
Dissecting the Readiness Potential

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN
READINESS POTENTIALS, CONSCIOUS WILLING, AND ACTION

*Prescott Alexander, Alexander Schlegel, Walter Sinnott-Armstrong,
Adina Roskies, Peter Ulric Tse, and Thalia Wheatley*

1. Introduction

The readiness potential (RP) was first described by Kornhuber and Deecke in 1965 as “a slowly increasing surface-negative cortical potential” recorded over the vertex preceding voluntary movements (Deecke & Kornhuber, 1965, 1). Further study led Deecke and colleagues to conclude that the RP probably represents “a preparatory process in the dendritic network of those cortical areas that are involved in the intended movement” (Deecke et al., 1976, 99). It was not until Benjamin Libet and colleagues conducted their now-famous experiments in the early 1980s that the RP became the focal point of the debate surrounding the causal (in)efficacy of the conscious willing of intended actions. Libet’s key innovation was to investigate the temporal relationship between the onset of the RP and what Libet referred to as W: the reported time at which subjects’ “subjective experience of ‘wanting’ or intending to act” began (Libet et al., 1983a, 623). His data revealed that on average the RP begins several hundred milliseconds (ms) before W, calling into question the ability of the conscious choice to influence the timing of the movement.

While Libet et al. (1983a) were specific about their use of W to refer to the time that subjects reported having initially become aware that they were about to consciously will an action, the term has since been used to refer to a number of related, though distinct, phenomena. In order to be clear, we will use W to refer to the psychological event of conscious proximal will and W_T to refer to the reported time that conscious processes related to this event began. Similarly, we will use M to refer to the actual resulting bodily movement, and M_T to refer to “the [reported] time of subject’s [initial] awareness that he/she ‘actually moved’” (Libet et al., 1983a, 627).

Libet interpreted his result as placing “certain constraints on the potentiality for conscious initiation and control of voluntary acts” (Libet et al., 1983a, 623). However, he concluded that his finding ruled out neither the possibility of a conscious “veto” power, as W_T occurs before movement onset, nor the possibility that acts preceded by conscious deliberation might be consciously initiated and controlled (Libet et al., 1983a).

More recently, the relationship between the lateralized readiness potential (LRP) and W_T has been investigated as well (Haggard & Eimer, 1999; Schlegel et al., 2013). The LRP is a motor-related potential that precedes unilateral movement and is generally expressed as a difference wave (contralateral activity minus ipsilateral activity) showing greater activity over the motor cortex contralateral to the movement side compared to the ipsilateral side (Eimer, 1998). Haggard and Eimer (1999) found that although the timing of the RP was not correlated with W_T , the timing of LRP onset was. The authors reported that “this finding rules out the RP as the unconscious cause of the conscious state upon which W judgment depends, but it is consistent with LRP having that role” (Haggard & Eimer, 1999, 132).

While the work of Libet, Haggard and Eimer, and others (cf. Sirigu et al., 2004; Soon et al., 2008, 2013; Fried et al., 2011) has been both illuminating and controversial, three fundamental questions about the RP and LRP and their role in the debate around free will remain unresolved:

1. What is the relationship between the RP/LRP and W_T ?
2. What is the relationship between the RP/LRP and movement?
3. Can the relationship between the RP/LRP and “conscious intention” be investigated directly, and if so, what is the nature of that relationship?

Here we attempt to answer these three questions through a series of five experiments with the hope that our data might guide the academic discussion of free will in a more fruitful direction.

2. Question 1—The RP/LRP and W_T

2.1. Background

Although the temporal relationship between the RP and W_T on individual trials is still a matter of debate (cf. Trevena & Miller, 2002; Roskies, 2010b; Schurger et al., 2012), the relative timing of the average RP and average W_T first reported by Libet and colleagues (1983a) has been replicated many times (cf. Haggard & Eimer, 1999; Trevena & Miller, 2002; Matsushashi & Hallett, 2008; Schurger et al., 2012; Schlegel et al., 2013, among others). While less established, the same relationship appears to exist between the LRP and W_T , such that the average LRP begins approximately 600–800 ms before M (depending on the calculation method; cf. Haggard & Eimer, 1999; Matsushashi & Hallett, 2008; Schlegel et al., 2013) with the average W_T following at approximately 200–400 ms before M (Libet et al. 1983a; Haggard & Eimer, 1999; Schurger et al., 2012; Schlegel et al., 2013).

The observed temporal discrepancy between the average RP/LRP and W_T , while consistent, is a woefully incomplete description of the relationship between the two phenomena. The brain activity indexed by the RP/LRP could, in principle, have no direct relationship with W at all. Libet's finding simply shows that the average RP/LRP begins before the average W_T (Haggard & Eimer, 1999; Roskies, 2010b).

In an attempt to more deeply investigate the relationship between the RP/LRP and W_T , Haggard and Eimer (1999) examined whether the onset of the RP or LRP were correlated with W_T in a way that would be compatible with the hypothesis that the RP or LRP caused W . Following the observation of John Stuart Mill (1843) that one characteristic of causal relations is “covariation of causes and effects” (Haggard & Eimer, 1999, 129), the authors argued that the presence of a covariation between the timing of the onset of the RP or LRP and W_T would be at least consistent with a causal relationship, while a lack of covariation would rule out the possibility of one or both of these brain potentials (RP or LRP) being the cause of the conscious awareness of commanding or intending to move (W).

To address this question, Haggard and Eimer split each subject's data into “early” and “late” awareness trials (median split based on time between W_T and M) and tested whether the RP or LRP began earlier for “early” compared to “late” awareness trials. The authors reported that RP onset did not differ between “early” and “late” awareness trials; however, LRP onset occurred significantly earlier on “early” awareness trials. If correct, this would imply that the LRP could be an “unconscious cause of the conscious state [W] upon

which $W_{[T]}$ judgment depends” (Haggard & Eimer, 1999 p. 132). However, careful examination of their data reveals that if either of two subjects were removed from their dataset of only eight subjects, the observed effect would no longer reach statistical significance (see Haggard & Eimer, 1999, 132, Table 2, subjects 3 and 6; Schlegel et al., 2013). Given this weakness and the importance of claims made on the basis of these findings, we felt that a replication experiment was needed.

2.2. Experiment 1—Revisiting Haggard and Eimer, 1999

2.2.1. Methods

We precisely followed the procedures used by Haggard and Eimer as described in their 1999 paper. Participants ($N = 21$; 9 female, 20 right-handed, mean age 28.9 years) each performed 320 trials of the standard Libet task while sitting 50 cm from a computer monitor on which a clock with a rotating hand (1.3 cm length, 2,560 ms period) and labeled positions (1–12 o'clock) were displayed. Trials could involve either fixed (response hand chosen by experimenter) or free (response hand chosen by participant) movements, either W or M judgments, and either right or left responses. Participants were instructed to make each movement spontaneously without any pre-planning or ordering of responses, as in the standard Libet paradigm. Participants were told to report “when you first began to prepare your movement” or “when you pressed the key” for W_T and M_T trials, respectively—exactly as in Haggard and Eimer (1999).

The EEG was recorded from 32 scalp locations (10–20 system; Jasper, 1958) and each mastoid at 2,048 Hz (BioSemi, Active 2, Ag/AgCl electrodes). Data from 8 electrodes (Fpz, Fz, Cz, Pz, C3, C4, and mastoids) from 19 participants were included in the analysis. Data from two participants were excluded due to experiment interruption (one subject) or excessive noise (one subject). Data were re-referenced offline to the average of the mastoids and bandpass filtered from 0.016 to 70 Hz. Epochs were defined from 2,600 ms before to 400 ms after each key press and baseline corrected using the mean signal from the first 100 ms. Epochs containing fluctuations exceeding $80\mu V$ at FPz or Pz or participant error were rejected (mean 18.8 % [SD 22.2 %] for each participant). RPs were calculated at electrode Cz; LRPs were calculated using the method of double subtraction between electrodes C3 and C4 (De Jong et al., 1988; Eimer, 1998).

2.2.2. Results

Consistent with Haggard and Eimer’s results, we found no difference in RP latency between “early” and “late” awareness (W_T) trials (Figure 11.1). However, contrary to their findings we found that LRP onset also did not

differ between “early” and “late” awareness trials, and in fact showed the opposite trend, with LRP onset occurring earlier (though not significantly so) on “late” awareness trials (mean LRP onset was -719 ms (SE 199 ms) for “early” and -851 ms (SE 124 ms) for “late” trials: see Figure 11.1 and Table 11.1) (Schlegel et al., 2013). It should be noted, however, that Haggard and Eimer used a somewhat unusual technique for calculating LRP onset (cf. Haggard &

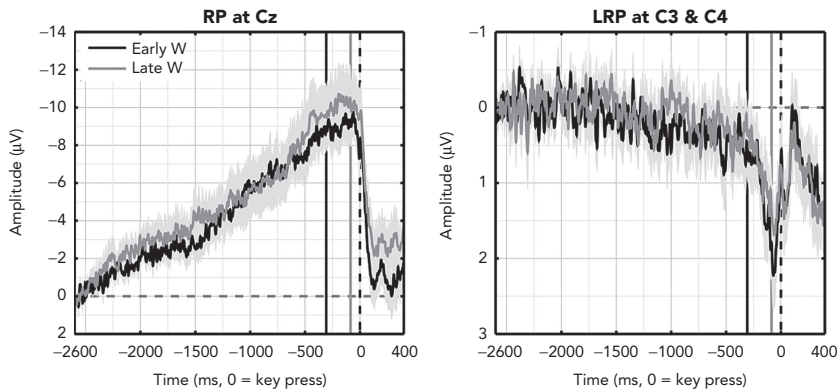


FIGURE 11.1. (Experiment 1): No significant differences exist between early and late awareness RPs at Cz or LRPs at C3 and C4. Solid black vertical line is the mean early W_T (-307 ms). Solid gray vertical line is the mean late W_T (-855 ms). Dotted black vertical line is the time of button press.

Table 11.1

T Test	Early	Late	t	p
RP onset mean	$-6.65\mu\text{V}$	$-6.68\mu\text{V}$	0.0330	0.974
LRP onset	-719 ms	-815 ms	0.857	0.799
LRP onset (jackknife)	-460	-679	0.448	0.670
LRP 50% peak latency	-383	-426	0.409	0.656
LRP 50% peak latency (jackknife)	-179	-200	0.740	0.766
LRP 25% peak latency	-695	-647	-0.386	0.352
LRP 25% peak latency (jackknife)	-335	-275	-0.408	0.344

Table 11.1 (*Continue*)

Correlation	r	r ²	p
LRP onset versus W	0.283	0.0801	0.227
LRP onset versus W (jackknife)	0.642	0.412	0.00230
LRP 50% peak latency versus W	-0.0468	0.00220	0.845
LRP 50% peak latency versus W (jackknife)	0.125	0.0157	0.599
LRP 25% peak latency versus W	-0.404	0.164	0.0770
LRP 25% peak latency versus W (jackknife)	0.0888	0.00789	0.710

AQ: Please provide the caption for table 11.1-11.3

Eimer, 1999, or Schlegel et al., 2013). In order to address any possible effect of LRP onset calculation method, we tested two other methods and then tested all three methods again using a jackknife procedure as suggested by Miller, Patterson, and Ulrich (1998) (see Schlegel et al., 2013 for details). None of these tests revealed a significant difference in LRP onset for “early” versus “late” awareness trials (see Table 11.1 and Schlegel et al., 2013).

Thus, following the same logic used by Haggard and Eimer to eliminate the possibility of a causal relation between the neural processes indexed by the RP and W, we conclude that neither the RP nor LRP is likely to be an “unconscious cause of the conscious state upon which W judgment depends” (Haggard & Eimer, 1999, 132).

3. Question 2—The RP/LRP and Movement

3.1. Background

While understanding the relationship between the RP/LRP and W_T is important for assessing their relevance to the debate concerning the question of free will, as Roskies argues, “The real questions at issue . . . are whether Libet is correct in causally connecting the RPs with impending motor movements” (Roskies, 2010b, 15). If the RP is not causally related to movement production or execution, then findings about the RP/LRP could not show that W does not play a role in producing movements.

The relationship between the RP and movement has been directly assessed several times (cf. Libet et al. 1983b; Castro et al. 2005; Trevena & Miller, 2010) although each of these studies has weaknesses. Unlike the original Libet paradigm (Libet et al., 1983a), the paradigms used by Libet et al. (1983b) and Castro et al. (2005) employed predetermined movement times. Subjects were told to prepare to make a movement at the instructed time but to only execute the movement on certain indicated trials. In fact, in this paradigm subjects had no choice whatsoever as they knew before each trial when the imperative stimulus would appear and whether or not they would execute the movement. Furthermore, the assumption that response preparation would be equivalent in the movement and no-movement conditions is highly suspect and a possible explanation for why both studies report lower amplitude RPs on no-movement trials. Thus, the ability of these studies to address the relationship between the RP and movement is questionable.

Trevena and Miller (2010) attempted to address this question using a different paradigm. In their task, subjects heard tones presented at random intervals and had to decide, upon hearing a tone, whether to move or not. As in the studies discussed previously, and quite unlike the original Libet paradigm, subjects did not choose the timing of their movements, but they did choose whether or not to move. Although subjects made a choice during the task, they were instructed to “try not to decide in advance what you will do” (Trevena & Miller, 2010, 449). This task is highly dissimilar to those usually used to elicit an RP. Unsurprisingly, even a cursory inspection of their data shows that no RP is discernible (the “RP” at Cz never appears to exceed $-2 \mu\text{V}$). The authors only report the lack of difference between movement and no movement trials and do not address whether any of their observed potentials deviate from baseline prior to the tone (for a more thorough critique see Gomes, 2010).

While the weaknesses in these studies are significant, the real issue is that for any task in which the timing of the choice is temporally unconstrained, some event must occur to which the data can be time-locked for averaging. It remains unclear what this event could be in the absence of a movement of some kind. While there seems to be no single experiment that can circumvent this limitation, here we report three experiments that together suggest that the RP is not motor dependent.

3.2. *Experiments 2 and 3—Motor Dependency of CNV*

The simplest way to avoid some of the limitations encountered by the studies discussed is to target the contingent negative variation (CNV) rather than the

RP. The CNV, like the RP, is a slow negative waveform measured at the vertex; however, the CNV is generally elicited in the time between a warning stimulus and an imperative stimulus indicating movement or action (Walter et al, 1965), whereas in “RP paradigms” the timing of the movement is not determined by a stimulus but is chosen by the subject on each trial. While some have argued that the two potentials share at least some common neural sources (van Boxtel, 1993; van Boxtel and Brunia, 1994), others argue that they are distinct, at least to some degree (cf. Ikeda et al., 1994; Ikeda et al., 1997). Thus, no strong conclusions about either the RP or the LRP should be drawn from CNV paradigms. Nonetheless, findings about the CNV may prove useful in establishing a conceptual framework on which RP studies can then be based.

The following two experiments utilize a “warning stimulus followed by an imperative stimulus” paradigm typical of CNV studies (often called an S_1 – S_2 paradigm). The main stimulus was a rapid serial visual presentation (RSVP) stream of randomly ordered characters (A–Z and 0–9) presented on a computer monitor at a rate of ~ 7 Hz (each character was on screen for 86.7 ms followed by a 57.1 ms blank). Characters were randomly determined shades of blue and subtended 5.8 degrees of visual angle. The warning stimulus was a gradual filling-in of the characters with yellow beginning at the top and bottom of the characters and progressing toward the middle (see Figure 11.2).

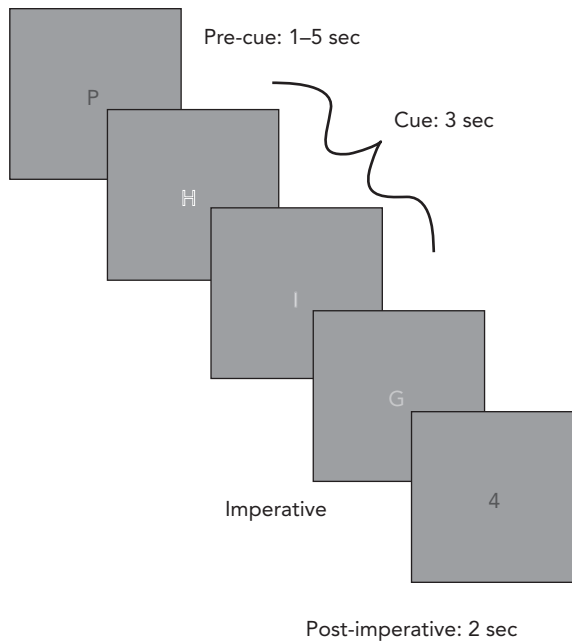


FIGURE 11.2. (Experiments 2 and 3): Trial schematic for Experiments 2 and 3 showing RSVP stream and “closing window” cue.

The warning stimulus lasted 3 seconds unless otherwise noted. Immediately following the “closing” of the yellow warning cue, that is, when the top and bottom yellow portions met in the middle of the character, the imperative stimulus, a specific character of a different color (e.g., red or green) was presented that prompted the subject to either perform or withhold the required action.

3.3. Experiment 2

3.3.1. Methods

Experiment 2 consisted of three types of trials: “Go” trials in which the warning cue was followed by a green letter “G” indicating that the subject should respond with a button press as quickly as possible; “No Go” trials in which the warning cue was followed by a red letter “G” indicating that the subject should withhold any response; and “No Cue” trials in which the green “G” appeared without a warning cue. Data pre-processing steps were the same as those used in Experiment 1, with the exception that epochs were defined from 3100 ms before to 400 ms after button press. The CNV was calculated at electrode Cz; lateralized CNV (L-CNV) was calculated using the double subtraction method at electrodes C3 and C4 (De Jong et al., 1988; Eimer, 1998).

3.3.2. Results

Average waveforms (Figure 11.3) clearly show that the CNV appears only on trials where the warning cue was present, regardless of whether the subject made a movement (Figure 11.3A, C), and the L-CNV appears only on trials where the subject made a movement, regardless of whether the warning cue was present (Figure 11.3B, D). These results suggest that the CNV reflects preparation independent of action while the L-CNV reflects action independent of preparation. As stated previously, these results must be interpreted carefully with respect to RPs and LRPs; however, to the extent that the RP and CNV reflect similar or overlapping neural processes, a similar relationship might exist between the RP/LRP and movement as between the CNV/L-CNV and movement.

3.4. Experiment 3

3.4.1. Methods

Experiment 3 was ~~essentially~~ a modified version of the task used by Donchin et al. (1972), including four trial types: “Go” trials, “Go/No Go” trials, “Predict” trials, and “Compute” trials. On “Go” trials, subjects made a

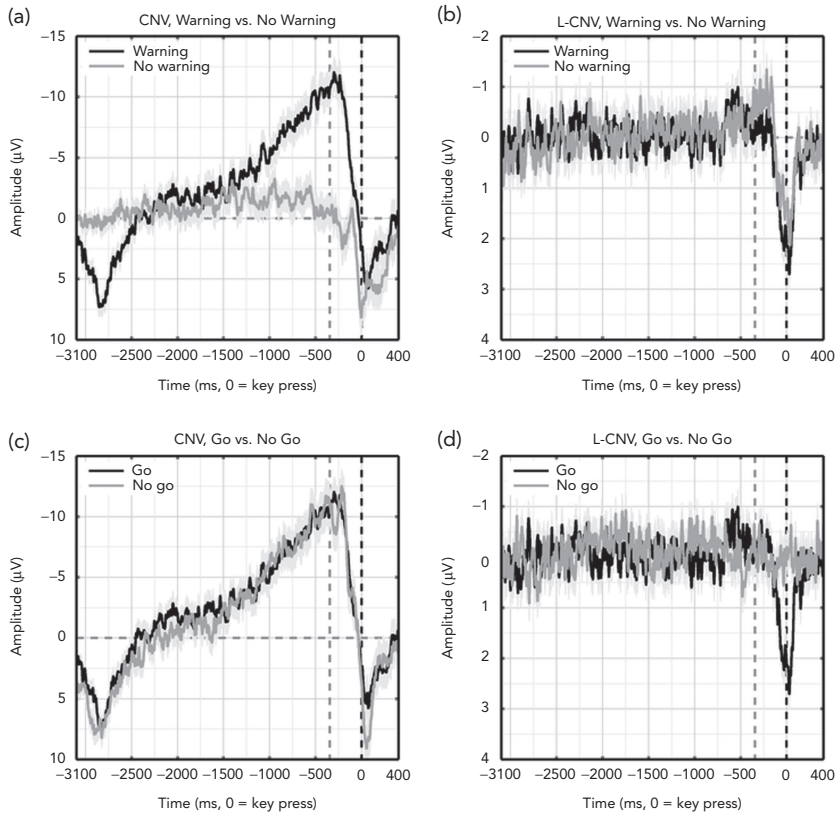


FIGURE 11.3. (Experiment 2): CNV waveform tracks preparation (A) regardless of whether a movement was executed (C); L-CNV tracks movement execution (D) regardless of preparation (B).

speeded response (button press) to the imperative stimulus (green “G”) on each trial. On “Go/No Go” trials, subjects made a speeded response only if the imperative was a green “G” (50% of trials) and withheld any response if the imperative stimulus was a red “N” (50% of trials). On “Predict” trials, subjects guessed whether the imperative stimulus on the current trial would be a green “L” or green “R”; no responses were made during trials. On “Compute” trials the imperative stimulus was always a number and subjects were instructed to add or subtract the “imperative number” on each trial from a running total. The initial value of the running total was a randomly selected three-digit integer between 300 and 700. The color of the imperative number indicated the operation to perform (green = add, red = subtract). All tasks included the 3-second warning cue described. Pre-processing and averaging followed the

steps used in Experiment 2 except that epochs were time-locked to imperative stimulus onset rather than button press.

3.4.2. Results

Consistent with our finding in Experiment 2, all tasks elicited a CNV regardless of whether a motor response was required, although there was a general trend of larger peak amplitude in the “Go” and “Go/No Go” tasks than in the “Predict” and “Compute” tasks (see Figure 11.4). These results provide further evidence that the CNV does not depend on movement and instead may reflect general anticipation for cognitive or motor actions. The observed amplitude difference between movement-related and purely cognitive tasks might reflect a unique contribution of motor preparation to the CNV, although it should be noted that task demands were not equal, as only the “Go” and “Go/No Go” tasks required a speeded response. Thus, the difference might also

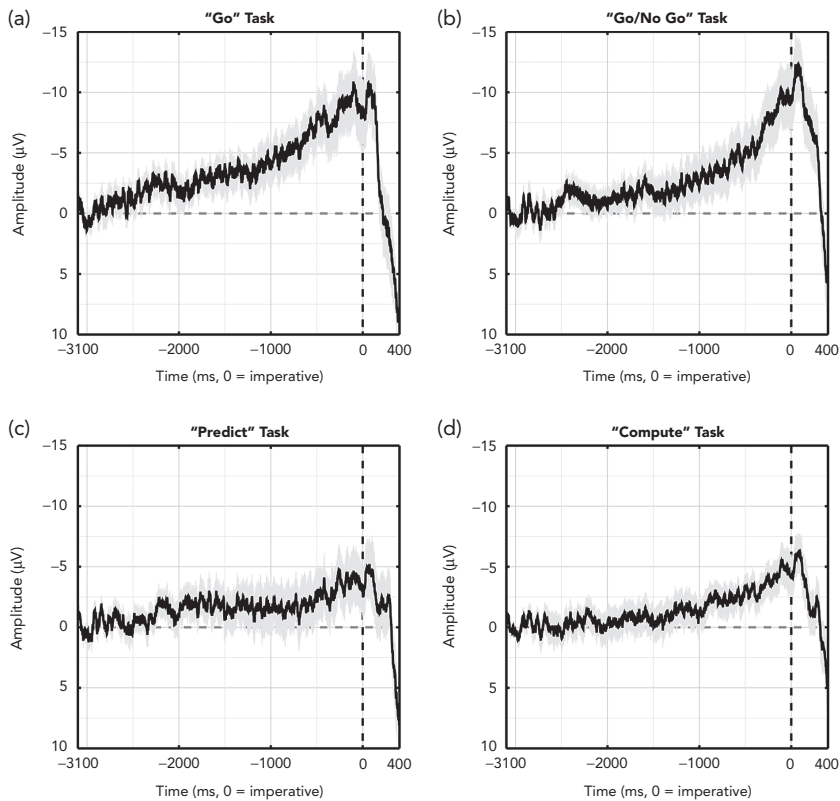


FIGURE 11.4. (Experiment 3): CNV waveforms are seen preceding motor-related acts (A & B), cognitive acts (D), and the arrival of informative stimuli (C).

reflect the intensity of anticipation as well as the modality of action. As mentioned previously, the relevance of these findings to the RP debate is limited by the uncertainty concerning the degree to which the causes of the CNV overlap with those of the RP. Nonetheless, these results do provide reason to consider testing whether an RP is seen preceding a purely cognitive action. Experiment 4 specifically addresses this question.

3.5. Experiment 4—Motor Dependency of RP

3.5.1. Methods

Experiment 4 was a variant of the standard Libet task with the addition of a quartered circle inside the clock (see Experiment 1 methods for a full description of the Libet clock stimuli). Before each trial the clock stimulus appeared, indicating that the subject could begin the trial at any time by pressing a key (Figure 11.5, Trial Start). Once the trial started, the clock hand/pointer began to rotate and a small ~ 7 Hz RSVP stream of random letters each with a randomly selected color appeared inside each section of the quartered inner circle. The RSVP streams continued until the clock hand/pointer reached the 3 o'clock position (2550 ms; see Figure 11.5, Waiting Phase). Once the 3 o'clock position was reached, the letters within each section stopped changing, though the color of the letters continued to change at ~ 7 Hz. At any time between the 3 o'clock and 12 o'clock positions (7650 ms), the subjects chose a letter and noted the clock position of the hand/pointer at the moment when they made their decision (Figure 11.5, Decision Phase). On “decision only” trials, subjects made no overt response, whereas on “decision plus movement” trials subjects were instructed to press a key at “the moment when you make your decision” in addition to noting the time. The clock hand/pointer always continued to rotate until it reached the 1 o'clock position for a second time (10200 ms period, 11050 ms total). After each trial, subjects reported both the position of the hand/pointer at the moment they made their decision and the letter that they had chosen.

The data were pre-processed twice, once using a 0.016 to 70 Hz bandpass filter to identify epochs containing eye-blink or eye movement artifact and once using a 0.016 to 15 Hz bandpass filter for averaging. Epochs were defined from 2,600 ms before to 500 ms after the reported decision time on each trial (“decision-aligned”) and baseline corrected using the mean signal from the first 100 ms. Epochs containing either fluctuations exceeding 80 μV at FPz or Pz in the 70 Hz lowpass-filtered data or participant error were rejected [mean 26.09% rejected (SD 13.85%)]. RPs were calculated at Cz separately for

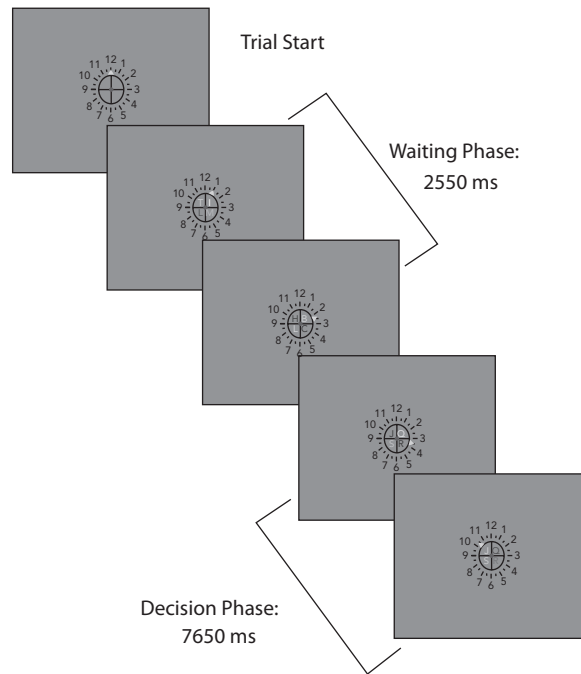


FIGURE 11.5: (Experiment 4): Trial schematic for Experiment 4 showing the modified Libet task. The four RSVP streams (one per quadrant inside the clock) stopped 2550 ms (3 o'clock position) after trial onset; the color of the characters changed throughout the trial.

“decision only” and “decision plus movement” trials. Subjects whose mean RP amplitude between the end of baseline (2500 ms before the decision) and the decision time for the “decision plus movement” condition did not exceed $0\mu\text{V}$ (i.e., showed no negative deflection) were excluded from all analyses. Five subjects were excluded by this criterion and 1 subject was excluded due to experiment interruption, leaving 11 subjects included in the analysis.

To verify that the “decision plus movement” condition resulted in a typical RP, another set of “movement-aligned” epochs were defined relative to the key press on “decision plus movement” trials only. This set of epochs was pre-processed identically to the “decision-aligned” epochs except for the different time-locking event.

3.5.2. Results

To verify that the addition of the purely cognitive “choose-a-letter” task would not adversely affect the RP, we calculated movement-aligned RPs for

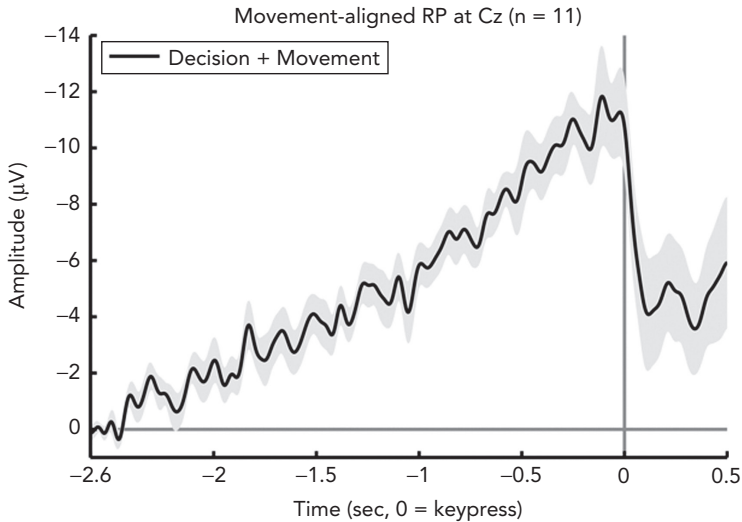


FIGURE 11.6. (Experiment 4): Average movement-aligned RP at Cz.

the “decision plus movement” condition. The movement-aligned RPs showed a typical RP shape (Figure 11.6). Mean RP amplitude between the end of baseline (2500 ms before keypress) and keypress was $-5.51 \mu\text{V}$ (SE $.55 \mu\text{V}$) and average peak amplitude was $-14.70 \mu\text{V}$ (SE $1.61 \mu\text{V}$). No statistical analyses were performed on the movement-aligned data; however, visual inspection confirmed that a robust RP is still seen with the addition of the “choose-a-letter” task as the RP amplitude and shape are comparable to what is typically seen in the classic Libet task (cf. Haggard & Eimer, 1999; Schlegel et al., 2013).

Average decision-aligned RPs for the “decision only” and “decision plus movement” conditions show that there was a nonsignificant trend for larger amplitude RPs in the “decision plus movement” condition (see Figure 11.7). Mean amplitude, as assessed between the end of the baseline period (2500 ms before the reported time of decision) and the reported time of decision, was $-3.41 \mu\text{V}$ (SE $1.31 \mu\text{V}$) and $-5.01 \mu\text{V}$ (SE $.64 \mu\text{V}$) for “decision only” and “decision plus movement” conditions, respectively [$t(20) = 1.05$, $p = 0.154$]. Likewise, peak amplitude, computed as the largest negative deflection between the end of baseline and decision time, was $-11.10 \mu\text{V}$ (SE $2.30 \mu\text{V}$) and $-13.67 \mu\text{V}$ (SE $1.14 \mu\text{V}$) for “decision only” and “decision plus movement,” respectively [$t(20) = 0.96$, $p = 0.175$].

One potential drawback of our design was that any inaccuracies in subjects’ reported decision time would introduce a temporal jitter in the time-locking event and thus potentially reduce the amplitude of the resultant

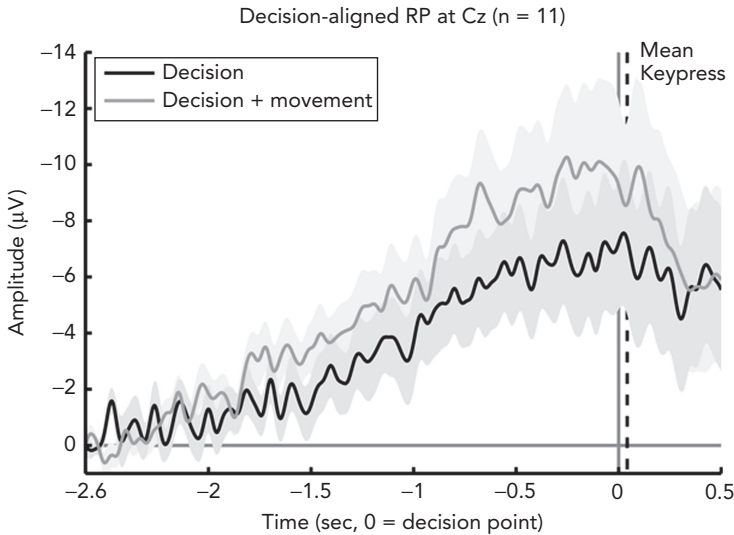


FIGURE 11.7. (Experiment 4): No significant difference is seen between RPs in decision plus movement and decision only conditions. RPs are timelocked to the subjects' reported time of decision on each trial.

decision-aligned RP compared to a movement-aligned RP. However, the “decision plus movement” condition allowed us to assess subjects' ability to retrospectively report their time of decision by comparing their reported decision time to the time of their key press on each trial. As subjects were instructed to simultaneously note the position of the clock pointer and press the key when they made their decision, any discrepancy between the two times is likely to reflect the imprecise nature of the judgment and the attentional load from the dual task (“choose a letter” task and pointer monitoring). Despite these factors, subjects were quite accurate, reporting to have made their decision on average 41.72 ms (SE 34.61 ms) before they pressed the key. Given this small difference and the minimal reduction in RP amplitude between decision-aligned versus the movement-aligned RPs, we can be reasonably confident that the RPs seen in both conditions reflect the cognitive and cognitive plus motor contributions to the RP.

The results of this experiment suggest that the RP does not reflect uniquely motor-related processes. Considered in isolation, this finding does not support or refute Libet's interpretation of the RP, though it does extend the debate into the domain of purely cognitive decisions. However, our data are also consistent with other possible explanations for the RP that suggest that it may instead reflect more domain general activity such as the buildup of

anticipation (van Boxtel & Böcker, 2004) or spontaneous random fluctuations (Schurger et al., 2012).

4. Question 3—The RP and Conscious Intention

4.1. Background

Experiment 1 already began to address the causal relation between prior brain processes and conscious intention (W), but the gold standard for assessing causal relations requires manipulation. This method has never been tried before in this domain because conscious intention is difficult to manipulate. To be clear, by “conscious intention” we simply mean the reportable experience of consciously deciding to make a movement. The ideal procedure for determining causation would allow comparison between RPs for spontaneously timed movements that were consciously intended and those that were not. While the ideal procedure may not be possible to execute in a fully controlled manner, hypnosis may provide a possible mechanism by which movements can be elicited outside of reportable awareness or intention. Although the neural basis of hypnosis is still unknown (Kihlstrom, 2012), there have been several recent studies that have validated its ability to produce effects (cf. Raz et al., 2002; Raz et al., 2005; Cojan et al., 2009; McGeown et al., 2012). Thus, in this experiment we used hypnosis to compare RPs preceding hypnotically induced and volitionally induced movements.

Hypnosis, as used here, consists of two stages: the hypnotic induction and what is called the “post-hypnotic suggestion.” Hypnotic induction is the process of inducing a trance-like state via guided imagery. A “post-hypnotic suggestion” is an instruction given to a hypnotized person that is to be followed after the person wakes from the hypnotic state.

4.2. Experiment 5—RP and Hypnotically Induced Movements

4.2.1. Methods

This experiment consisted of five phases: EEG preparation, first hypnotic induction, first task phase, second hypnotic induction, and second task phase. For the first 14 subjects the phases followed this order, and for the last 4 subjects the order of the EEG preparation and first hypnotic induction were reversed. Subjects were selected based on high susceptibility scores on a shortened version of the Harvard Group Scale of Hypnotic Susceptibility: Form

A (HGSHS) (Shor & Orne, 1962) that was administered in a large group setting for screening purposes.

For the first task phase, subjects sat 50 cm from a computer monitor on which a series of 20 second, silent nature videos were displayed (width \times height: $14.47 \times 10.88^\circ$ visual angle). A fixation point was displayed at the center of each clip and a red arrow was displayed on the right or left side indicating the hand with which subjects should respond (see Figure 11.8). Subjects' hands rested palm up on a pillow positioned on their lap under the table on which the display monitor sat. Each hand loosely held a stress ball. The task used was a self-paced squeeze task similar to those previously used to investigate RPs (cf. Deecke et al., 1976; Ball et al., 1999). Subjects squeezed the stress ball indicated by the red arrow once during each video clip at a time of their choosing. The task phase consisted of two blocks (respond right and respond left) of 40 randomly selected clips with a 3 second pause between each clip and a longer break between blocks. The order of right/left blocks was randomized and the arrow was on screen throughout the entirety of each block. The second task phase was identical except that a blue semicircle was used in place of the red arrow to indicate the response hand. Phillip Glass's soundtrack to the film *Dracula* was played in 20 second clips along with the videos. The video and music clips were used to engage subjects' attention and

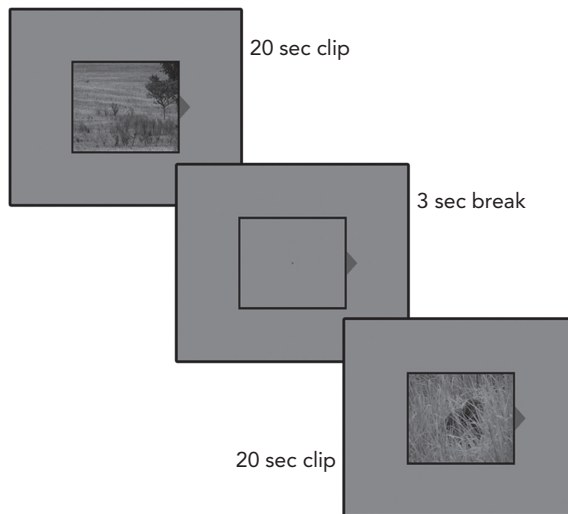


FIGURE 11.8. (Experiment 5): Trial schematic for Experiment 5. Arrows (hypnotic movement condition) and semicircles (volitional movement condition) indicating response hand were on screen for the entire block of 40 clips (4 blocks total: hypnotic right/left, volitional right/left).

thereby minimize boredom-related fidgeting and decrease the likelihood that they would discover or recall the post-hypnotic suggestion.

Hypnotic inductions followed two unique, modified versions of the HGSHS that differed from the one used in screening. The first hypnotic induction included a post-hypnotic suggestion instructing subjects to squeeze the stress ball in their right or left hand according to the red arrow on the screen once during each video clip at a time of their choosing. Subjects were further instructed that they would not remember any part of the hypnotic induction until told to do so. Upon being woken from the hypnotic state, subjects were told a cover story to minimize any suspicions they might have had, were they to find themselves involuntarily squeezing the stress ball during the movie clips. The cover story given to subjects was that during the first task phase the experimenter would be calibrating the electromyography (EMG) electrodes during each clip and that the calibration involved sending electrical current through one of the EMG electrodes while recording the muscle response from the other. Subjects were told that they probably would not be able to feel the calibration, except that it might cause their forearm muscle to contract. Subjects were told to inform the experimenter if the process became uncomfortable or annoying at any point. After subjects completed the first task phase, a second hypnotic induction was used only to remove the suggestion embedded in the first induction. After being woken from the second induction, subjects were given instructions for the second task phase. These instructions were almost identical to those used as the post-hypnotic suggestion during the first induction. Following each task phase, subjects completed a form asking them to write down everything they could remember from the preceding hypnosis session. Any subjects who made mention of the post-hypnotic suggestion from the first induction were excluded from the analysis.

This procedure, though elaborate, allows the direct comparison of RPs that precede hypnotically induced movements to those preceding normal, intentional movements. The drawback is that the order of task phases cannot be counterbalanced, as having subjects perform the intentional movement task first would likely alert them to the purpose of the hypnosis, undermining the manipulation.

Nineteen subjects (14 female) were run using this procedure with 15 (11 female) subjects excluded due to lack of amnesia for the post-hypnotic suggestion. Data pre-processing and averaging steps were identical to those used in Experiment 4 except that epochs were defined 2000 ms before to 500 ms after movement onset as indicated by the EMG data. Only trials with detectable

EMG bursts 2000 ms or more after clip onset were included in the analysis (mean 45.62% [SD 23.45] excluded per subject).

4.2.2. Results

We found no difference in RP amplitudes between the hypnotically induced and intentionally induced movement conditions (see Figure 11.9). Mean amplitude calculated between end of baseline and movement onset was $-1.7 \mu\text{V}$ (SE $0.12 \mu\text{V}$) and $-2.64 \mu\text{V}$ (SE $0.87 \mu\text{V}$) for the hypnotic and volitional movement conditions, respectively [$t(3) = -1.18$, $p > 0.1$]. Similarly, we found no difference between mean LRP amplitude between conditions (Figure 11.10): mean amplitude was $2.64 \mu\text{V}$ (SE $2.34 \mu\text{V}$) and $0.30 \mu\text{V}$ (SE $1.01 \mu\text{V}$) for the hypnotic and volitional movement conditions, respectively [$t(3) = -0.74$, $p > 0.7$]. However, due to the small number of subjects who met all stringent criteria for inclusion in the final analysis, a paired t-test may not be ideal for assessing differences between conditions. Thus, we also conducted unpaired t-tests for each subject individually, to assess within-subject differences between conditions. RP amplitudes were not significantly different between hypnotic and volitional conditions for any of our subjects. The same held for LRP amplitudes (see Table 11.2 for a summary). Because statistically indistinguishable RPs and LRPs occur whether or not subjects are

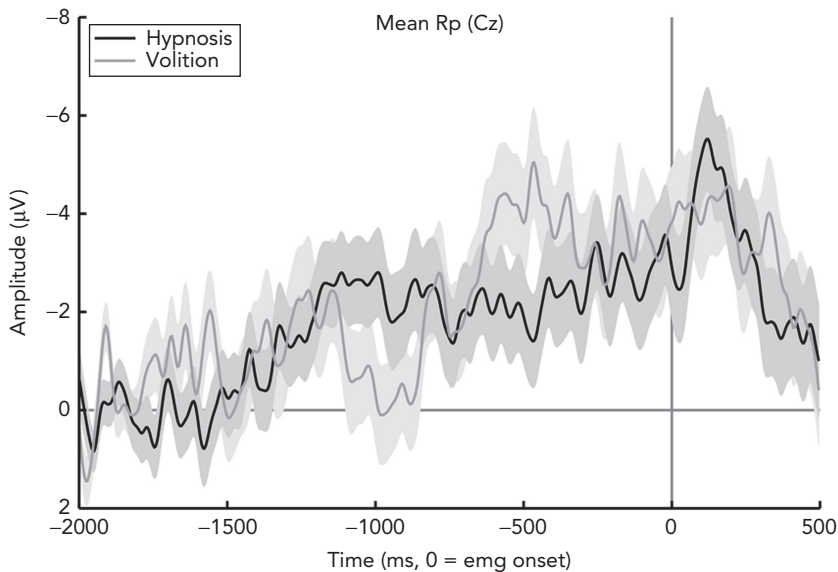


FIGURE 11.9. (Experiment 5): No difference is seen between RPs preceding hypnotically induced or volitionally initiated movements.

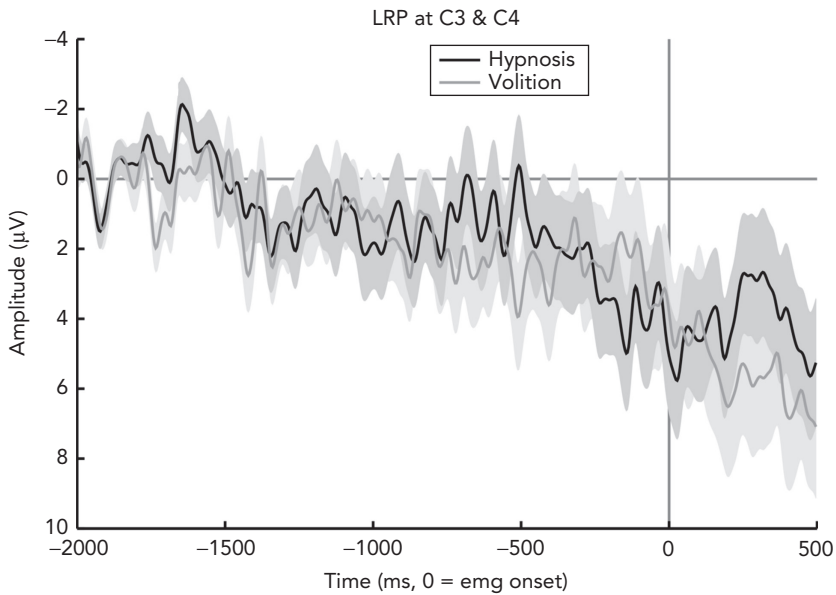


FIGURE 11.10. (Experiment 5): No difference is seen between LRP’s preceding hypnotically induced or volitionally initiated movements.

Table 11.2

Subject	Mean Amplitude Hypnotic (μV)	Mean Amplitude Volitional (μV)	t	dof	p
RP					
1	-774.44	-1383.16	0.752	119	0.454
2	-819.37	-526.99	-0.373	110	0.710
3	-1050.01	-2456.67	0.786	27	0.439
4	-732.65	-776.40	0.062	101	0.950
LRP					
1	-750.32	-419.07	-0.268	119	0.789
2	560.90	-715.37	2.082	110	0.040
3	-1905.16	-627.45	-0.607	27	0.549
4	-276.28	-134.39	-0.380	101	0.705

conscious of having caused a motor act, these results suggest that neither the RP nor LRP cause conscious intention or W .

While we found no difference in the RP or LRP between hypnotic and volitional conditions, some, but not all, subjects did show significant

Table 11.3

Subject	Hypnotic Condition	Volitional Condition	t	dof	p
EMG Amplitude (μ V)					
1	82.079	73.720	0.307	43	0.760
2	10.632	118.533	-4.750	126	<0.001
3	197.723	291.596	-1.859	124	0.065
4	117.571	146.095	-0.816	125	0.416
EMG Duration (ms)					
1	210.938	179.688	0.824	43	0.415
2	187.951	259.817	-3.603	126	<0.001
3	142.478	282.715	-7.972	124	<0.001
4	225.079	199.788	1.163	125	0.247
EMG Onset (ms)					
1	3404.297	4899.554	-1.208	43	0.234
2	14231.145	10989.155	5.512	126	<0.001
3	7972.857	5475.016	6.312	124	<0.001
4	8731.903	3714.844	7.787	125	<0.001

differences in EMG response between volitional and hypnotic conditions (see Table 11.3). This shows that, aside from removing the reportable feeling of having authored the movements (\mathbb{W}), hypnosis may have had an effect on the movement production process.

We found that the LRP appears without any reportable awareness by the subject of initiating the ensuing movement (\mathbb{W}). This conclusion is consistent with our findings from Experiment 1, which suggested that neural processes indexed by the LRP are unlikely to comprise an unconscious cause of \mathbb{W} (a possibility left open by Haggard and Eimer, 1999). Moreover, given the results of Experiment 2, it is not surprising that the LRP appears preceding hypnotically induced movements. This finding provides further evidence that the LRP, like the L-CNV, reflects neural processes involved with movement execution regardless of conscious awareness.

The fact that we find no difference between RPs that precede hypnotic and volitional movements is even more interesting. This suggests that the neural processes that generate the RP operate, or can operate, wholly outside of reportable awareness. However, if the neural activity reflected by the RP determined the timing of the eventual movement regardless of whether a subject was aware of that motor act, it could be argued that an RP would be expected

to precede hypnotically induced movements as well. Thus, based on these data alone, the possibility that the RP reflects a preconscious or nonconscious neural decision to move cannot be ruled out.

5. Summary of Findings

In sum, we conclude that neither the RP nor the LRP index neural processes that are causal of *W* (Experiment 1). Also, the RP, like the CNV, does not reflect uniquely motor-related processing (Experiments 2, 3, and 4), while the LRP, like the L-CNV, likely does (Experiments 2, 3, and 5; see also Eimer, 1998). Since both the RP and LRP occur even when subjects make a motor act without being conscious of having commanded it (from their point of view the ball squeeze just happens), it seems that the RP and LRP are unrelated to conscious intentions to move at all (Experiment 5). Given these findings, we conclude that the LRP is associated with an actual neural signal to move. On the other hand, while the exact nature of the neural processes reflected by the RP remains unclear, we can conclude that the processes are not specific to any particular action domain. Next we discuss the implications of our findings for the scientific and philosophical debate surrounding free will and the RP/LRP.

6. Discussion

The central issue here is not whether choices or acts of willing are free in the sense of being uncaused. Instead, the central question is whether consciously willing to move, or its neural correlates, really does cause the bodily movements that it is subjectively felt to cause. Given that conscious willing must itself be caused by previous neural events, one reasonable question to ask is whether the readiness potential is a signature of neural activity that is causal of willing and/or movement itself. Another is to ask whether willing is causal of the actions that we studied here. These are the questions we have focused on in the present experiments.

In discussions of will, it is useful to distinguish distal acts of willing, for example, willing to take part in an experiment and what it entails, from proximal acts of willing, for example, willing to move one's finger during a particular trial of that experiment. Experiments in the tradition of Libet, including our own described here, test the assumption that acts of proximal conscious will play a causal role on each trial where a movement is made. What we and Libet and his followers have studied is whether the proximal will to make a

movement at a particular time—what Mele (2009) calls a “proximal intention” to move—plays a causal role in the sequence of events that include the RP and the subsequent motor act. Before describing how our data relate to will in this sense, we wish to make clear that neither our data nor those of Libet test models of the possible causal efficacy of distal willing, which could be causal of subsequent motor acts even if proximal acts of willing are not. Thus neither our data nor Libet’s can be used to support or rule out any possible role for free will in the domain of distal willing, that is, intending to perform a future action or complex series of actions. Nonetheless, our findings do help us understand the kinds of actions that participants performed in our experiments.

Does the RP cause the conscious sense of proximal will? Libet’s seminal study and the many replications of it clearly establish that neural activity, reflected in the RP, reliably precedes the reported moment W_T at which subjects become conscious of their proximal will. However, his paradigm leaves to conjecture the exact relationship between the RP, will, and movement. Libet himself inferred that the neural processes that generate the RP cause the subsequent conscious proximal will. However, our Experiment 1 replicates the finding of Haggard and Eimer (1999) that the timing of the RP and W_T do not correlate. We additionally find the same lack of correlation between the LRP and W_T , suggesting that, in fact, there may be no relationship between readiness potentials and proximal will. They may instead reflect independent, noninteracting processes. Experiments 2, 3, and 5 further show several scenarios in which readiness potentials and other related ERPs can occur with no subsequent conscious willing of an action.

Does the RP cause movement? According to another common interpretation, the actual cause of movement in the Libet paradigm is the nonconscious neural process reflected in the RP. Experiments 2, 3, and 4 clarify the nature of the relationship between the RP, the LRP, and movement. We show that the RP/CNV does not necessarily lead to movement and that movement can occur without a preceding RP/CNV (Experiments 2 and 3). Experiments 3 and 4 show that the RP/CNV can occur in situations that do not even involve movement, such as anticipation of feedback, mental arithmetic, and decision making. These findings suggest that the RP does not reflect the presence of an unconscious decision to move, since it occurs in the absence of movement and is not time-locked to movement. At the very least, then, the RP/CNV would appear to reflect a more remote process that is neither necessary nor sufficient to cause movement. In our experiments, however, the LRP occurs if and only if movement follows it, suggesting that it reflects a much more direct antecedent of movement (cf. Eimer, 1998).

What is the RP? If the RP does not directly cause conscious proximal will or movement itself, then what is it and how does it relate to the Libet paradigm? One hypothesis is that the RP reflects one or more of a number of other general processes, such as anticipation or preparation, that accompany actions in the Libet paradigm but are not explicitly measured. This view is supported by our experiments showing that the RP occurs in a variety of tasks and closely resembles a number of other ~~event-related potentials (ERPs)~~ such as the stimulus preceding negativity (SPN; Damen & Brunia, 1987) that occurs when subjects merely anticipate external feedback. An alternative model recently proposed by Schurger and colleagues (2012) is that the RP reflects a random-walk process that can conditionally lead to movement once it crosses a threshold. Regardless of its exact neural correlate, we conclude that the RP is of limited use in answering the primary question at hand, which is whether proximal conscious will has causal power.

Is proximal conscious will necessary for nonreflexive, uncued actions? It should be clear that proximal conscious will is not necessary for each and every action we take. Reflex actions can occur automatically in response to a stimulus and in some cases do not even require input from the brain. We are not interested in these automatic movements, but in actions that, like the finger movements in the Libet paradigm, seem to require the immediate intervention of conscious processes. In other words, is conscious proximal will necessary for the execution of nonreflexive actions that have not been cued exogenously? Our finding in Experiment 5, that subjects, via post-hypnotic suggestion, can initiate actions endogenously while reporting no sense that they were the agents of those actions, indicates that this may not be the case. A caveat to this finding, however, is that our subjects may not have been in a typical state of mind. The conditions created by post-hypnotic suggestion may result in alterations to the causal pathways that typically operate under normal circumstances. Subjects' reports from Experiment 5 suggest that this is the case, as under normal circumstances people are unlikely to misattribute squeezing a stress ball to an external force. Furthermore, the EMG data show that there were indeed differences in the force, duration, and temporal distribution of squeezes between hypnotic and volitional conditions. We cannot be clear about how conscious proximal will was extinguished and the effect that that may have had on the causal pathway that led to movement until we understand more about the mechanisms of hypnosis itself. Because of these factors, in addition to the low number of subjects who passed our stringent criteria for inclusion, caution should be exercised in interpreting the results of Experiment 5.

Is proximal conscious will sufficient for nonreflexive, uncued actions?

We know that the human brain supports multiple neural pathways that can lead to action. Thus it may not be very surprising if actions, even complex actions, can occur without immediate conscious intervention. However, the central question is whether conscious proximal will can be sufficient for action, not whether it is necessary. Cojan et al. (2009) showed that subjects can be paralyzed through hypnosis, suggesting that this may not always be the case. Again, however, we do not understand the mechanisms through which hypnosis alters normal brain functioning. Showing that conscious proximal will can be made ineffectual is not equivalent to showing that it is not effectual in typical scenarios, and to our knowledge no study has provided evidence either that proximal conscious will can be sufficient or that it is not typically sufficient to cause movement. Thus, we maintain that the central and most pressing question on which the debates over Libet's studies have focused—the causal sufficiency of proximal conscious will—remains untested and unanswered.

Is Libet's paradigm appropriate? An assumption underlying Libet's and our experiments is that proximal acts of willing are operative on each trial. The conclusion that proximal will plays no causal role in the generation of finger movements on these types of tasks is consistent with scenarios in which either (1) proximal will is present but epiphenomenal and not causal of action, or (2) proximal will is not actually present during such possibly automatized motor acts. In either case it could be that free will is operative in the domain of distal rather than proximal intentions. For example, an efficacious conscious will may set an internal threshold (or parameters or criteria) for what shall, when met or satisfied, trigger a finger movement automatically at some future point in time. Schurger and colleagues' (2012) recent data offer an account that is consistent with this scenario. On their account, the RP is essentially an average of random activity that crosses a threshold just prior to movement, and it is the random crossing of this threshold that triggers the movement. If that account is correct, and finger movements in Libet-like scenarios are generated automatically upon the crossing of such a threshold, then neither our experiments nor those of Libet test for free will because there would be in fact little in the way of conscious will occurring on each trial. Furthermore, Schurger and colleagues suggest that their model can explain why W_T is consistently reported just prior to the movement. According to their model, the crossing of the threshold represents a "neural commitment to move now" and it is this event that subjects report as W_T . Beginning at that point in time, the typical process of motor preparation

and execution unfolds, accounting for the ~ 150 ms delay between W_T and the movement. In this framework, the timing of the movement is not determined until the threshold is crossed. However, if W_T reflects the crossing of the threshold for movement, one might predict a temporal correlation between W_T and that part of the RP that corresponds to the threshold-crossing in Schurger and colleagues' model. We observed no relationship between the RP and W_T in our experiments, and so future work is needed to test the Schurger et al. (2012) hypothesis more directly.

One possibility that is not tested by Libet-like experiments is that subjects infer the time at which they must have felt an urge to move based on the instructions that are given to them. Subjects are not given the option to say that they felt no such urge or that the urge did not begin at a definite instant in time. If they never experienced a sense of will or if, rather than sensing will as a punctuated event that presents itself to consciousness at an instant, they experienced it as a process that develops gradually over time out of preceding non-will processes such as anticipation, then it would be reasonable for them to report that proximal will occurred shortly before movement. Furthermore, it has been shown that several factors can shift W_T judgments, or similar judgments, by up to hundreds of milliseconds (cf. Lau et al., 2007; Matsushashi and Hallet, 2008; Banks and Isham, 2009), suggesting that the mental event that W_T judgments are supposed to indicate may not be as clear and punctuated as many have supposed.

Given our own and Libet's data, we think it is reasonable to conclude that proximal willing is not a necessary cause of action in the kinds of cases our experiments have tested. But it is important to acknowledge that there are other scenarios where conscious willing might be causal of movement, as described. These findings are only about a very special class of actions, so they should not be generalized into broad conclusions about all actions or about free will in general. Future experiments should go beyond the Libet tradition to test whether distal intentions and willing play a causal role in subsequent actions.

Acknowledgments

This chapter and the experiments described herein were made possible through the generous support of a grant from the John Templeton Foundation. The opinions expressed in this chapter are our own and do not necessarily reflect the views of the John Templeton Foundation.

REFERENCES

- Banks, W. P., & Isham, E. A. (2009). We infer rather than perceive the moment we decided to act. *Psychological Science*, 20(1), 17–21.
- Castro, A., Díaz, F., & van Boxtel, G. J. (2005). What happens to the readiness potential when the movement is not executed? *Neuroreport*, 16(15), 1609–1613.
- Cojan, Y., Waber, L., Schwartz, S., Rossier, L., Forster, A., & Vuilleumier, P. (2009). The brain under self-control: modulation of inhibitory and monitoring cortical networks during hypnotic paralysis. *Neuron*, 62(6), 862–875.
- Damen, E., & Brunia, M. (1987). Changes in heart rate and slow brain potentials related to motor preparation and stimulus anticipation in a time estimation task. *Psychophysiology*, 24, 700–713.
- De Jong, R., Wierda, M., Mulder, G., & Mulder, L. J. (1988). Use of partial stimulus information in response processing. *Journal of Experimental Psychology: Human Perception and Performance*, 14(4), 682.
- Deecke, L., Grözinger, B., & Kornhuber, H. H. (1976). Voluntary finger movement in man: cerebral potentials and theory. *Biological Cybernetics*, 23(2), 99–119.
- Eimer, M. (1998). The lateralized readiness potential as an on-line measure of central response activation processes. *Behavior Research Methods, Instruments, & Computers*, 30(1), 146–156.
- Fried, I., Mukamel, R., & Kreiman, G. (2011). Internally generated preactivation of single neurons in human medial frontal cortex predicts volition. *Neuron*, 69(3), 548–562.
- Gomes, G. (2010). Preparing to move and deciding not to move. *Consciousness and Cognition*, 19(1), 457–459.
- Haggard, P., & Eimer, M. (1999). On the relation between brain potentials and the awareness of voluntary movements. *Experimental Brain Research*, 126(1), 128–133.
- Kihlstrom, J. F. (2012). Neuro-hypnotism: Prospects for hypnosis and neuroscience. *Cortex*, 49, 365–374.
- Lau, H. C., Rogers, R. D., & Passingham, R. E. (2007). Manipulating the experienced onset of intention after action execution. *Journal of Cognitive Neuroscience*, 19(1), 81–90.
- Libet, B., Gleason, C. A., Wright, E. W., & Pearl, D. K. (1983a). 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(3), 623–642.
- Libet, B., Wright, E. W. Jr., & Gleason, C. A. (1983b). Preparation-or intention-to-act, in relation to pre-event potentials recorded at the vertex. *Electroencephalography and Clinical Neurophysiology*, 56(4), 367–372.
- Matsushashi, M., & Hallett, M. (2008). The timing of the conscious intention to move. *European Journal of Neuroscience*, 28(11), 2344–2351.
- McGeown, W. J., Venneri, A., Kirsch, I., Nocetti, L., Roberts, K., Foan, L., & Mazzoni, G. (2012). Suggested visual hallucination without hypnosis enhances activity in visual areas of the brain. *Consciousness and Cognition*, 21(1), 100–116.

- Mele, A. R. (2009). *Effective Intentions: The Power of Conscious Will*. New York: Oxford University Press.
- Raz, A., Shapiro, T., Fan, J., & Posner, M. I. (2002). Hypnotic suggestion and the modulation of Stroop interference. *Archives of General Psychiatry*, 59(12), 1155.
- Roskies, A. L. (2010). How does neuroscience affect our conception of volition? *Annual Review of Neuroscience*, 33, 109–130.
- Schlegel, A., Alexander, P., Sinnott-Armstrong, W., Roskies, A. L., Tse, P. and Wheatley, T. (2013). Barking up the wrong free: readiness potentials reflect processes independent of conscious will. *Experimental Brain Research*, 229(3), 329–335.
- Schurger, A., Sitt, J. D., & Dehaene, S. (2012). An accumulator model for spontaneous neural activity prior to self-initiated movement. *Proceedings of the National Academy of Sciences*, 109(42), 2904–2913.
- Shor, R. E., & Orne, E. C. (1962). *Harvard group scale of hypnotic susceptibility: Form A*. Consulting Psychologists Press.
- Soon, C. S., Brass, M., Heinze, H. J., & Haynes, J. D. (2008). Unconscious determinants of free decisions in the human brain. *Nature Neuroscience*, 11(5), 543–545.
- Soon, C. S., He, A. H., Bode, S., & Haynes, J. D. (2013). Predicting free choices for abstract intentions. *Proceedings of the National Academy of Sciences*, 110(15), 6217–6222.
- Trevena, J., & Miller, J. (2010). Brain preparation before a voluntary action: evidence against unconscious movement initiation. *Consciousness and Cognition*, 19(1), 447–456.
- van Boxtel, G., & Böcker, K. (2004). Cortical measures of anticipation. *Journal of Psychophysiology*, 18, 61–76.