# Libet's Experiment: A Study on Readiness Potentials

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This manuscript was compiled on February 6, 2021

**Results from the Libet's experiment (1983) shows that the onset of the readiness potential precedes the subjective time of volition, while performing a voluntary act. We regain the results and look for readiness potentials in various tasks including: mouse click at time of choice and at instructed time. And show that it is possible to veto an action even in the presence of readiness potential.**

Libet | Free Will | Readiness Potential

The role of consciousness is not yet clear in the process of decision making. Is it just an epiphenomenon of the underlying dynamics of the brain which acts as a mere observer of the results after they have been already decided by the brain? or is it actively contributing to or even initiating actions and decisions? Results from the Libet's experiment (1983), not denying the latter, favoured the former assumption about the role of consciousness in acts of volition. This was done by showing that the onset time of readiness potential in a simple task of pressing a button, preceded the time of subjective experience of the urge to act.

Here we confirm this fact once again. Furthermore we look for the prevalence of readiness potentials with various characteristic such as onset times, and types and among mouse click tasks with pre-set and freely decided times. Moreover, We show that it is possible to veto an action even in the presence of readiness potential. Additionally, we investigate the prevalence of different types of RP's across different tasks, including tasks with pre-set and arbitrary time of action.

## Results

**W/M series.** In this section we are going to present plots of ERP's, averaged across participants and sessions, along with the introspective time averages, which allows us to interpret the order of events. Our first and main aim is to reproduce and verify B. Libet's results from his original work (1). In this direction we have indicated the mean of the introspective times (for values and standard errors refer to Table 1) on the plots of pre-event potentials as recorded by EEG. The ERP's are time locked to the event of EMG onset of the Extensor Indicus muscle, which indicates initiation of movement of right index. The ERP's are obtained by averaging the EEG signals across trials and participants, which was provided on the Grand Average spread sheet of EEG data. The expected order of events is: readiness potential onset, subjective awareness of intention, subjective time of muscle movement, the EMG onset and finally mouse click. The task carried out by the participants in the W or M series, was to perform a mouse click with their right index at their time of choice. In these tasks, the onset of the readiness potentials observed in each channel is calculated using the $RP_{90\%}$ method.

M indicates the average reported time of subjective realization of movement initiation, and W is the same quantity for intention. Both times are reported in milliseconds with respect to the EMG onset (the actual muscle movement time) along with their standard errors (see 1). The errors are too small but there may be a systematic error in the reported introspective times, W and M, due to the participants bias in interpreting self-initiated action and perception of stimuli. One evidence supporting such bias is apparent from Fig. 2. In the figure, surprisingly the awareness of movement initiation as reported by the participants, precedes the actual muscle movement onset as recorded by EMG. This bias in reported times reduces their reliability and widens the error span of introspective times, M and W.

**Table 1.** Time (in milliseconds) of events with respect to muscle movement

| | RP onset | M | W | click |
|---|---|---|---|---|
| A | -427 ± 30 | -73 ± 6 | -113 ± 7 | 62 ± 1 |
| O | — | 0 ± 20 | -70 ± 21 | — |

M and W have been measured in the absolute (A) and order (O) modes of recall. In the absolute mode, the participant reports the time by remembering the position of a clock hand at the time of intention in the case of W, or movement in the case of M. Whereas in the order mode of recall, the participant has to compare the mentioned introspective times with a suggested random time. The values of M and W are reported in milliseconds with respect to EMG onset, in Table 1, same as the mouse click time along with their standard errors. The fact that the click time is positive is consistent with the expectation that it must happen after the onset of muscle movement, otherwise we should doubt the validity of the EMG or computer data.

The ERP's from different channels are depicted in Fig. 1. RP's observed across different channels are of different onset times and amplitudes. As is apparent in the top panel, the channels located above the frontal lobe have a reaction to the event, so the activity cannot be interpreted as a readiness potential. The central electrodes show the a significant drop in potential preceding all subjective experience times and the event, and so can be said to show readiness potentials. Highest amplitude is observed in the most central electrode Cz. This is in line with previous accounts on the central role of the SMA in initiation of movement programming. Second in line with highest amplitudes are the lateral central electrodes, namely C3 and C4, which in addition to SMA, are also affected by other motor areas, such as motor (area 4) and premotor (ventro-lateral parts of area 6). C3 which is located on the left

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hemisphere, shows a more prominent activity compared to C4. This is due to the role of the left hemisphere in controlling the contralateral limb movements. The onset times of RP's precedes the EMG onset for about 400 ms and the drop initiation is rather sudden, so here we are observing RP's of type II. The channel located on the left parietal lobe, P3, also shows a readiness potential of Type II, although with a low amplitude. The low amplitude might be due to the different types (e.g. granular vs. pyramidal) of neuronal populations in the parietal (affecting P3) and premotor areas.

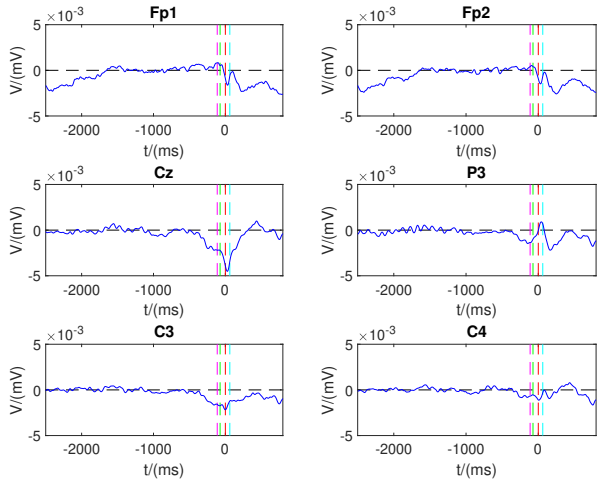


**Fig. 1.** ERP of different channels produced from EEG data recorded while performing the Libet task, i.e. button press at time of choice.

In order to be able to see the order of events, A narrower interval around the EMG onset is shown in Fig. 2. In this figure all the subfigures from Fig. 1 are combined in addition to a Readiness potential onset time indicated by the dotted black vertical line which precedes all the other events, namely w, M, EMG onset, and mouse click. W precedes M slightly as one could expect. Interestingly the awareness of movement precedes the actual muscle movement, i.e. M is negative. EMG onset, being the reference event of the ERP's, is set on zero and the click happens after the EMG onset as it should. The onset time of the RP is measured by the $RP_{90\%}$ method with the baseline set as the mean voltage in the interval (1500,1000)ms.

**S series.** In this series, stimulus is delivered on the skin of the left wrist of participant, who should report the time of sensation; once again using the two modes of recall: "Absolute" and "Order". The difference between this introspective reported time of sensation and the time of stimulus delivery, The average of which is denoted by S, gives a measure of the error that the participant might have in other introspective determination of time of events, such as W and M. The value of S and its standard error is calculated to be

$$S = (146 \pm 6)ms$$

In this experiment the ERP is time-locked to the event of stimulus delivery. The ERP's from different channels are shown in Fig. 3. P300 positivity is observed clearly in the channels P3, C3, and C4 which are affected by the Sensory and Motor areas of the brain. Interestingly before the stimulus delivery a widening in the potential range across channels is

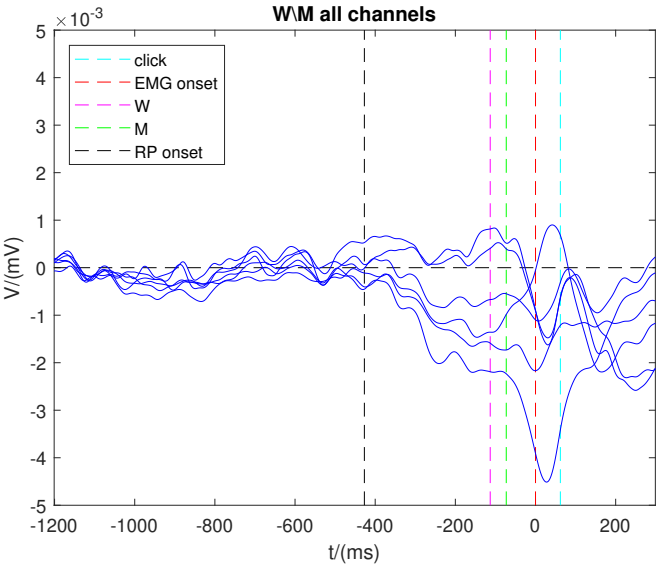


**Fig. 2.** A zoom in of the ERP's of all channels given in Fig. 1. W and M are measured by averaging the absolute recall mode times of awareness of intention and movement respectively.

observed. We lack an explanation for this seemingly preceding activity prior to the stimulus delivery. This might be a silly observation which might be accounted for by the manner of data acquisition.

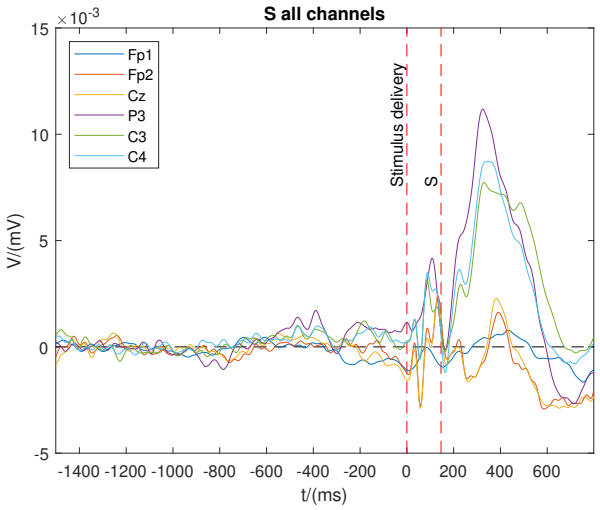


**Fig. 3.** ERP's from the S series for all the channels are plotted. This task involved a stimulus delivery (at t=0 in the figure) and a consequent reported time of sensation (S at about 150 ms).

**RP onset precedes W.** Taking into account the systematic error due to bias of introspective data. Assuming that the calculated W might have a systematic error of order S. We subtract S from W and compare the result with the RP onset time. From Table 1 and the calculated value of S, the RP precedes W statistically significant by at least the following amount:

$$(W - s) - RP = -113 - 146 - (-427) = (168 \pm 35)ms$$

Which turns out to be positive and so yielding the same result as B. Libet's.

**P and Pv series.** In the W/M series the action time is freely chosen by the participant. In the P series the time of the action is set beforehand. The participant is instructed to click the mouse at a particular pre-set target time. The presence of a target affects the shape of the readiness potentials and the activity of the channels involved. The ERP's, time-locked to the target time, obtained from the records of different channels, are depicted in Fig. 4. Except for the two central channels, C3 and C4, other channels show no account of readiness potentials. C3 and C4 show an RP forming as early as second before the event. This early and gradual drop in ERP is a characteristic of the type I RP. This early RP onset most likely is indicating of planning and preparing for the target action.

The participants performed yet another targeted task, the Pv series, which is similar in every way to the P series except that the participant is instructed to plan on clicking the mouse at the target time, but not to click it after all, i.e. to veto the decision. Interestingly the channels activated in Pv series is rather different from that of the P series.

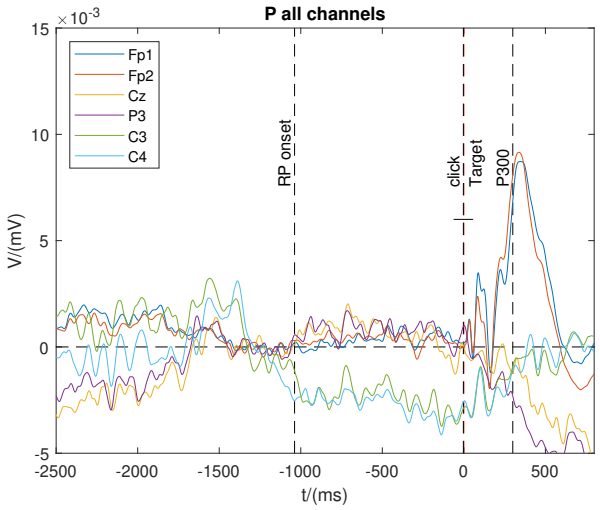


**Fig. 4.** ERP from pre-set task. Other than C3 and C4, which show type I readiness potentials, other channels only show activity very close to or after the event. P300 positivity is observed in the frontopolar channels.

**RP types and tasks.** for RP types refer to the data description pdf file, EEG.xslx and 4.2 sections. We analyzed the individual EEG dataset, and the results are shown in Table 2. It can

**Table 2.** Analysis of RP types and tasks

| RP Type | # | M | W | S | P | Pv |
|---|---|---|---|---|---|---|
| 1. I | 14 | 4 | 7 | 1 | 1 | 1 |
| 2. II | 26 | 6 | 10 | 5 | 5 | 0 |
| 3. III | 15 | 3 | 7 | 2 | 1 | 2 |
| 4.Pre-set | 14 | 0 | 0 | 1 | 8 | 5 |

be seen that RP's of type I,II,III can be seen more frequently in W, and then M. But Pre-set is only seen in P or Pv series. In Table 3, we demonstrated which electrode shows RP for

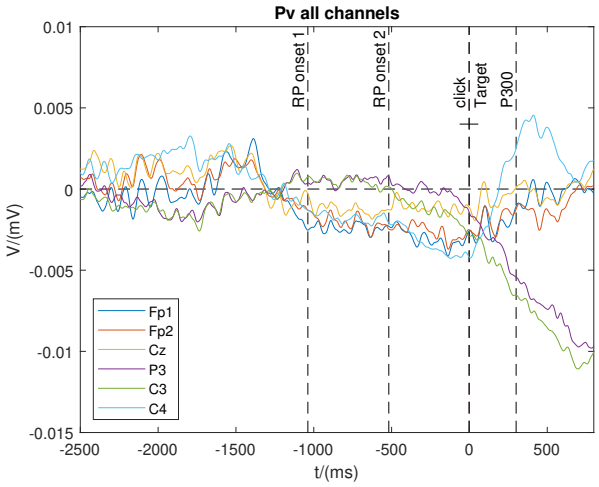


**Fig. 5.** ERP from "veto targeted action" task (Pv series). The frontopolar electrodes show a type I readiness potential as well as Cz and C4. C3 shows a type II readiness potential with onset indicated as "RP onset 2".

**Table 3.** Analysis of tasks and electrodes

| Tasks | Fp1 | Fp2 | Cz | P3 | C3 | C4 |
|---|---|---|---|---|---|---|
| 1. M W | 12 | 4 | 8 | 26 | 14 | 0 |
| 2. S | 6 | 3 | 2 | 16 | 18 | 0 |
| 3. P | 4 | 2 | 0 | 3 | 0 | 0 |

This table shows the relation between tasks and brain areas that are engaged more. It can be seen that in M and W tasks, in which the action is self-initiated, Fp1 and Cz electrodes are more active. This is in accordance with other studies suggesting frontal lobe's engagement in decision making. Moreover, for the S task, P3 and C3 are more active and informative than other electrodes. Probably activity in C3 is due to Somatosensory cortex activity and P3 is due to activity in the Parietal lobe. Another noteworthy observation is that C4 is not active in any of the RPs (or rather shows weak activity, low amplitude RP's). Keeping in mind that the contralateral part of the brain should be active in the movements of a limb, this observation suggests that the experiment was done with right handed subjects.

each task. Using this data we can analyze which part of the brain corresponds to each task. For further experiments, it is reasonable to focus on the data from active areas for each task.

**P300 positivity.** There were 110 total number of trials in individual EEG data, in which 42 number of P300 positivity was recorded. Looking at different electrodes separately there were 574 recordings, in which 76 number of P300 were positive.

## Suggested Investigations

**RP types, Channels and Tasks.** What is the distribution of RP types across channels and tasks? What are their rates? With rate of an ERP for a particular series and channel defined as follows (Example: rate of type I RP in W/M series in Fp1):

$$\lambda_{Fp1}^{W/M} = \frac{\#\text{Type I RP's recorded in Fp1 in all W/M sereis}}{\#W/MSeries.}$$

Note: W and M include the same clicking task so they are

considered together.

The rate function can be defined more generally on the space of all tasks, channels and ERP types (including: Type I, II, III RP's, no RP and P300).

**Hemispheric Analysis.** Investigate whether there is a higher activity (RP peak amplitude) or higher rate of RP or P300 positivity in the left hemisphere compared to the right. Note that the participants are all presumably right handed and thus are more likely to have done the task with their right hand. Convention: Odd numbered channels (including Fp1, C3, P3) are placed on the left and even numbered channels (including Fp2, C4) on the right hemisphere.

**Brain circuit:.** The frontal lobe initiates the decision, the movement is planned and programmed in the parietal lobe and then sent to the SMA (a litt to the anterior of the central sulcus, so its activity may be measured by central EEG channels) and from there to the motor area.

**Table 4**

| area | Frontal | → | Parietal | → | Central |
|---|---|---|---|---|---|
| channel | Fp1 | → | P3 | → | C3 |

The presumed brain circuit behind the decision of volitional mouse click with the right index, in which the contralateral, left, hemisphere should be more involved and so the odd numbered channels are considered.

Is this suggested order statistically observable in the data? How can we approach this problem? Is the differences of onset times of RP's statistically meaningful across different channels? If so one might consider the order in which the channels were activated to confirm or reject the hypothesis suggested in Table 4.

## References


1. Benjamin Libet, Elwood W Wright Jr, and Curtis A Gleason. Preparation-or intention-to-act, in relation to pre-event potentials recorded at the vertex. *Electroencephalography and clinical Neurophysiology*, 56(4):367–372, 1983.