# The Libet Clock Experiment: A Segmented Regression Study of the Readiness Potential

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## Abstract

Libet's original Clock Experiment showed that the brain becomes active before the first will (W) to act is reported by participants. This Readiness Potential (RP) showed that electrical activity in the brain significantly rises as preparation for a button press (M) before the participant is aware. This study attempted to improve Libet's studies to see if RP onset would indeed be significant, and expected its results to match Libet's original findings. Twenty-four participants performed the original Libet Clock Experiment. A control task was added in this study to see how well the participants are able to accurately estimate time. Not only were they asked to estimate the first will to act as in Libet's original experiment, but they also performed a task in which they were asked to report the moment of button press after the participant had pressed the button. These tasks were recorded with an EEG, EOG, and EMG. Participants' scores were averaged individually and electrode $C_3$ was further analyzed as its location lent itself perfectly to pre-motor cortex activity for the right hand. The question posed in this study was; is the RP significantly active before W, relative to the baseline potential? Significant RP onset ($\psi$) was found through segmented regression. Results revealed that $\psi$ deviated significantly from a baseline potential, showing that the brain became active significantly before W. This showed that the brain already prepared movement before conscious intention to act, confirming Libet's original findings.


*Keywords*: Libet Clock Experiment, segmented regression, consciousness, readiness potential, free will, EEG

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Every day we make conscious decisions based upon our beliefs, morals, cravings, our dreams, our history, our, present, and our future. We strive to shape our own life through conscious decision-making and we believe we can control our mind. Consciousness is often seen as an elusive concept, and the term is hard to define perfectly. Consciousness and voluntary action are vital for our way of life, though. So, what exactly is consciousness? Searle (1992, 1993) defined consciousness as the participative state of sentience or awareness that we carry throughout our lives, whenever we are awake and performing tasks. Consciousness is necessary for many of our higher functions, but the exact line between automated processes and consciousness is not always clearly defined. It is furthermore difficult to recognize where reflex stops and consciousness begins. When do instincts stop, and when does consciousness take over? And if our brain controls everything, how can we truly believe in the concept of free will?

The Libet Clock experiment was the first scientific attempt at answering these philosophical questions through the field of neuroscience. The outcome of this experiment sparked an enormous debate over how we view free will, a debate that is still very much alive today. The Libet Clock Experiment measured the brain activity of six participants using electroencephalography (EEG) and specific muscle activity through electromyography (EMG) while they were performing a voluntary task with their right hand (a flexing of a muscle in the wrist to press a button). During this voluntary task, the participants were looking at a clock and had to report the time where they first felt the conscious intention to move, or will (W) to act. Libet, Wright, Gleason & Pearl (1983) state that the voluntary will to move (W) is preceded by measurable electrophysiological readiness potentials (RP's).

The RP is a scalp-recorded slow shift in electrical potential, generated by the brain and more specifically the pre-motor cortex. Of course, it seems only logical that motor activity is preceded by pre-motor activity in the brain. But the following question arises; why does the brain actively start pre-motor activity before we are consciously aware of our will to move?

The RP begins up to one second or more before a self-paced, apparent voluntary motor act (Deecke, Grozinger & Kornhuber 1976; Gilden, Vaughan & Costa 1966; Kornhuber & Deecke 1965). Libet et al. (1983) used the RP as the indicator of neural preparation for the movement (instigated by the given task). RP's are measured relative to the brain's electrical baseline potential. In the Libet Clock Experiment, this electrical baseline potential was established by using the measured EEG in between tasks (recorded from 2500 to 1500 ms before the conscious intention or will W). It was found that the RP preceded the W by approximately 350ms and the actual conscious movement by 500ms. Libet concluded from this that the conscious will to act only arises after the action has already been determined by the brain, and free will therefore must be an illusion.

One of the questions that arose from this experiment was; is conscious activity truly preceded by Readiness Potentials? In other words, do our decisions only ascend into consciousness after they have already been subconsciously decided by our brain? This raised a partly philosophical question, too. If our brains have decided upon action before it reaches our conscious awareness, do we truly have free will? The Libet Clock Experiment showed that our voluntary actions only ascend into our consciousness after the electrophysiological response in our brain already occurred (Libet, 1985).

This would suggest that free will is a mere illusion, as our brain would already have made up its mind before we are even consciously aware of the decision it made (given that the W is estimated correctly by the participant).

In an analysis of Libet's experiments, Wegner (2017, p. 52) suggested that the experience of conscious free will could be nothing more than a "loose end. Just a coming together of circumstances, caused by prior brain and mental events". In other words, Wegner believed that the state of consciousness is nothing more than a coming together of certain brain events. Wegner's notion of the illusory nature of free will also states that (Wegner, 2017, p. 2) "the experience of consciously willing an action is not a direct indication that the conscious thought has actually caused the action. It does not prove causation." Wegner states that conscious will does not prove free will, but merely a correlation between will and action. A lot of philosophers, however, think that Libet's experiments have not provided enough evidence to refute the existence of free will yet (Bernáth, 2020).

Other studies such as Soon, Brass, Heize, and Heynes (2008) show that subconscious neural activity predicts for decision-making, supporting the notion that free will does indeed not exist. Even though in this particular study the participant's decision could only be predicted with an average 60% accuracy, the authors daringly concluded that conscious decisions are indeed determined by unconscious neural activity.

This might lead one to believe that the answer to the question 'Do we truly have free will?' Is answered with a stern 'no.' The answer to this question, however, is deemed more complicated than that. Brass, Furstenberg & Mele (2019) have shown that even though the brain shows activity before the decision ascends into consciousness, conscious decision-making is still possible. They stated that the readied movement could be canceled by consciousness decision, a phenomenon later wittily dubbed 'free won't'.

Brain activity preceding conscious decision-making seems to reflect only the decision process, rather than its outcome. Libet's groundbreaking research into RP activity and conscious choice has been the foundation for the discussion regarding free will. The RP is a recurring and vital part of the Libet Clock Experiment and studies alike. Libet et al. (1983) found, as previously mentioned, that the RP precedes the conscious intention to act by ~350ms and the actual movement by ~500ms on average.

Countless studies have criticized the Libet Clock Experiment for its conclusion about the non-existence of free will (Brass et al., 2019; Bergner, 2018; Fischborn, 2016; Mele, 1997). The Libet Clock Experiment has been a controversial one in both its conclusion and methodology. For example, Libet only analyzed total averages in the original experiment, instead of analyzing each participant's data individually. Differences between participants are obscured when averaging all the participant's data onto a single pile. Contrary to previous examples, rare cases have been measured where the conscious intention to act actually *preceded* the RP onset (Verbaarschot, Farquhar & Haselager, 2015), although this was a singular result and not recurring throughout said study. An important lesson to take away from this though is that the RP onset and start of consciousness can vary greatly among individuals. This is why Libet's original averaging technique is rarely used in modern studies, and instead individual averaging assessment is more prevalent.

Mele (1997) criticized not Libet's Clock Experiment, but rather Libet's initial interpretation of its results. He claimed that a few important distinctions had to be made. Their beliefs were that the urge to act as described by Libet is not the same as a person *wanting* to act. They debated that individuals often have urges, but that does not equal the *want* to act. In Libet's experiments, an RP was still recorded even when the participant was asked not to perform an action, but simply get ready to move. Libet agreed with Mele's criticism, and he too believed the phenomenon 'free won't' to be a possibility. Cancellation of an action is possible if veto-ing the movement occurred before 200ms prior to movement onset (Schultze-Kraft et al., 2016). This means that from 200ms prior to the action onwards, an action can no longer be canceled.

The present study will attempt to improve the Libet Clock Experiment and therefore its results, using modernized measurement tools for precision and an added control variable R to control for estimation skill in the participants. Segmented regression will be used to pinpoint the significant onset of the RP in time, which will be named 'ψ'. The question that will be attempted to answer is: Is the RP significantly active before W, relative to the baseline potential? The hypothesis is that the significant onset of the RP (ψ) will indeed precede the start of the conscious will to act (W), matching Libet's original findings.

# Methods

## Participants

This study consisted of 24 participants, of which 14 reported to be female and 10 to be male. The participants had ages ranging from 18-27 years old (Mean age = 21.2 and SD = 2.2). All of the participants were right-handed, voluntarily took part in this study, and provided written informed consent. All of the participants were students and received course credit as compensation for their time. This study was ethically approved by the Tilburg University TSB ethics commission (EC-2016.48t).

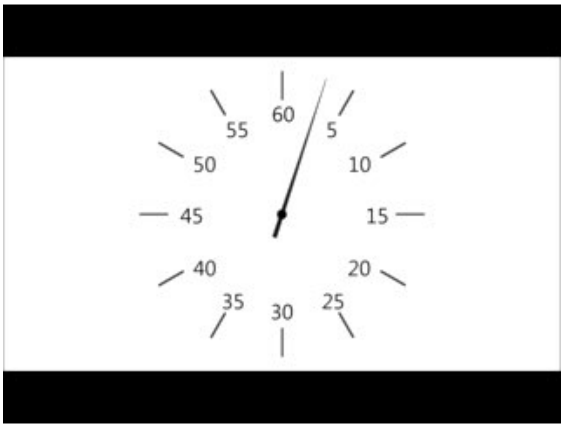
## Materials

The participant was sat down in a closed, sound-attenuating, and dimly lit room in front of a computer monitor. The participant was informed that the researchers could see them through a camera placed inside of the room, and that they could communicate or signal if something was wrong through an intercom system. The task was explained to the participant prior to them entering the room. On the computer monitor, a clock was shown similar to the original Libet Clock (see Figure 1), which is a simple analog clock making a circular motion with a single handle.

In the original Libet Clock Experiment, a single clock rotation took 2560ms or approximately 2.56s. In this experiment, the monitor used had a refresh rate of 60Hz, meaning every 16.667ms a new image can be shown on the monitor. This experiment offered a new image every 2 screen refreshments in which the clock moved forwards 1 second on the clock. This comes to (16.667ms x 2) x 60 clock positions = 1999.8ms = ~ 2s. The clock, therefore, completed one circular motion in almost exactly 2 seconds.

**Figure 1.**

*The clock used in this experiment; moving at ~2s per rotation*




**Procedure**

The participant was asked to perform a voluntary finger movement by pressing on the spacebar on the keyboard in front of the computer screen, whilst looking at the computer screen that showed the moving Libet clock as shown above. The participant was instructed that they were free to press the spacebar whenever they wanted to. When having pressed the spacebar, the clock would continue for anywhere in the range of 1000ms up until 2000ms. This was randomized to prevent learned behavior from the participants.

If the exact same, fixed amount of time were used, the participants could notice and count back strategically or develop a reflex, defeating the purpose of the study. Free will must be maintained. Two tasks were performed during the experiment. First, the R task was performed. The R control task asked the participant to report at which clock position (00-60) they estimated to have performed the button press. The R control task was added to this study to determine whether the participants were skilled at estimating time, and to improve their time estimation skills prior to the W task. If the participants were not able to accurately estimate time, the W data would be less reliable. After the R task, the W task was performed. The W task asked the participants to report at which clock position (00-60) they first felt the intention (W) to press the spacebar.

This value of 00-60 was to be entered into the keyboard as an estimate in both tasks. Every participant performed 10 practice trials to get comfortable with both tasks and was given the possibility to ask questions and try again if they wished to do so. Once they communicated to fully understand, they performed 100 recorded trials.

**EEG, EOG, and EMG measurement and analysis**

The EEG was measured using an EEG cap with 64 electrodes, according to the 10-20 system. Parker Signa Gel was used to increase conductivity from electrode to scalp. The EEG was live monitored and tested during the practice trials. Electrodes that were found to not be behaving properly were adjusted until showing normal signals. The baseline used for the EEG recording was taken 1000ms - 800ms prior to the participants' movement during the experiment and was averaged at 0μV. EEG, EOG, and EMG were recorded using the Biosemi Active2 system. EEG signals were referenced off-line to linked mastoid reference, before being low-pass filtered with 30Hz. The influence of blinking movements was filtered out using linear regression. Data in the form of EEG activity were then segmented, where intervals 1000ms before and 500ms after the button-press were selected to continue analyzing. Of all these chosen segments, a frequency distribution was made of the maxmin EEG amplitude within every segment. This was done for every electrode individually. Segments that ended up outside of the 95% confidence interval of the normal distribution, were eliminated as outliers. Of the remaining segments, an average was calculated for each participant. Segmented regression was then performed using the R package 'segmented'. This was done to determine the significant start of the RP (ψ or psi) in a statistical manner. A 40ms segment average was calculated around every ψ amplitude value to reduce the effect of noise.

The EOG was measured with four electrodes. One above the eye, one on the cheekbone under the eye (in line with the above-eye electrode), and one on the right as well as the left temple. The EMG was placed on the lower right arm of the participant. The EMG was high-pass filtered with 20Hz, rectified, and then low-pass filtered with 50Hz. The EMG data were used to show if all trials were preceded by muscle activity.

Electrodes $C_3$, Cz, FCz, and $C_4$ were all considered to further analyze. Electrode $C_3$ was chosen to analyze, as the location of this electrode on the EEG cap most accurately measures pre-motor activity as it is located on top of the premotor cortex, and is contralateral to the dominant hand of all participants in this study. This electrode also has less noise from surrounding areas relative to Cz and FCz, with Cz recording more disturbance from the ipsilateral hemisphere and FCz recording more frontal activity and less pre-motor activity than $C_3$ would. $C_4$ was shown to have relatively little activity as this electrode is located ipsilateral to the dominant hand, with the dorsolateral side showing more activity. Therefore, only EEG data from the $C_3$ electrode was further analyzed. Normal distribution was checked and violated in several datasets. The averaged dataset over all RP onset data ($\psi_{avg}$) was normally distributed, as was the R task. No outliers were removed from this study.

# Results

## R task responses relative to button press M

The mean R across participants differed between -128.28ms to 22.34ms. The mean R across all participants was measured at -27.37ms (SD = 38.83) relative to button press M. The mean R significantly differed from button press M ($t(23) = 3.453$, $p = .002$). This shows that the participants on average estimated the button press M to be sooner than it was in reality.

## W task responses relative to button press M

The mean of W across all participants was measured at -215.21ms (SD = 228.35) relative to the actual button press M which was set at 0ms. SD was relatively high, showing that there was a lot of variation between participants and therefore making the data less reliable. The mean W across participants differed between -991.67ms to 24.18ms. Only one positive mean W was recorded (24.18ms), suggesting that this participant communicated the will to move (W) after the performed action (M) consistently. This participant might not have understood the task or had difficulties filling in their estimate. The Libet Clock Experiment is about free will, so the participant's data was not removed from the dataset as it was still a conscious decision to report the W data as they did. The mean W significantly differed from M ($t(23) = -4.617$, $p = .000$).

**W task responses relative to R task responses**

The W task (M =-215.21, SD = 228.35) was compared to the R task (M = -27.37, SD = 38.83) using a Paired-Sample t-test, and W and R were shown to differ significantly (t(23) = -4.177, p = .000). This shows that the first urge to act W occurs significantly before the reported button-press estimate R.

**ψ time relative to button press M**

$C_3$ activity was averaged over all participants, and ψ was found through segmented regression relative to the baseline potential, set to 0μV. The ψ had an overall average of -388.87ms in the W task (ψW), and an average of -367.56ms in the R task (ψR). Both ψW (t(23) = -6.567, p = .000) as well as ψR (t(23) = -6.683, p = .000) averages differed significantly from the button press M at 0ms. Means of ψW and ψR were compared using a Paired-Sample t-test, and ψ was shown not to significantly differ between the W and R tasks (t(23) = -.285, p = .778). The significant start of the RP (ψ) for all participants was also calculated by averaging ψW and ψR, and this combined dataset was named $\psi_{avg}$. This was done to analyze the average significant start of the RP (ψ) across the entire study. The $\psi_{avg}$ significantly differed from M (t(23) = -8.757, p =.000). This means that the start of the RP (ψ) significantly precedes the button-press M over all tasks.

**ψ time relative to W task responses**

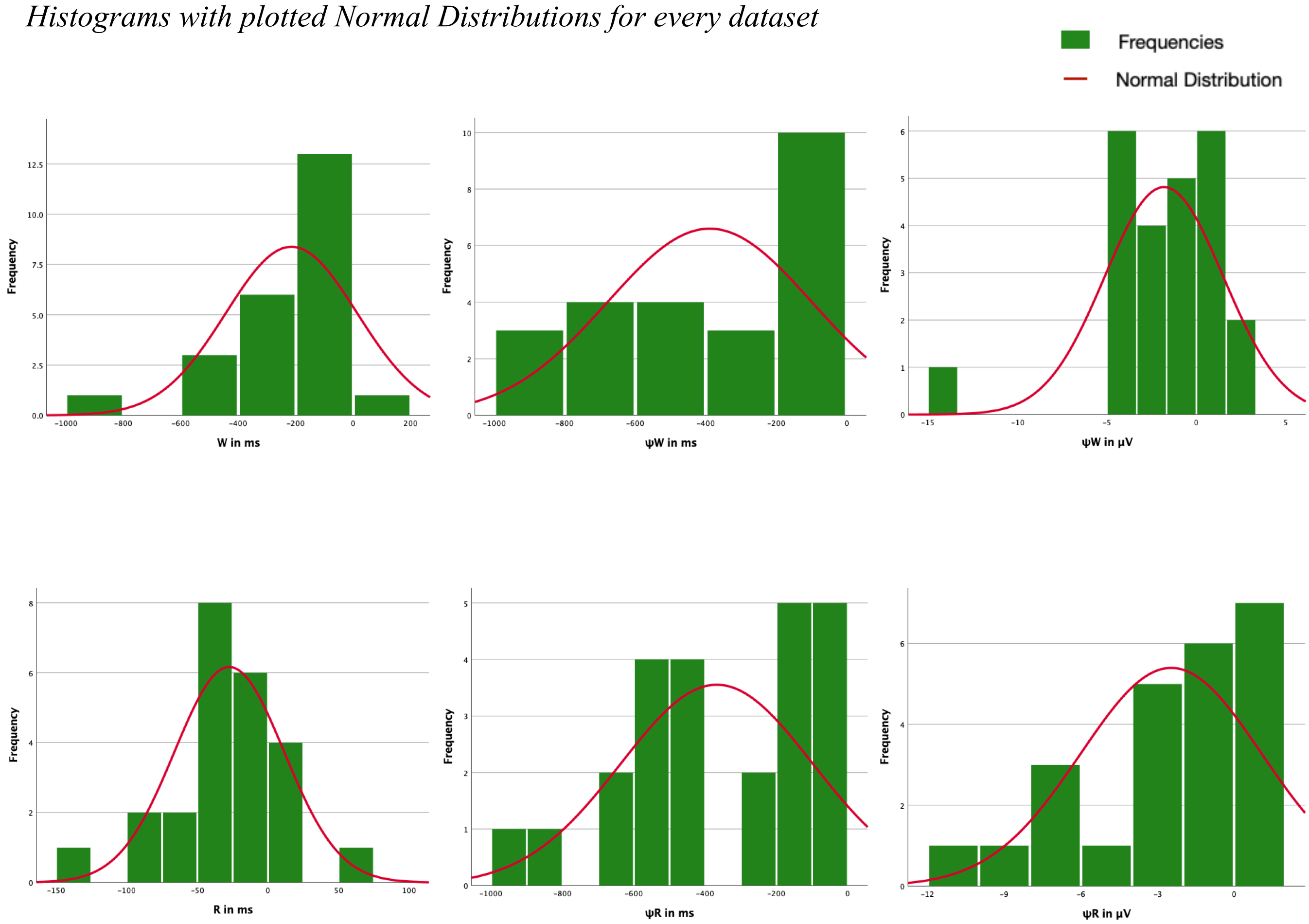
The significant start of the RP was analyzed separately for ψW and ψR. Both ψW (t(23) = 2.112, p = .046) as well as ψR (t(23) = 2.199, p = .038) showed that RP onset ψ was significantly before reported will to move W. The $\psi_{avg}$ was compared to the average reported will to move W using a Paired-Sample t-test, and ψ was shown to differ significantly from W (t(23) = 2.463, p = .022). Therefore, in every data set, the RP significantly starts before the average first reported will to move W across all participants, matching Libet's original findings.

**ψ amplitude relative to baseline potential at W and R task responses**

The average ψ amplitude was -1.81μV for the W task (WμV) and -2.47μV for the R task (RμV). Means of WμV and RμV were compared using a Paired-Sample t-test, and μV was shown not to differ significantly between the W and R tasks (t(23)= -1.008, p = .324). Both WμV (t(23) = -2.681, p = .013) as well as RμV (t(23)= -3.406, p = .002) differed significantly from the baseline potential set to 0μV. This means that the ψ amplitude was significantly higher than 0μV at time of W as well as R, showing that the brain was indeed significantly active.

**Figure 2a.**

*Histograms with plotted Normal Distributions for every dataset*




*Note.* Normal distribution was checked for test validity when normal distribution is assumed.

The Shapiro-Wilk test was used to determine the significance of normal distributions.

$W_{SD}$= 228.35

$W_{mean}$= -215.21

p=.000*

$\psi W_{SD}$= 290.10

$\psi W_{mean}$= -388.87

p= .014*

$W\mu V_{SD}$= 3.32

$W\mu V_{mean}$= -1.81

p= .000*

$R_{SD}$= 38.83

$R_{mean}$= -27.37

p= .723

$\psi R_{SD}$= 269.45

$\psi R_{mean}$= -367.56

p=.027*

$R\mu V_{SD}$= 3.55

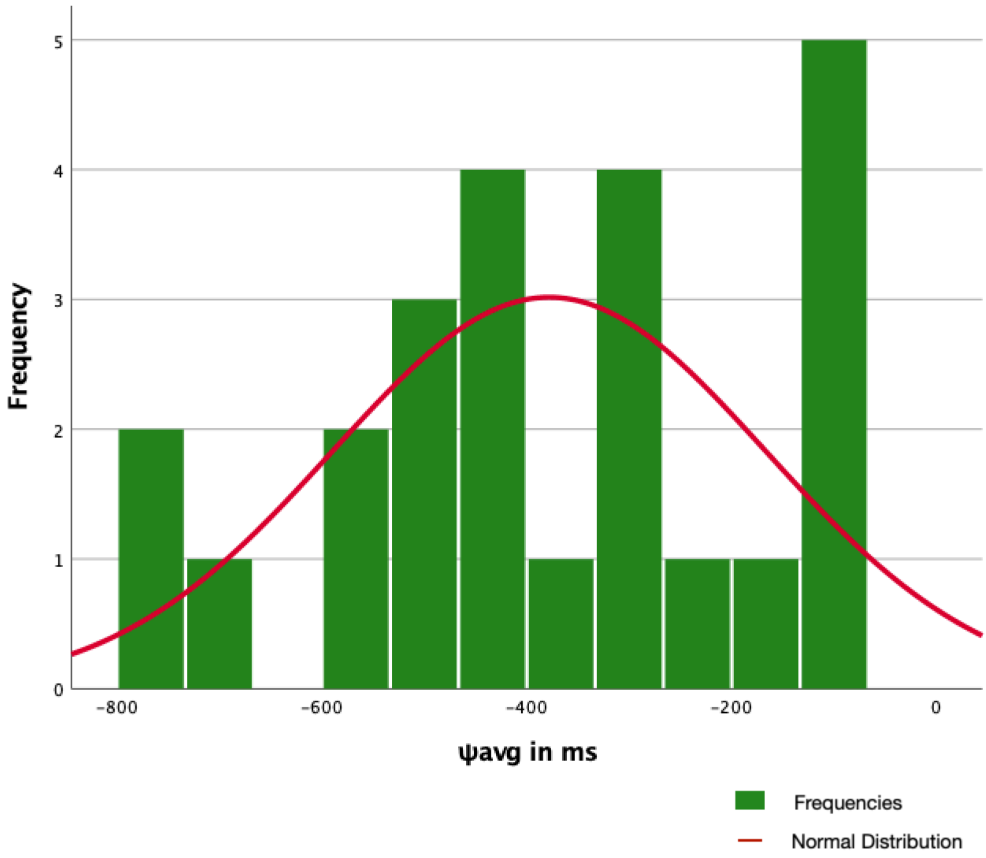
$R\mu V_{mean}$= -2.47

p= .008*

** = Sig ($p < 0.05$), therefore not normally distributed*

**Figure 2b.**

*Histogram with plotted Normal Distribution for $\psi_{avg}$, combining the datasets $\psi R$ and $\psi W$*




*Note.* The Shapiro-Wilk test was used to determine the significance of the normal distribution.

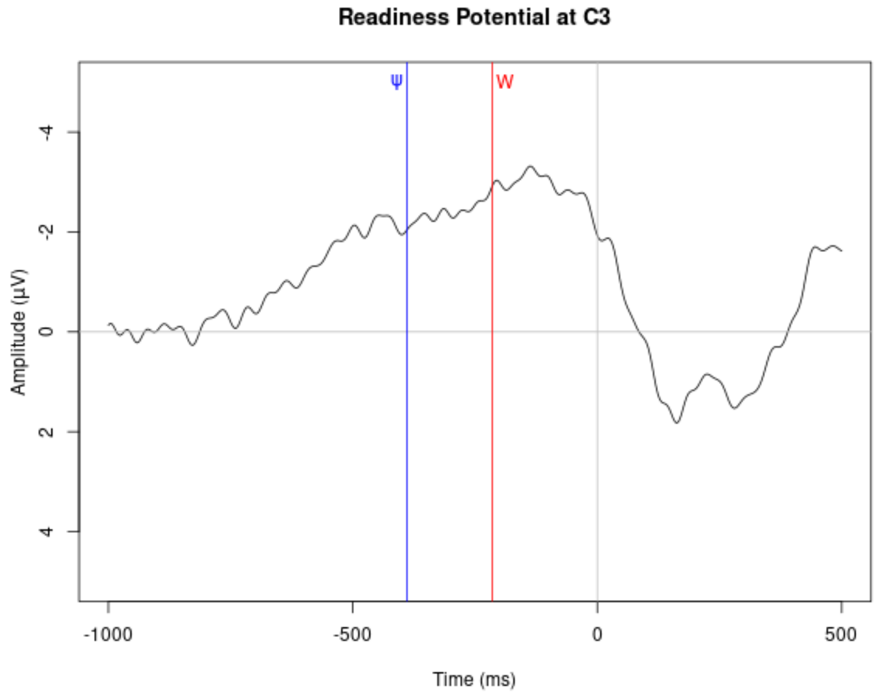
$\psi_{avgSD} = 211.57$

$\psi_{avgMean} = -378.21$

$p = .272$

**Figure 3.**

*The Readiness Potential at electrode $C_3$ set out as amplitude (µV) over time (ms)*




As seen in Figure 3, the average RP across all participants over electrode $C_3$ is shown as changes in µV over time. Blue indicator ψ is the significant start of the RP, whereas the red indicator W is the average of the first reported will of the participants to act. The actual button press was chosen as the 0ms point of reference. The chosen timeframe is -1000ms prior to the button press and 500ms after the button press, as these were the data segments used as described in the Method section. As displayed in the above figure, ψ occurs before W does, meaning Readiness Potential at electrode $C_3$ becomes active before the conscious will to act is reported.

## Discussion

The current study replicated the original Libet Clock Experiment and focused on improving the original experiment by adding a different statistical approach and an added control group. Results revealed that the RP onset was indeed before the W (see Figure 3), therefore providing further evidence for Libet's original results and confirming the research question as posed at the start of this study. The original Libet experiment is therefore successfully improved, solidifying the results of the original experiment. This study has improved the reliability of Libet's original results by replicating them with a more reliable design.

However, in excluding all other data except for the $C_3$-electrode, valuable data could be lost. Data that brings more noise, but when filtered might give different or perhaps more nuanced outcomes. In this study, results were clear and absolute that $\psi$ preceded W, but this might not be so clear-cut when more data is involved. Clusters of electrodes could be chosen to analyze instead of a single electrode as was done in this experiment, possibly changing the outcome and significance of the experiment.

This study also showed that the participants' task, whether it be R or W, did not affect $\psi$ . This means that the average RP in this experiment is not influenced by which task is performed. Data also showed, however, that within tasks the W and R differed immensely between and within participants. One participant even reported the first will to act after their button press consistently, and as explained in the results, it was decided that this participant would not be removed as an outlier. Were this participant removed it would slightly improve the data, but it would destroy the philosophical basis on which the Libet Clock Experiment was founded; free will.

The current study further solidifies the Libet Clock Experiment and its original findings, but Libet's conclusion about the absence of free will was often found too strong and received a lot of critiques (Brass et al., 2019; Bergner, 2018; Fischborn, 2016). He stated that as the brain activity precedes the first reported will to act, free will can not exist. Free will and early brain activity are not mutually exclusive. So-called 'free won't' is the ability to cancel one's action after the intention to move has already occurred. Since this is possible (Obhi, S., & Haggard, P., 2004), free will is not disproven by the Libet Clock Experiment. Breitmeyer, B. (1985, p. 529) argued that the role of conscious will is "not to initiate a specific voluntary act but rather to select and control volitional outcome." Breitmeyer therefore argues that the Libet Clock Experiment does not disprove free will, as we are still able to decide whether an action is performed or not. Breitmeyer states that conscious will is not initiation, but selection of outcome. In summary, even though Libet's findings were found to be accurate, the conclusion is debatable. Future studies regarding 'free won't' could shed more light on this matter.

A limitation of the Libet Clock Experiment is the subjectively reported W (will to move). The controlled R group was added to this study to determine whether the participants were skilled at estimating time. As the average R only differed from the actual button press M by 27ms, it seems that in this particular study, the participants are fairly accurate in their estimates and that would be true for W as well. The R control group is not without flaw though, as the R and the W task are different.

In the R task, the participant was asked to estimate the time of the button press. This is accompanied by physical movement and could therefore possibly be easier to estimate relative to the W task, where the participant had to estimate when they felt the first urge to move- a purely psychological phenomena. This problem is difficult to overcome, as there needs to be a factor of free will in the experiment and there will always be a subjective element to that. An added note would be that the R and W tasks seem to differ somewhat in difficulty, with the W task asking the participant to estimate a conscious thought, and the R task asking the participant to estimate a physical action.

A limitation of the current study is the use of mostly non-normally distributed data sets. Only the R data group and the $\psi_{avg}$ were normally distributed and the various t-tests can therefore without a doubt be used on this these dataset, making their outcomes reliable. Although t-tests are robust against violation of normal distribution, this is lesser the case when working with small sample sizes (small sample sizes are considered $N < 50$, this study consists of $N = 24$). Larger sample sizes in general would possibly forge a more reliable data set, diminishing the chance of error and perhaps even yield different results.

# Conclusion

In summary, this study's results show that the RP precedes the first will to move, therefore confirming Libet's original findings. Although the partly philosophical argument about free will still stands, the data suggests that our brains do become active before we are consciously aware of it. The $C_3$ activity that begins before our intention to move is logical in the sense that there needs to be cause for our consciousness to realize its first will to move, so it appears logical for the brain activity to precede the conscious realization of this seemingly voluntary decision to move. But the question remains; Why does the brain's activity start before we are consciously aware? This will likely remain to feel paradoxical. Free will will always be a controversial topic, making it all the more fascinating.

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