Reaction time
Decision: y/n
3921
2000 Hz tone
2
Control phase

1. Step: Activation contrasts (ROI): Encoding phase vs. control phase

   ⇒ *Where* in the brain?

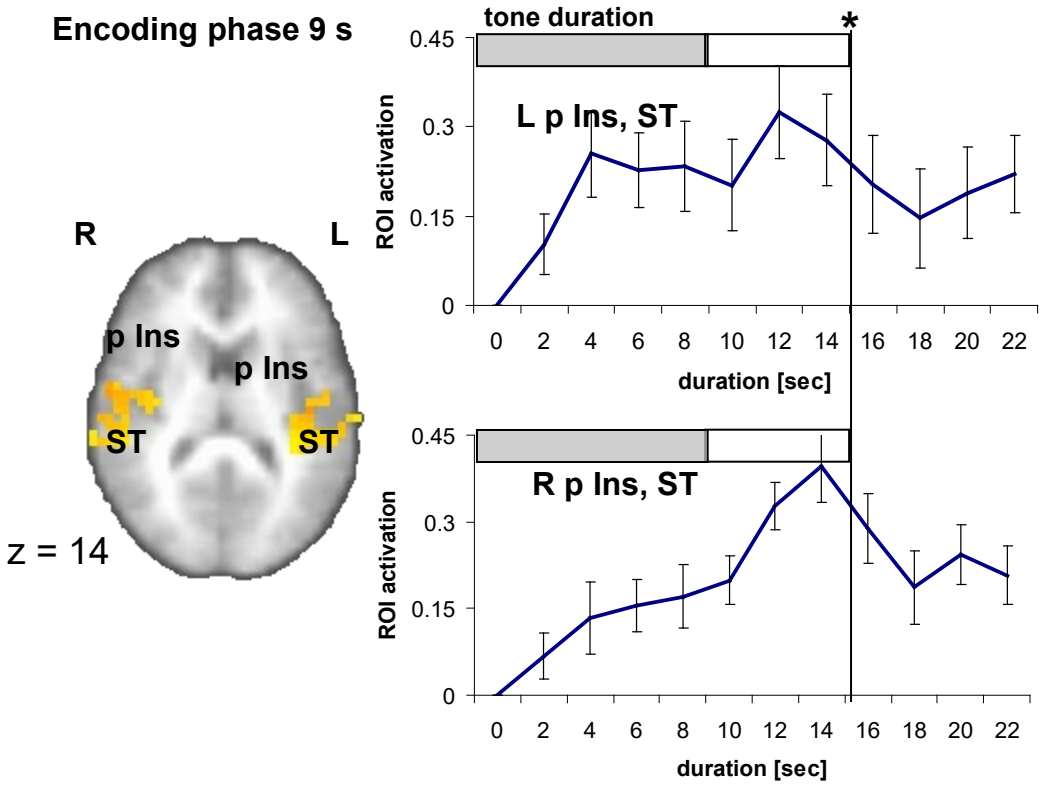
3 s				9 s				18 s			
Brain area	µl	Talairach (x y z)	t	Brain area	µl	Talairach (x y z)	t	Brain area	µl	Talairach (x y z)	t
Encoding phase> control phase											
R SMA	832	3 –24 55	4.8	L R SMA	2752	1 –22 56	6.3	L R SMA	896	2 –22 54	5.6
R subgenual ACC, caudate	1088	3 18 –1	7.5	R pre- post-central	5888	25 –29 59	7	R pre-central	768	43 13 50	4.6
L caudate, thalamus	832	–19 –35 16	5.2	R pre-central	768	48 12 48	4.6	R posterior insula, post-central	1536	45 –15 15	5.9
L angular gyrus, precuneus	896	–39 –70 34	4.6	R posterior insula, pre-central, superior temporal	5760	53 –19 14	6.3	L posterior insula, transverse temporal	1280	–40 –25 14	6.2
				L posterior insula, pre-central, superior temporal, transverse temporal	4864	–45 –23 12	8.2	L inferior frontal, superior temporal	768	–33 6 –16	6.4
								R inferior frontal, superior temporal	768	26 10 –11	8.9
								R superior temporal, inferior parietal	896	55 –30 16	5.6
								R superior temporal (temporal pole)	832	45 12 –19	4.6

2. Step: Time activity curves

   in bins of 2 sec (TR) in ROI during encoding and reproduction phase

   ⇒ *How* in the brain?

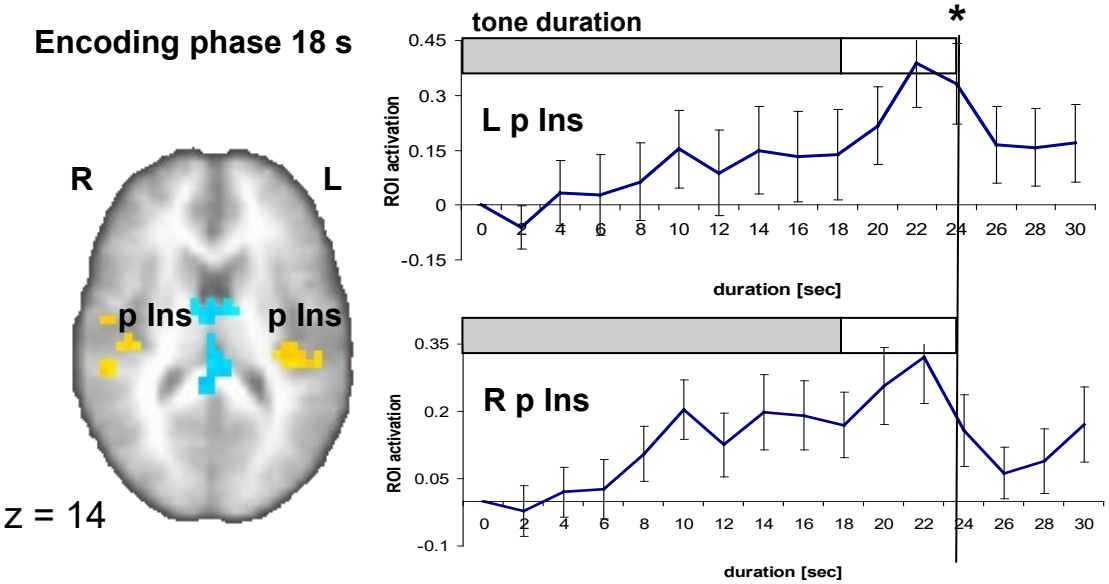
encoding phase 9 s



*** projected peak of hemodynamic response**

Wittmann, Simmons, Aron, Paulus (2010) *Neuropsychologia*

encoding phase 18 s



*** projected peak of hemodynamic response**

Wittmann, Simmons, Aron, Paulus (2010) *Neuropsychologia*

Insular cortex: primary interoceptive area

1. Represents physiological conditions of the body => homeostatic regulation of physiological needs (thirst, hunger, temperature, pain, etc.)

2. "Interpretation" of physiological states: basis of complex human emotions
(James-Lange theory; Damasio: *Somatic Marker Hypothesis*)

<u>Neuroimaging and lesion studies:</u>

- Physiological needs: thirst, hunger, pain, touch, drug craving, …

- Emotions: affective stimuli, anxiety, empathy, guilt, …

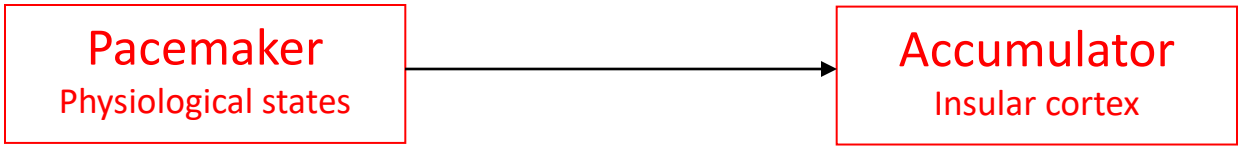
- Complex decision making ("gut feeling")

- Music perception (temporal structure, emotion)

- Meditative states (concentration on self, body self)

Working hypothesis: Insula and the encoding of duration

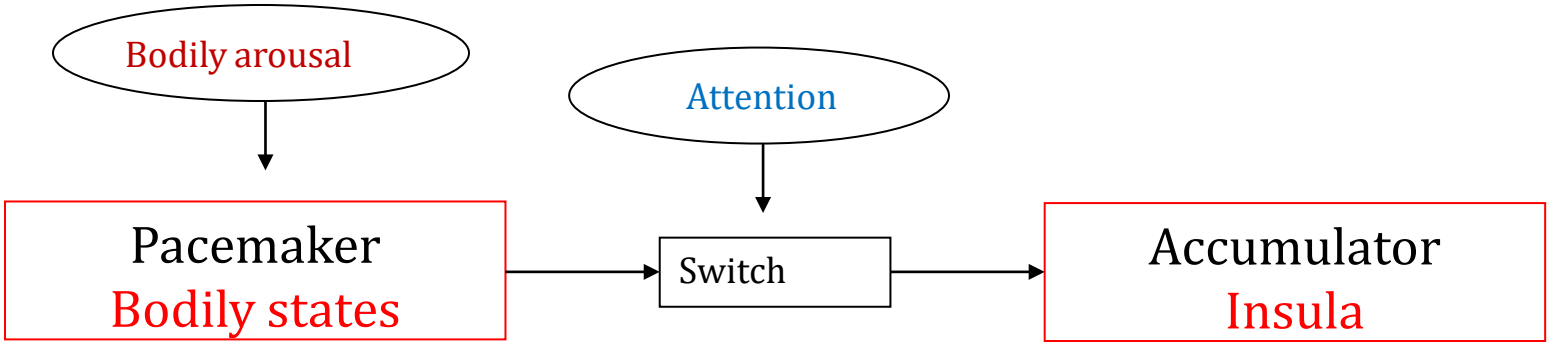
Body states, interoceptive signals → encoding of duration



Time is not perceived in the outside world
=> But through interoception, by the “material self”

Phenomenology: Embodied Cognition
Maurice Merleau-Ponty

Modulators of prospective time perception



Amount of pacemaker impulses in accumulator = subjective duration

→ Subjective expansion of duration through

1. **Attention to bodily states** (meditative states, waiting time)
2. **Increased bodily** arousal (affective states)

Embodied time: Hugo Münsterberg (1863—1916)

- Studied with Wilhelm Wundt in Leipzig
- Founded in Freiburg one of the first experimental psychology labs
- By invitation of William James moved to Harvard in 1892

Freiburg study:

- Duration reproduction task with intervals between 6 and 60 seconds
- Temporal reproductions most accurate when the onset or offset of intervals coincided with breathing in.

" … the sense of time relies on the sensation of tension in different organs which are caused by muscle contractions." (Münsterberg 1889)

Münsterberg H. (1889). Beiträge zur experimentellen Psychologie, Heft 1, Freiburg: J.C.B. Mohr

The heart and time

- Right anterior insula activation: perception of synchronisation between heart beat and tones (Critchley et al. 2004)

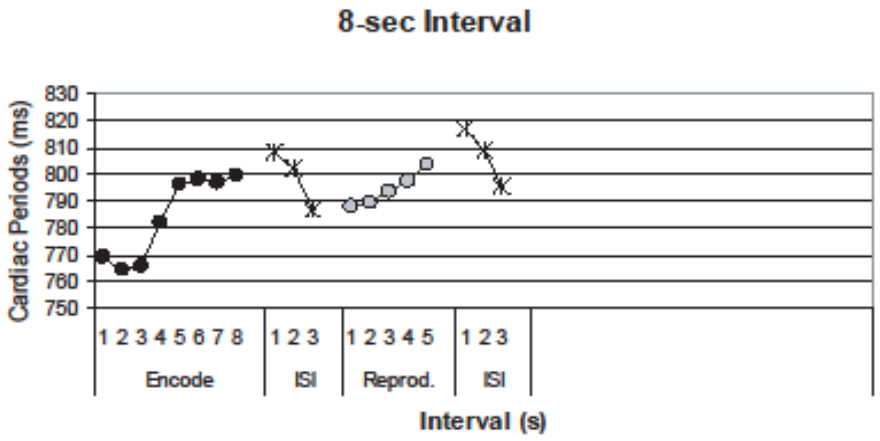
- Heart-rate variability (HF power, total power of HRV) correlates positiviely with timing ability in milliseconds range (Cellini et al. 2015)

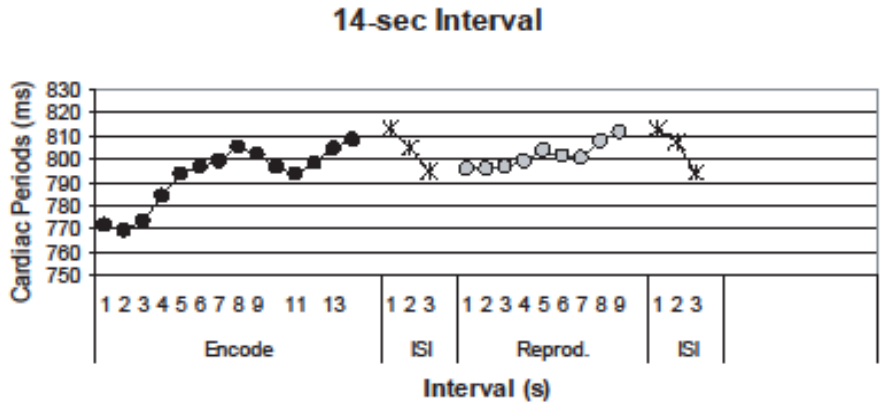
- Individuals with higher body awareness (Schandry heart-beat perception task) reproduce duration in the seconds range more accurately (Meissner & Wittmann 2011)

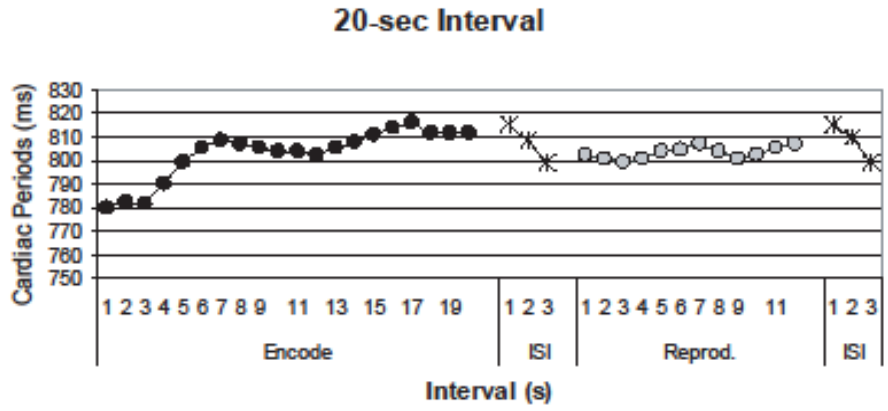
Evidence: Heartbeat slows down during interval timing of multiple-seconds intervals

linear trend correlates positively with duration reproduction performance

= the steeper the slope, the longer the reproduced duration







Meissner & Wittmann (2011) *Biological Psychology*

Insula & time

- **Reviews of neuroimaging studies** on time perception: Sub-second and supra-second time domain (Wiener et al., 2010; Teghil et al., 2019; Nani et al., 2020)

- **fMRI duration reproduction** of acoustic and visual stimuli (**500 to 1500 ms**): activity in mid-insula (encoding phase) and left anterior insula (reproduction phase); related to the feeling of time passage? (Bueti / Macaluso, 2011)

- **fMRI duration reproduction (8 – 18 sec.):** Resting-state connectivity with posterior insula correlated with timing of **irregular cue condition** (Teghil et al., 2020)

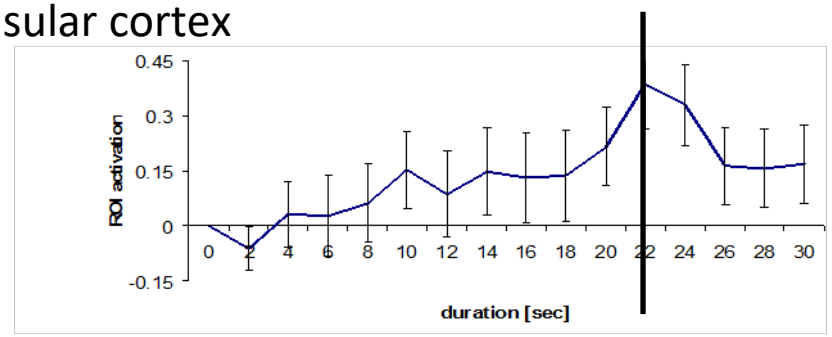
- **Duration estimation 300 ms and 1500 ms**: 21 patients with stroke in RH or LH compared to CG. Patients with RH insular cortex lesions, but not LH insula impaired (Mella et al., 2019)

Concerning problem of reproducibility … follow-up studies

1. fMRI study: Increasing activation over time in insular cortex

   Replication: 2010 => 2011

   (Wittmann et al., 2010, 2011)

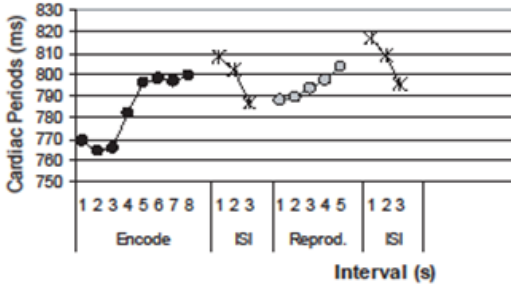


2. Slowing of heart-beats over time

   Replication: 2011 => 2015

   2014: auditory & visual

   (Meissner & Wittmann, 2011; Otten et al., 2015)



3. Correlation: Schandry heart-beat task & time perception accuracy

   Not replicated (2011 => 2015): no association

   2nd study with older subjects; Schandry task methodologically weak

   (Meissner & Wittmann, 2011; Otten et al., 2015)

Multiple parallel neural systems for processing time

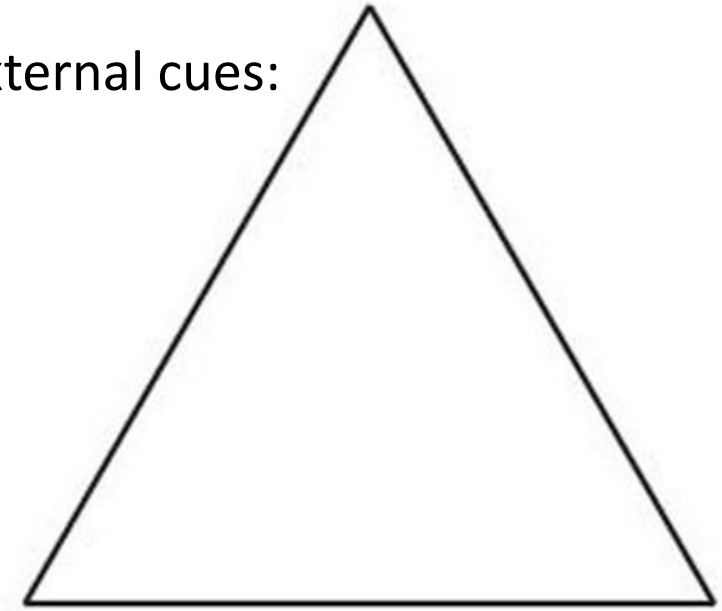
Self-awareness continuum

Self-awareness <u>lowest</u>

External focus/external cues:

Flow

Absorption



Sensory-motor areas

Insula

Interoception

Self-awareness <u>highest</u>

Internal focus /no external cues:

Mindfulness

Boredom

Emotions, the body, and time

- Psychophysics: Stimuli with emotional content are judged to last longer
- Individuals with high body temperature (fever) overestimate time
  (Francois 1927, Hoagland 1933; see Wearden 2019)
- Time passes more slowly when smokers have a physical urge for nicotine
- Surprise/effortful self-regulation correlated with overestimation of duration
- During body-focused meditation subjective time expands

Psychopathology, bodily symptoms & time perception

Overestimation of duration / Slowing down of subjective time / Being "stuck" in time

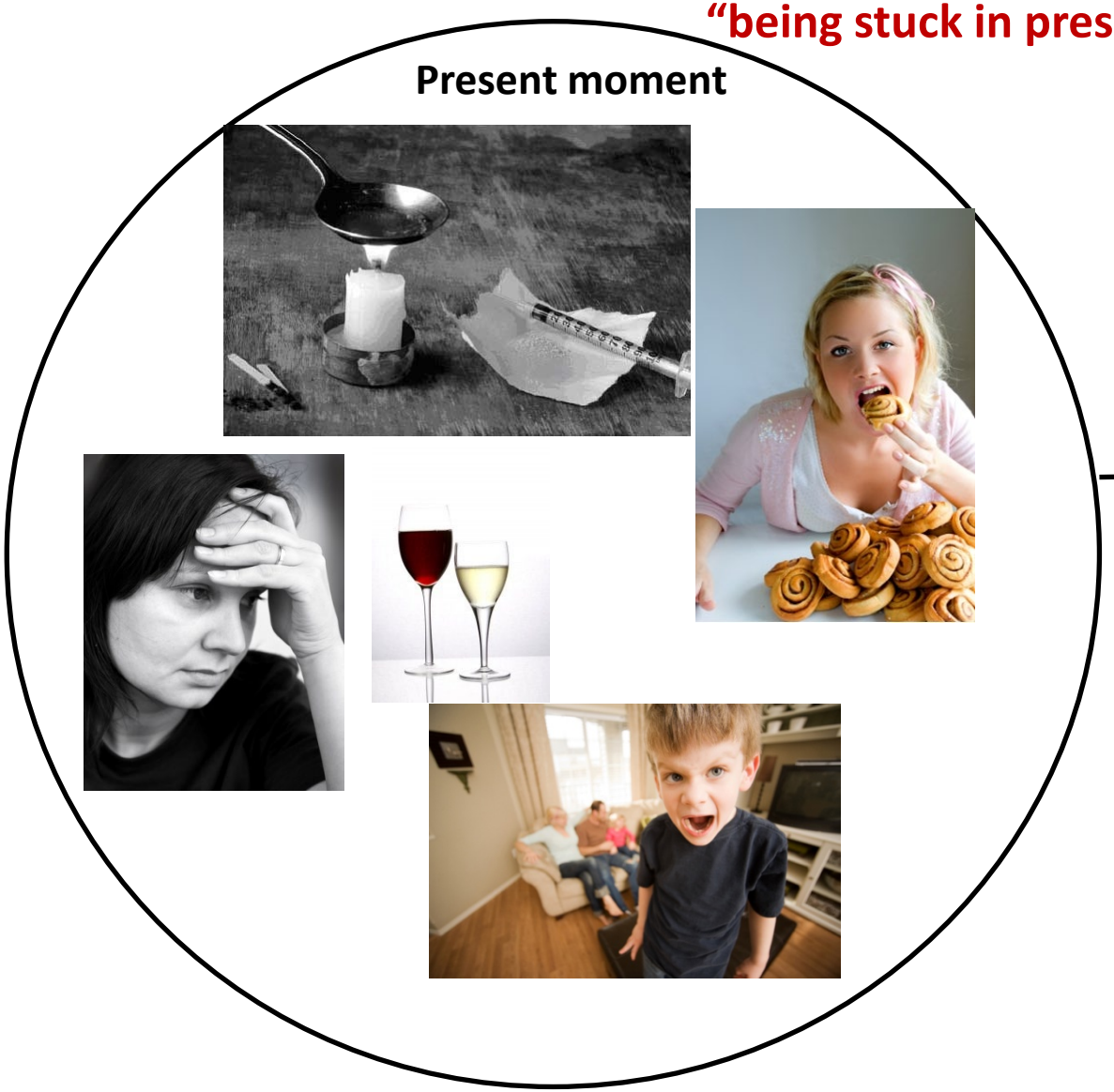
- Patients with depression (Bschor et al. 2004, Vogel et al. 2018)
- Patients with cancer and anxiety / depression (Wittmann et al., 2006)
- Drug dependent patients in rehab: methamphetamine, cocaine (Wittmann et al., 2008)

- Impulsivity as symptom of psychiatric/neurologic syndromes (Wittmann & Paulus, 2008)

Psychiatric disorders: overestimation of **duration**

discounting of **future**

"being stuck in present moment"



Syndromes:

Drug dependence
Depression
Anxiety
ADHD
Borderline

Symptoms:

- emotional overshooting
- impulsivity
- aggression
- boredom

Embodied time: Gabriel Revault d'Allonnes (1872-1949)

- Psychiatrist at Sainte-Anne psychiatric hospital in Paris
- Describes female psychiatric patient *Alexandrine* in article (d'Allonnes 1905)

No sense of body feelings and urges (hunger, satiety, thirst, urinate, fatigue)

Tests: no reactions to ice water / needle prick

No emotional feelings

Physiological reactions of emotions (tears), but no feeling/sentiment

No sense of time

Cognitive control of time through newspapers, daylight, clocks

No subjective sense of duration in the seconds-to-hours range

Tests: Impaired sense for different metronome speeds

"… the duration perceived by consciousness is nothing less than visceral sensibility … we have something resembling internal clocks made up of various physical rhythms, supplied by signals from our gut, bladder, lungs, arteries, and heart."

D'Allonnes G.-R. (1905). Rôle des sensations internes dans les émotions et dans la perception de la durée. Revue Philosophique de la France et de l'Étranger 60, 592–623.

Hypothesis:

Self (body) consciousness ↕ = Time consciousness ↕

Intensified awareness of the self (body, feelings): intensified awareness of time

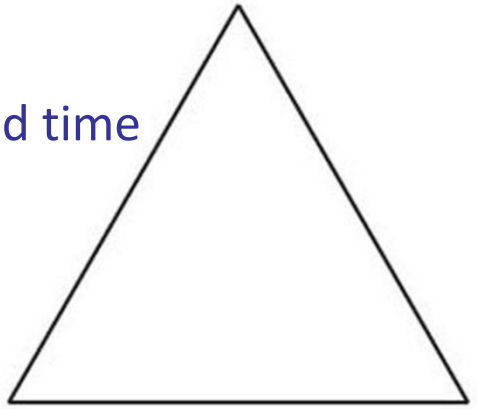
Weakened awareness of the self (body, feelings): less awareness of time

⇒ Altered states of consciousness modulate the “self“ and “time“

Flow:

Absorbed in activity => loss of sense of self

⇒Time speeds up dramatically: no feeling of self and time



Boredom/ Waiting time:

Particular **intensive** (negatively experienced) self awareness

⇒Time dilation: intensive feeling of self and time

Self & time: Altered states of consciousness

Intensified self-experience => „Ego“ dissolution

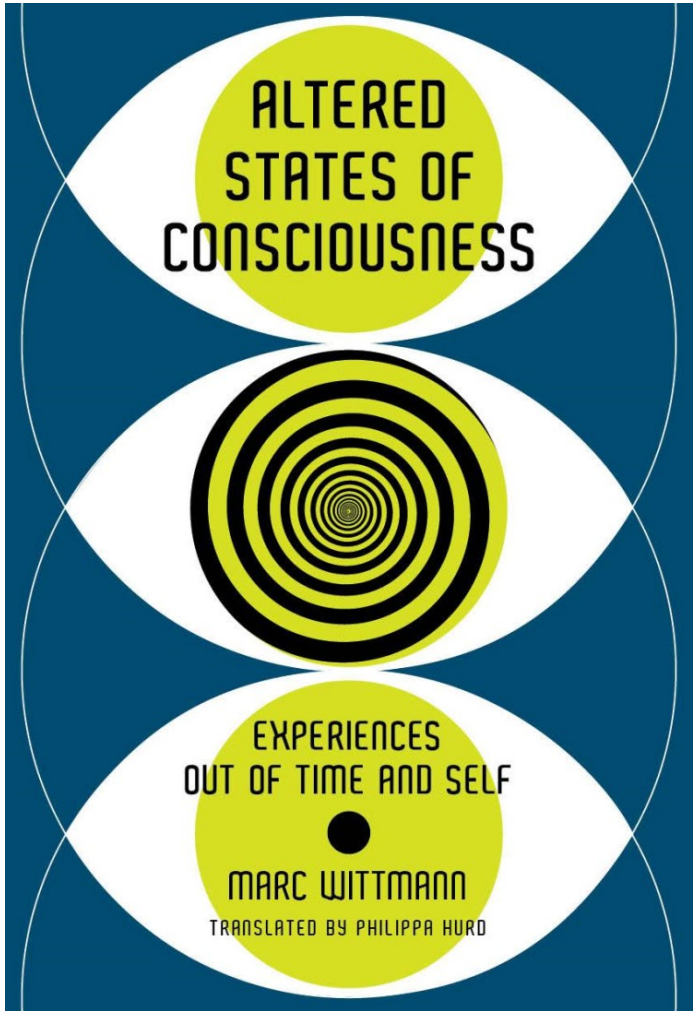
Slowing down of time Dissolution of time & space

Video games

Meditation

Isolation Tank

Drugs, Psychedelics



Timelessness & Meditation

Tilmann Lhündrup Borghardt – Buddhist meditation teacher

- 35 years experience in meditation
- 21 years monch in buddhist monastery
- for 10 years: 12 hours meditation per day
- > 50.000 hours of meditation

Dissolution of self & time: “The awakening“

The timeless awareness during meditation is an awakening. It has no beginning and no end. This timeless time is an immersion into a being where no comparing happens. When we are comparing, there are always relations between a before and an after. It is timeless presence without the sense of an ‘I’, without observer. Perception and perceiver are one.

Wittmann M (2018). Altered States of Consciousness. MIT Press

Floatation tank

- Two modes of consciousness: Interoception & Mind wandering
- No stimulation through external senses

Initial experience:

Prospective: subjective slowing of time/ increased awareness of time

Retrospective: Shortening of time / loss of time

Forgays & Belinson (1986) *Journal of Environmental Psychology*

With more experience:

Loss of sense of self and time

"Instant meditation"

Justin Feinstein, *Clinical Floatation*

Psychedelics: LSD, Psilocybin, Ayahuasca, Mescaline

Oceanic Boundlessness Scale (5-D ASC): Vollenweider lab U Zurich

Item correlations: **Ego** dissolution

Dissolution of **time**

Feeling of **disembodiment**

Shanon (2001): Time distortions on Ayahuasca

Peak experience: No time, no self

Parameter	Temporality	Modified Temporality
Passage	Time flows	Cessation of time
Measure	Rate flows	Modified rate of flow
Order	Before/after	Confusion of order
Directionality	Past/future	Confusion of directionality Confusion of mental states

Video games in VR for inducing flow states

VIRTUALTIMES
Horizon 2020
European Union funding
for Research & Innovation

Components of flow experience:

- Intense and focused concentration on the present moment
- Loss of reflective self-consciousness
- Distortion of temporal experience (peak: loss of sense of time)

Mihaly Csikszentmihalyi

Game Thumper (2-D, VR)

The more flow experienced,

the faster time passed

(r = .351, p = <.001, N = 100)

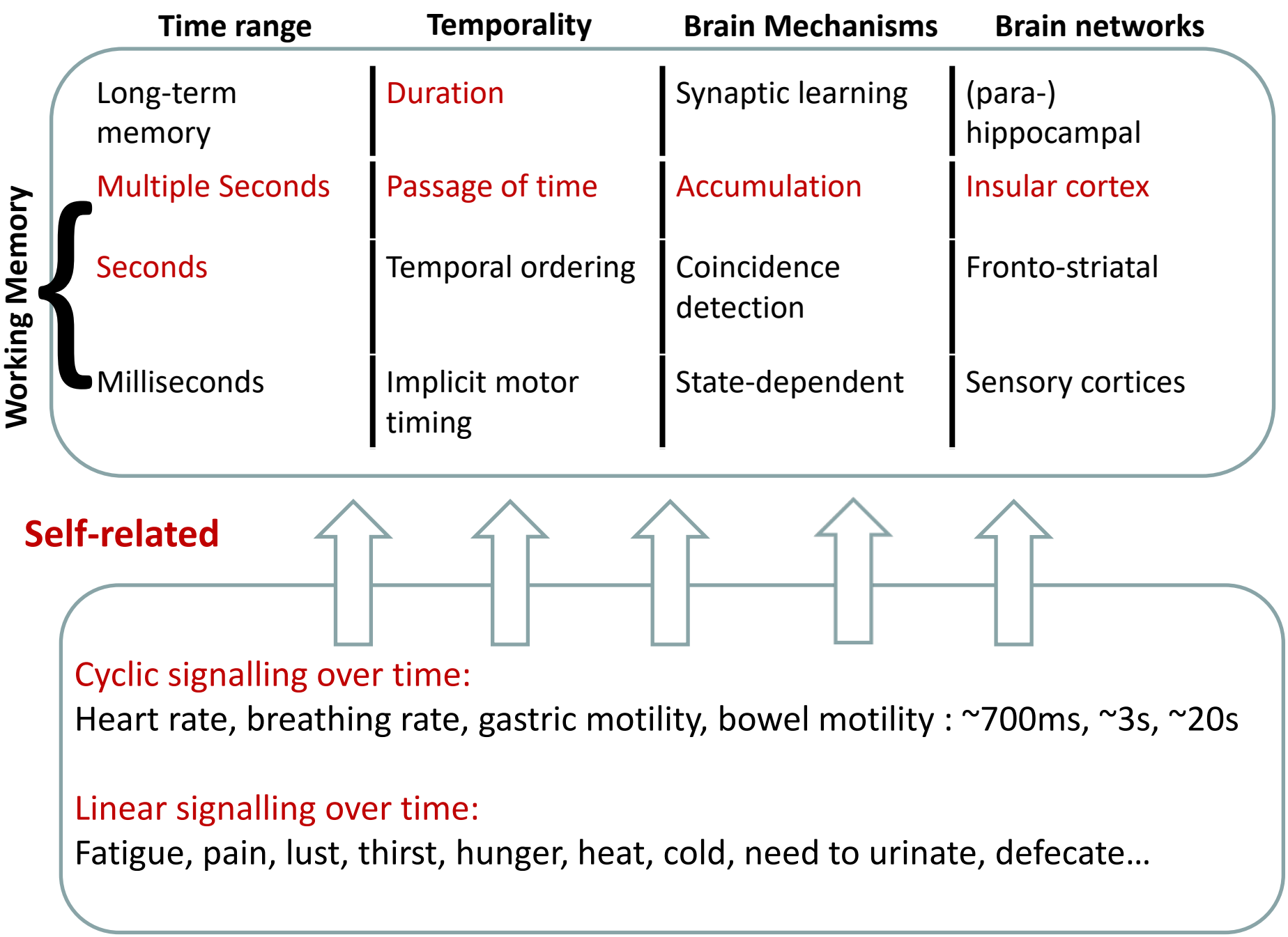
Rutrecht, Wittmann, Khoshnoud, Alvarez (2021)

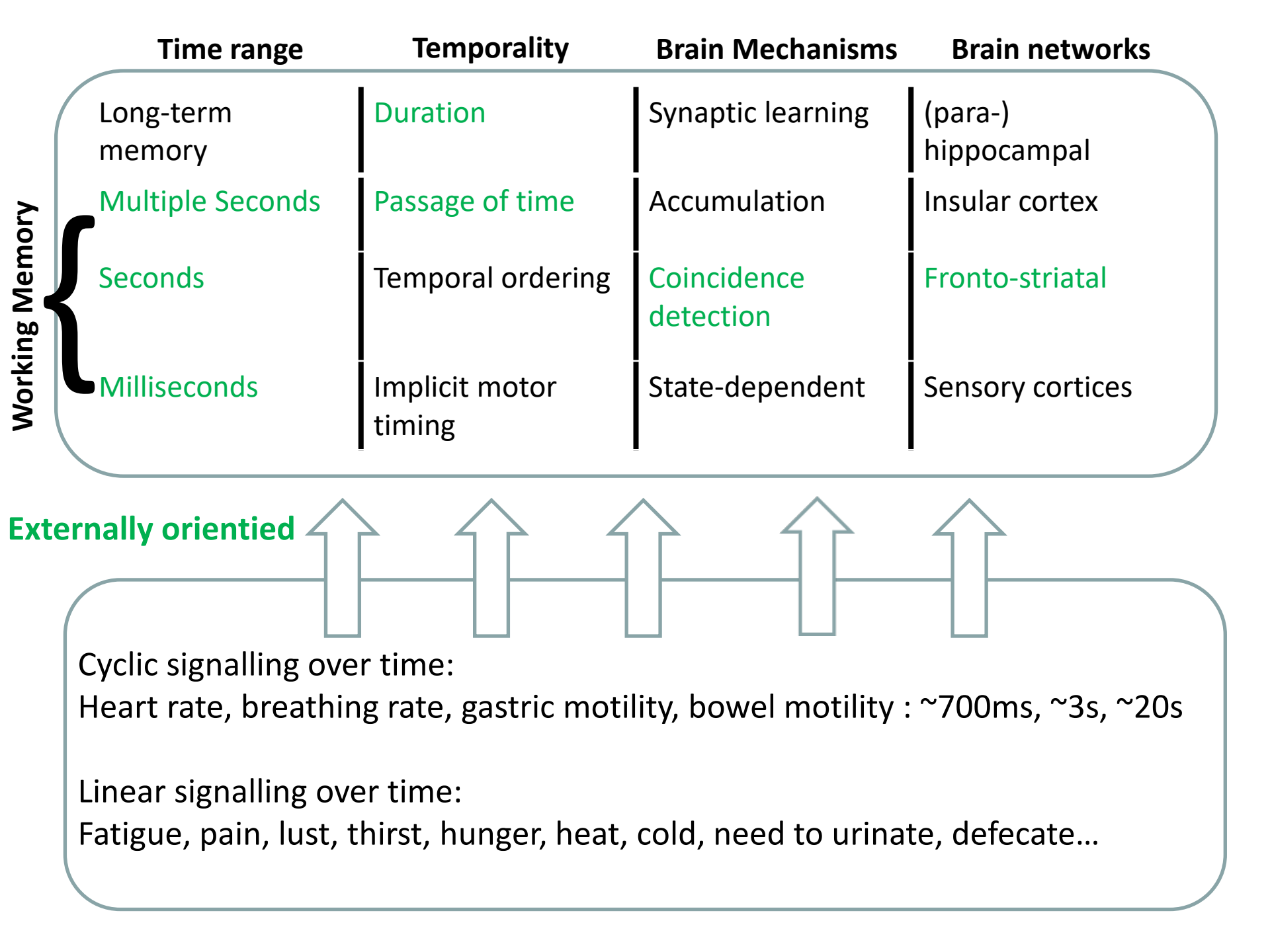
What is subjective time?

momentary time: experienced self

body time : insular time : emotional time

Time Consciousness & Self Consciousness


Time range
Temporality
Brain Mechanisms
Brain networks
Working Memory
Long-term memory
Duration
Synaptic learning
(para-) hippocampal
Multiple Seconds
Passage of time
Accumulation
Insular cortex
Seconds
Temporal ordering
Coincidence detection
Fronto-striatal
Milliseconds
Implicit motor timing
State-dependent
Sensory cortices
Self-related
Cyclic signalling over time:
Heart rate, breathing rate, gastric motility, bowel motility : ~700ms, ~3s, ~20s
Linear signalling over time:
Fatigue, pain, lust, thirst, hunger, heat, cold, need to urinate, defecate…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Collaborations & Sponsors

IGPP lab: Damisela Linares Gutierrez, Sebastian Kübel, Federico Alvarez, Shiva Khoshnoud

fMRI & time:
Martin Paulus, Alan Simmons
U California San Diego / LIBR Tulsa

Psychopathology & time:
Anne Giersch – *U Strasbourg*
Kai Vogeley – U Cologne

Psychophysiology & time:
Karin Meissner
U Munich, U Coburg

Waiting & time:
Eric Pfeifer – *Applied U Freiburg*
Joanna Witowska – *U Warsaw*
Tijana Jokic - *London*
Dan Zakay – *IDC Herzliya*

Altered States of Consciousness & time:
Stefan Schmidt – *U Freiburg*
Cyril Costines – *U Mainz*
Niko Kohls – *U Coburg*
Rui M. Costa – *ISPA Lisbon*

NIDA NATIONAL INSTITUTE ON DRUG ABUSE
The Science of Drug Abuse & Addiction

THE KAVLI Institute for Brain and Mind at UCSD
University of California, San Diego

FUNDAÇÃO Bial
Instituição de utilidade pública

European Commission
HORIZON 2020

1. Step: Activation contrasts (ROI)

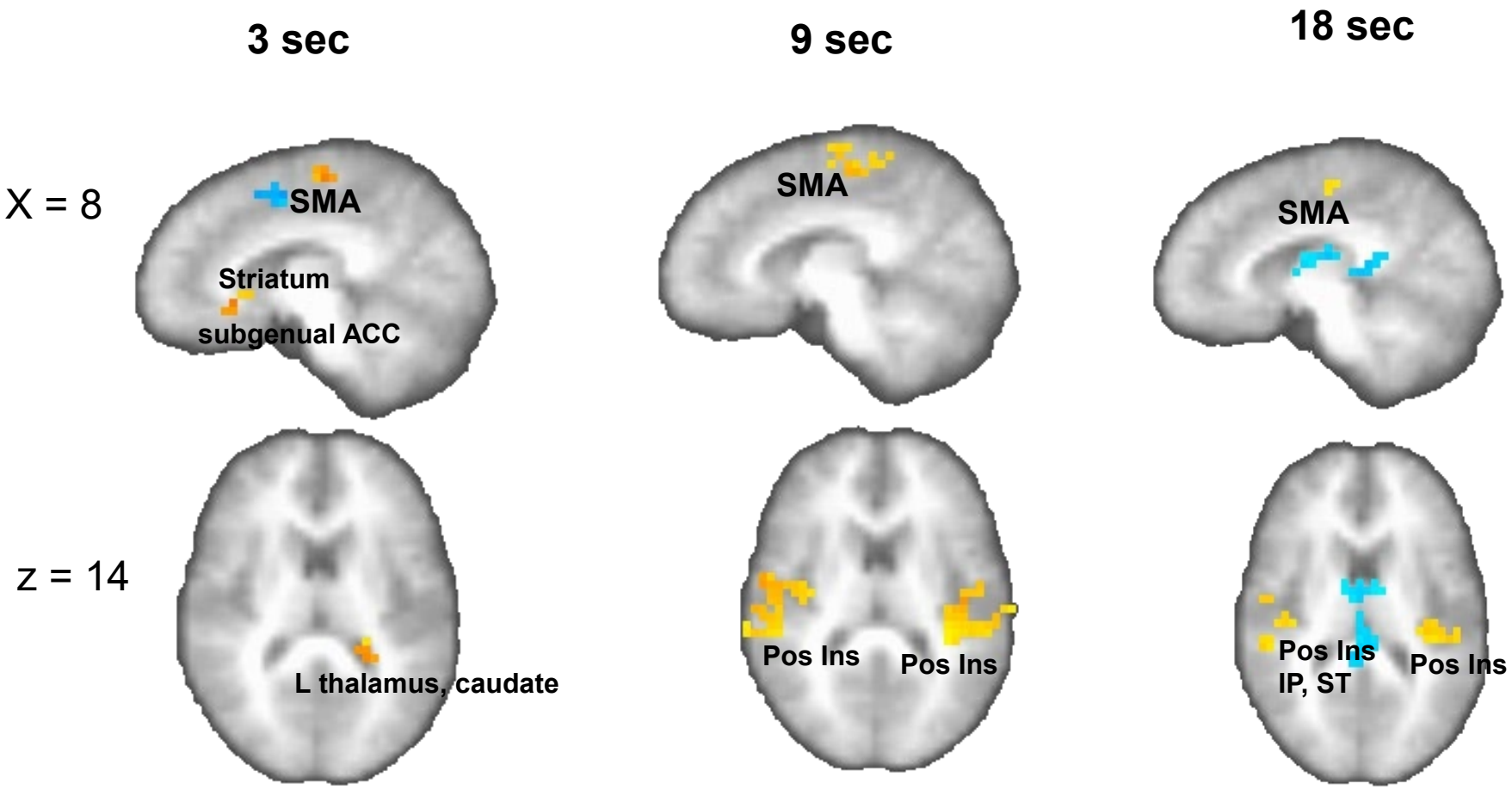
   $\Rightarrow$ *Where* in the brain

2. Step: Time activity curves

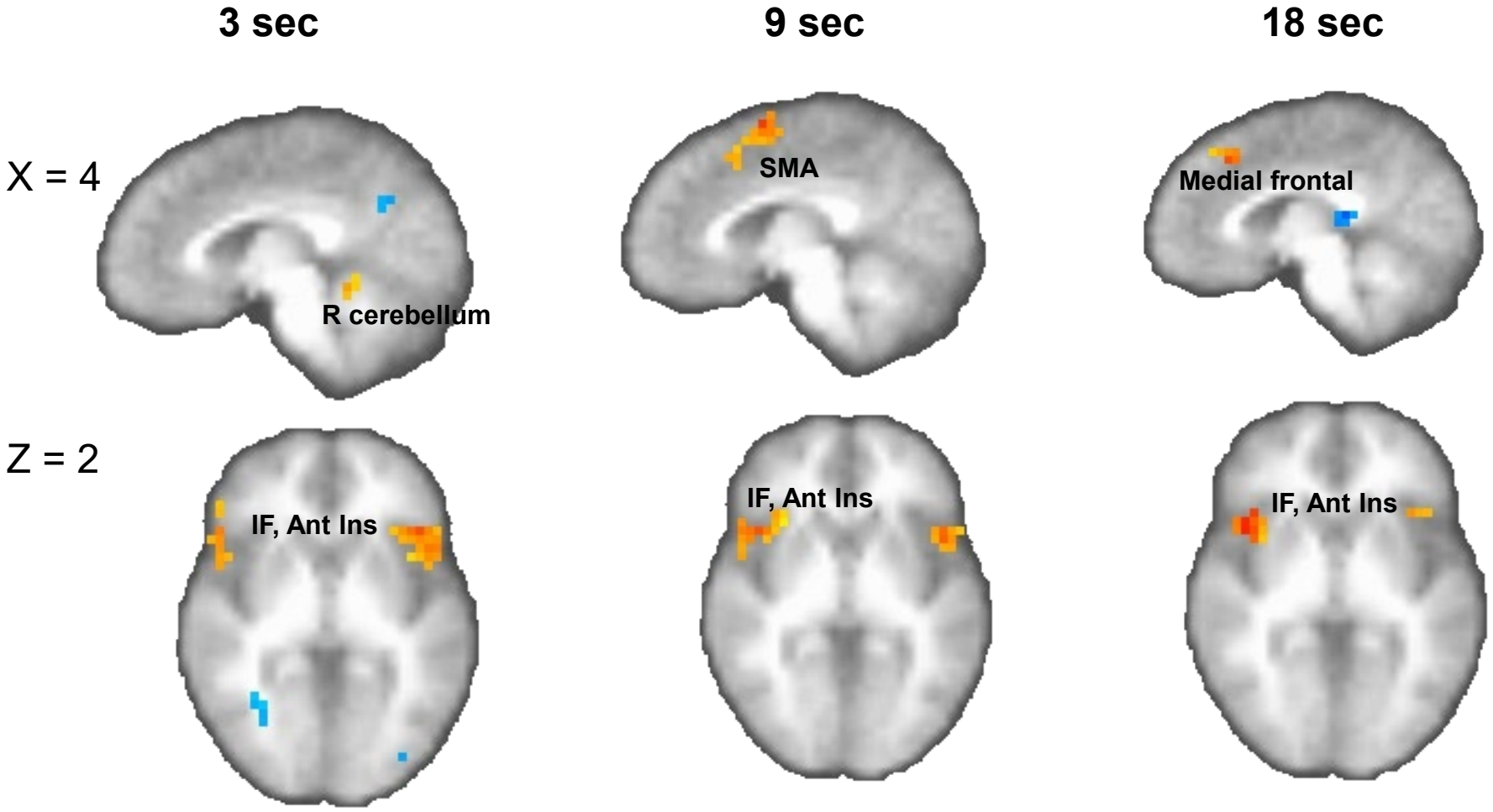
   in bins of 2 sec (TR) in ROI during encoding and reproduction phase

   $\Rightarrow$ *How* in the brain

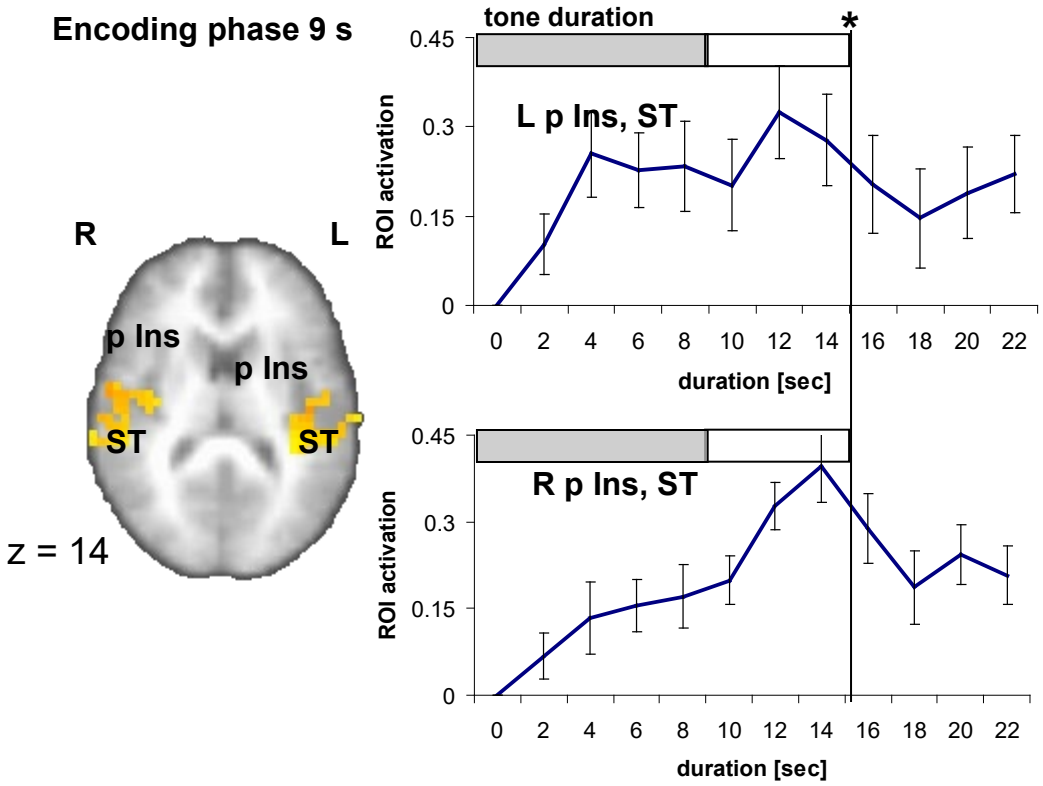
encoding vs. control phase



reproduction vs. control phase



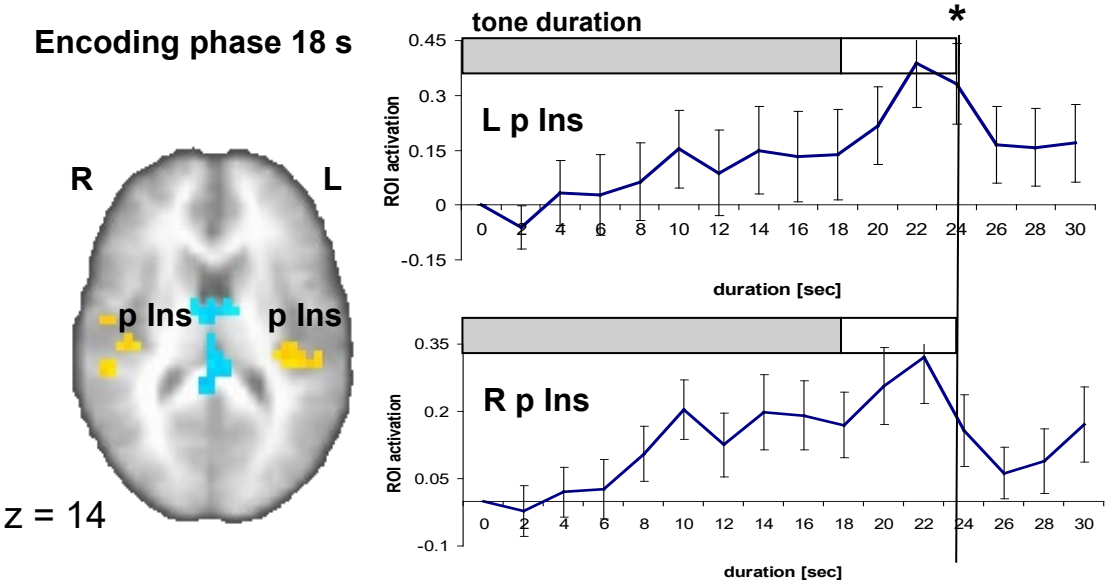
encoding phase 9 s



*** projected peak of hemodynamic response**

Wittmann, Simmons, Aron, Paulus (2010) *Neuropsychologia*

encoding phase 18 s



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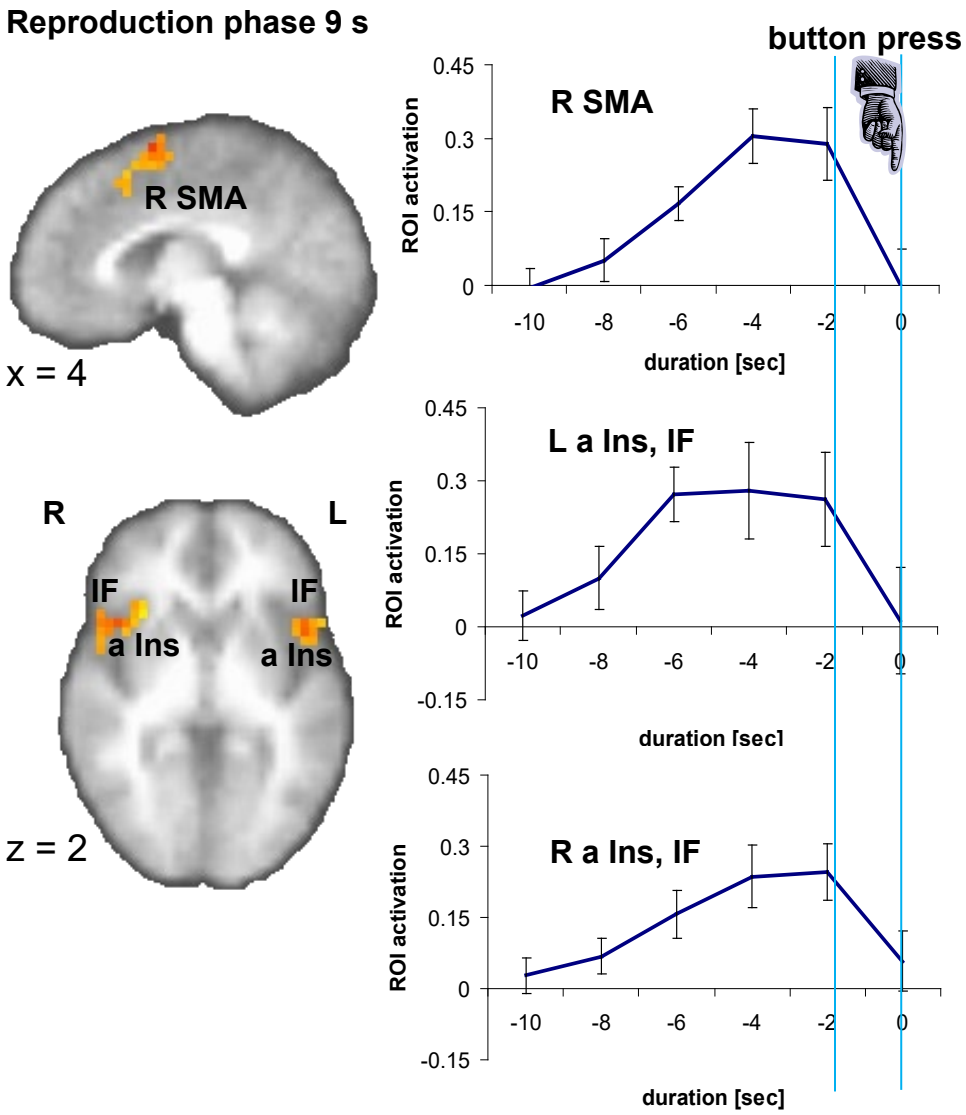
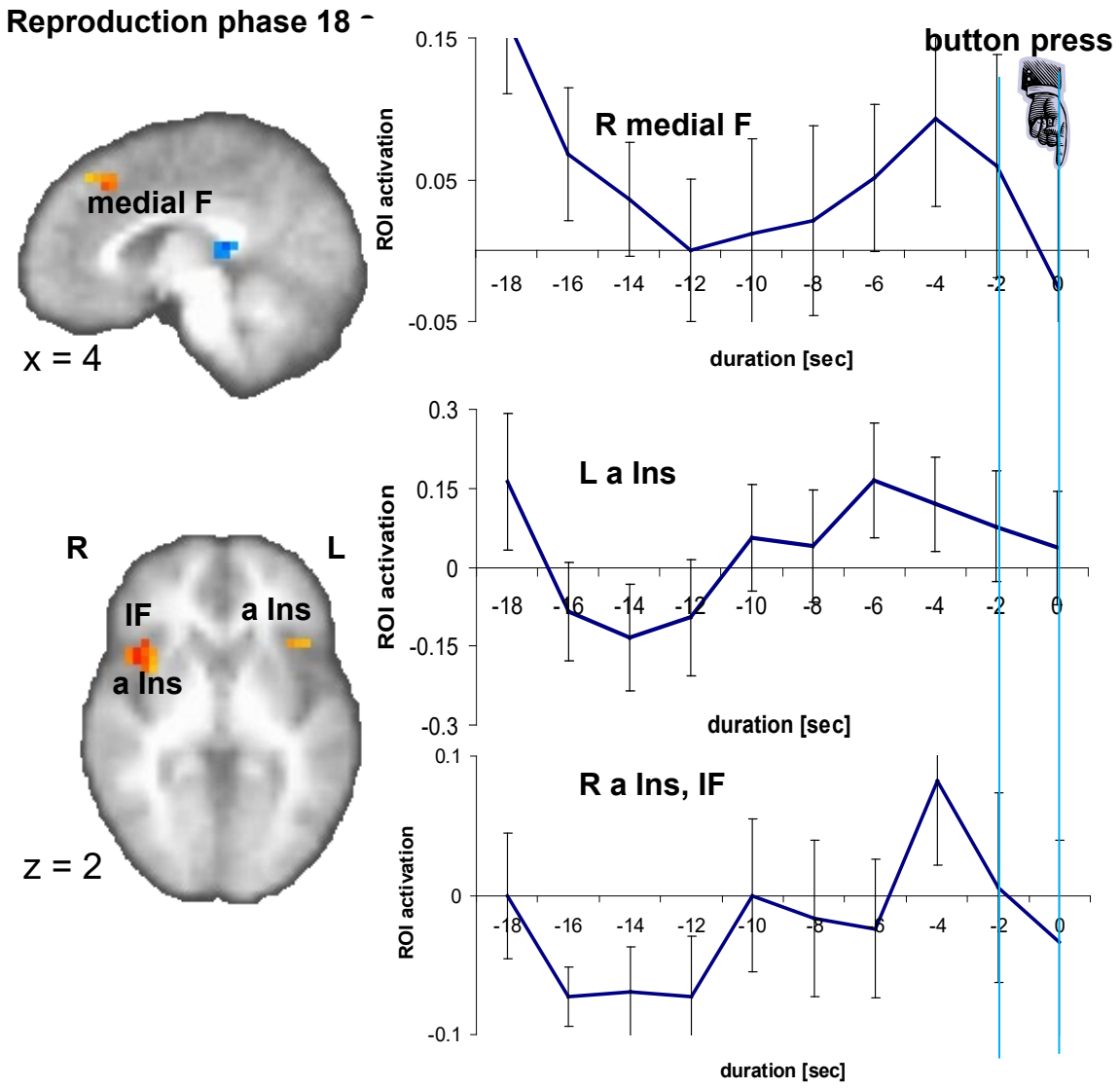
Wittmann, Simmons, Aron, Paulus (2010) *Neuropsychologia*

reproduction phase 9 s



Wittmann, Simmons, Aron, Paulus (2010) *Neuropsychologia*

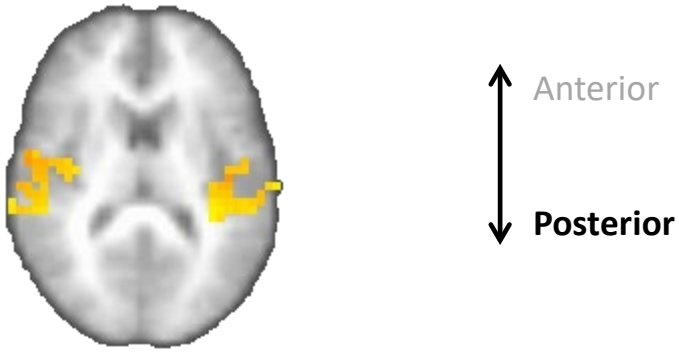
reproduction phase 18 s



Wittmann, Simmons, Aron, Paulus (2010) *Neuropsychologia*

Insular cortex:

Build-up of duration representation: *posterior* insula



Temporal reproduction of duration representation: *anterior* insula