# Spontaneous action initiation with temporal constraints on the response time: an MEEG study

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## Abstract

The Readiness Potential (RP) is a slowly increasing surface-negative cortical potential that precedes spontaneous voluntary movements. A recent interpretation provided by the Stochastic Decision Model (Schurger, 2012) suggests that this slow buildup could be the result of event-locked averaging of ongoing sub-threshold fluctuations in neural activity. According to the model, autocorrelated background activity plays an important role in the preparation of actions when the external imperative to act is weak or absent: slow fluctuations continuously drift randomly closer to or farther from the decision-threshold for initiating action in an integration-to-bound fashion where 'noise' in the brain is integrated over time.

In particular, the model predicts that movement is more likely to happen at a 'crest' in these ongoing fluctuations, and less likely at a trough. In classical RP studies subjects are instructed that they have an unlimited amount of time in which to perform the movement.

We developed a new experimental paradigm in order to investigate the effect of varying amounts of temporal freedom on the shape of the RP/RF (Readiness Field, for MEG recordings). We perform a variant of Libet's (1983) task in which subjects are asked to initiate a finger tap within a given time window on each trial. Participants are free to make the movement whenever they want as long as they do it before the time has elapsed. The time limit variable, signalled by an animated clock, will vary among blocks in a counterbalanced way across subjects.

Our main prediction is that the movement-preceding activity in pre-motor areas of the frontal lobe will appear to begin earlier, and be more prominent in the time-locked average, as the window of time within which the subject is allowed to move becomes longer. The temporal constraint is predicted to affect the Early but not the Late component of the RP/RF.

We would like to investigate parametric variations of the shape of the Readiness Potential/Field under temporal uncertainty, to unveil the timing mechanisms behind the non-movement and the movement states in the brain.

## The question of 'when?'

Which are the **neural events** in the brain **that commit the motor system** to initiate a spontaneous voluntary action in a specific moment ('now') and not later?

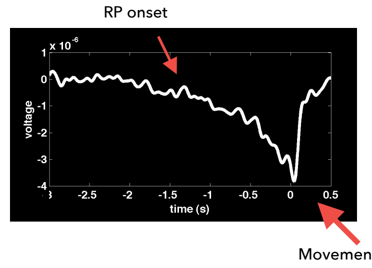
1) **What determines whether or when** an action is initiated in the case of absent/incomplete/noisy evidence?

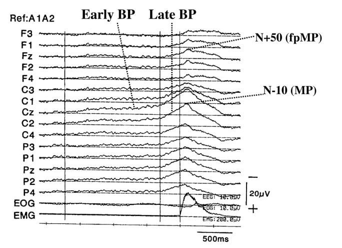
2) What is the **role of sub-threshold fluctuations** in neural activity in the initiation of a spontaneous action (=when there is no external cue or imperative to act)?

3) **Can we predict parametric variation of the amplitude** of the readiness potential as a function of temporal constraints?

## Introduction

The Readiness Potential (RP) is a slowly increasing **surface-negative cortical potential** that precedes spontaneous voluntary movements. (Kornhuber & Deecke, 1965)

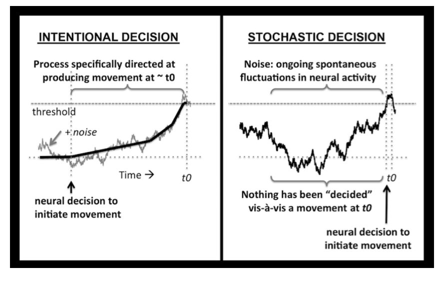



[Adapted from Shibasaki & Hallett 2006]

**According to the classical view**, the RP reflects a **purposeful process that linearly builds up** to produce a movement at moment t0.

**A recent interpretation** provided by the stochastic decision model suggests that this slow exponential preceding the motor event could be the result of a **time-locked average of ongoing sub-threshold fluctuations** in neural activity (Schurger et al. 2012)

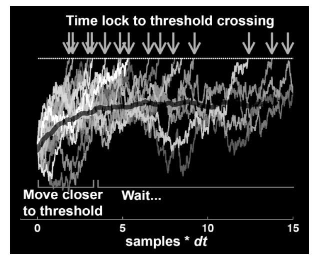



[Reprinted from Schurger, Sitt, & Dehaene, *PNAS*, 2012]

## Model & Predictions

Neural activity preceding spontaneous- self-initiated-movements **continuously drifts randomly closer to or farther from the decision-threshold** for initiating action in a bounded-accumulation fashion where 'noise' in the brain is integrated over time.

In particular, the model predicts that the **movement is more likely to happen at the 'crest' of these ongoing fluctuations**, and less likely to do so if it coincides with a trough.

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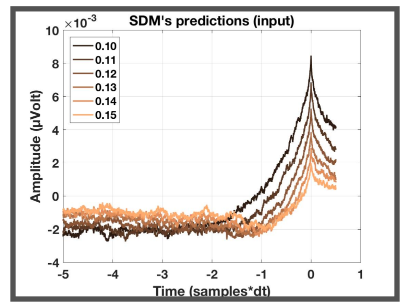


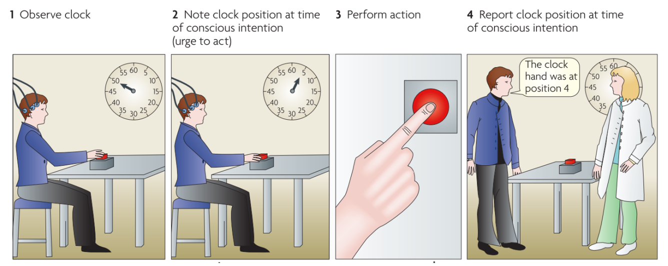

(drift) leak noise

$$dx = (I - kx) + \xi$$

According to our model, the **urgency** value increases with shorter time limits. The RP amplitude decreases correspondingly.

Our main prediction is that the **movement-preceding activity** in pre-motor areas of the frontal lobe **will appear to begin earlier, and be more prominent** in the time-locked average, **as the window of time** within which the subject is allowed to move **becomes longer**.

## Methods & Design



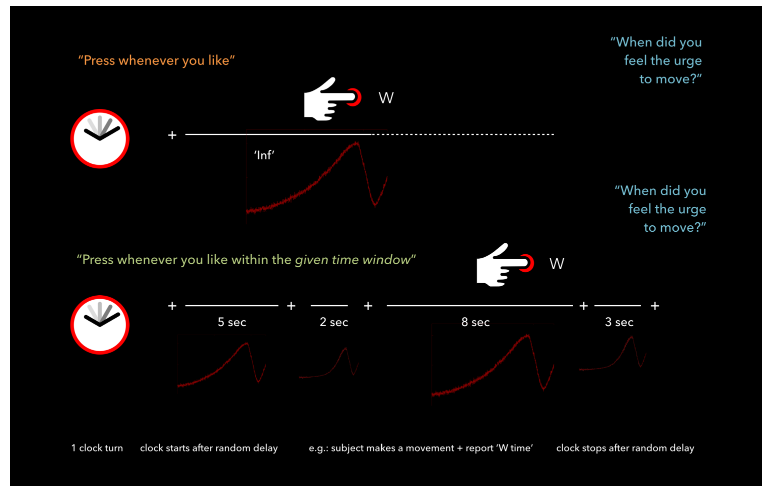

[Libet paradigm (1983): reprinted from Haggard 2008]

In classical RP studies, like the Libet study, the window of opportunity in which to perform the movement is almost unlimited.

So we developed a new experimental paradigm in order to investigate the parametric variations of the RP shape as a function of **increasing levels of temporal freedom** (temporal uncertainty).

The '**cortical wave metaphor**': ongoing fluctuations in brain activity act like sea waves. If one only has a strict amount of time to ride a wave, s/he may not end up with a very good wave. But if one has a lot of time, then the chances of catching a really good wave are higher. Similarly, we imagine that with longer waiting times the Readiness Potential/Field has a longer and more gradually buildup of activity, while with a short waiting time the buildup will be more abrupt and shorter.

### Experimental design




**Conditions**: 5 conditions with **increasing temporal freedom**: **2 sec, 3 sec, 5 sec, 8 sec, 'Inf'**.

**Blocked design**: 10 blocks x 20 trials each, 2 blocks x condition. First 2 conditions fixed for each subject as a control: original Libet task ('Inf' or 'infinity condition'). In all the other 8 blocks the conditions are randomised following a Latin square matrix.

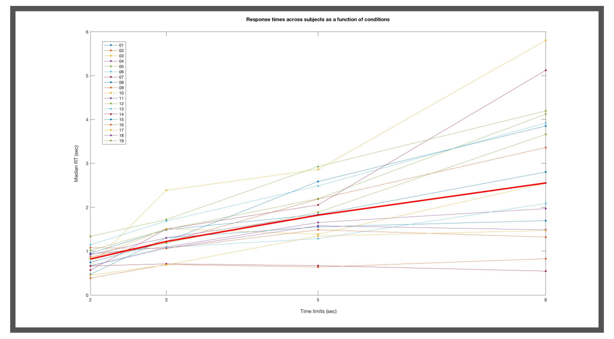
**Task**: subjects were asked to initiate a spontaneous movement (**finger lift**) within a given time window (timelimit) for each trial and then reported the time at which they 'felt' the urgency to move (**W-time**). Participants are free to make the movement whenever they want as long as they do it within the allotted time window. The time limit variable, signalled by an animated clock, will change among blocks in a counterbalanced way across subjects.

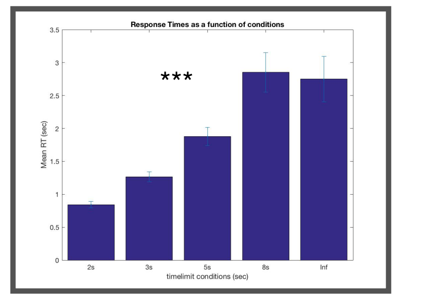
**Stimuli**: after a fixation cross, a 'Libet clock' will show up on the screen with one hand marking the 'minutes' of the clock, i.e. the time limit, and a faster flickering hand keeping track of the 'seconds', i.e. the W-time. The stimuli were made with Psychtoolbox and Matlab R2016a (Mathworks).

**Acquisition**: simultaneous EEG (60 electrodes cap) and MEG (306 channels Elekta Neuromag system) recording.

## Results (1): behavioural

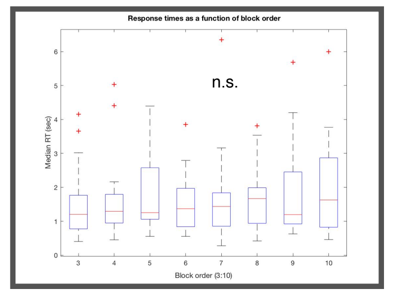
Data were analysed with Matlab (Mathworks), n= 19. Median RT for 19 subjects are plotted (below).






Response time increases linearly with increasing time limit, apart from the Infinity condition. Repeated Measure Anova shows an effect of conditions on response times, $F(4, 18) = 26.23$, $p < .001$.

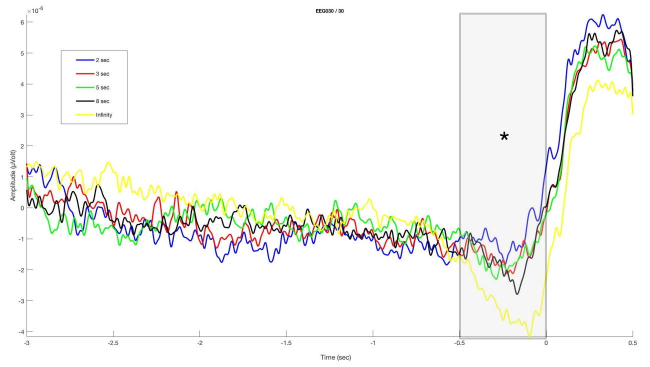
Response times are not affected by block order. Repeated Measure Anova: $F(7, 18) = 0.50$, *n.s.* For this reason, we decided to keep the Inf condition at the beginning of each session.



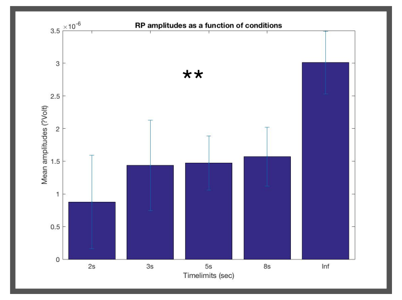

We also analysed the relationship between the (Wt-RT) and the timelimit condition but we didn't find any significant difference. For the electrophysiological analyses we decided to exclude subjects that were reporting negative Wt (= the feel of 'urge' after the movement instead of before).

## Results (2): ERP

EEG data were analysed with Matlab 2016a (Mathworks) and Fiedltrip toolbox, n= 14. Mean amplitude of the Infinity condition was greater than that of the other conditions averaged (tstat= -2.65, p= 0.019) but not from each condition taken independently. We analysed electrode CZ (=30). No baseline correction was applied. In grey the last 500ms before movement (0 s) that we used for statistical analyses.

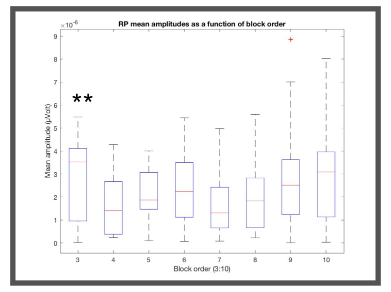



## Results (3): ERP




Mean RP amplitude from -500 ms until the response is significantly affected by the conditions. Repeated Measure Anova, $F(4, 13) = 4.05$, $p = .006$.

Contrary to our predictions and to the behavioural results, the Repeated Measure Anova for mean RP amplitude (-500ms to response) shows an effect of block order, $F(7, 13) = 2.98$, $p = .007$. This effect is gone if we remove the third condition, which always comes after the fixed Infinity conditions, $F(6, 13) = 1.62$, $p = .153$.




**MEG** data of 14 subjects were also analysed but we didn't find any clear RF across the channels of interest.

## Discussion

Unexpectedly we did see an effect in the Late tale of the RP and not in the Early part.

As expected by the model prediction, **the RP amplitudes follows a 'gradient' as a function of each time limit condition**: the 'longer' time window corresponds to highest amplitude in absolute values and the 'shorter' one to the smallest. In particular **the Infinity condition is significantly different from the other conditions' average**, but not from each time limit condition taken by itself. So, at present we don't know if these effects are purely due to the time limit constraints, as hypothesised or are block order effects caused by the control condition (Infinity) being fixed at the beginning of each block.

Interestingly, it seems there is a **dissociation between the behavioural and the neural data**, for which the waiting time (RT) for Infinity condition is always shorter than the longest time limit. Instead, in the ERP the amplitude seems to linearly increase with 'temporal freedom'.

The same kind of dissociation seems to hold for the block order effect, only present when we look at the mean ERPs and specific to the first experimental condition, suggesting a difficulty in switching from the Libet task to the time-limit one.

## References

[1] Schurger A., Mylopoulos M., Rosenthal D. (2016), Neural Antecedents of Spontaneous Voluntary Movement: A New Perspective, *Trends Cogn Sci*, 20(2):77-79.

[2] Schurger A., Sitt J., Dehaene S.(2012), An accumulator model for spontaneous neural activity prior to self-initated movement, *PNAS*,109(42).

[3] Shibasaki H., Hallett M.(2006), What is the Bereitschaftspotential?, *Clin Neurophysiol.,*117(11):2341-56.

[4] Libet B., Gleason C.A., Wright E.W., Pearl D.K(1983), Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). The unconscious initiation of a freely voluntary act, *Brain,*106:623-42.

[5] Kornhuber H.H.,Deecke L.(2016), Brain potential changes in voluntary and passive movements in humans: readiness potential and reafferent potentials, *Pflugers Arch - Eur J Physiol*, 468 (1115).

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