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Hypnotizing Libet: Readiness potentials with non-conscious volition

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ABSTRACT

The readiness potential (RP) is one of the most controversial topics in neuroscience and philosophy due to its perceived relevance to the role of conscious willing in action. Libet and colleagues reported that RP onset precedes both volitional movement and conscious awareness of willing that movement, suggesting that the experience of conscious will may not cause volitional movement (Libet, Gleason, Wright, & Pearl, 1983). Rather, they suggested that the RP indexes unconscious processes that may actually cause both volitional movement and the accompanying conscious feeling of will (Libet et al., 1983; pg. 640). Here, we demonstrate that volitional movement can occur without an accompanying feeling of will. We additionally show that the neural processes indexed by RPs are insufficient to cause the experience of conscious willing. Specifically, RPs still occur when subjects make self-timed, endogenously-initiated movements due to a post-hypnotic suggestion, without a conscious feeling of having willed those movements.
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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 (Kornhuber & Deecke, 1965). Further study led Deecke and colleagues to conclude that the RP represents “a preparatory process in the dendritic network of those cortical areas that are involved in the intended movement” (Deecke, Grözinger, & Kornhuber, 1976). It was not until 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, Gleason, Wright, & Pearl, 1983). Note that, while Libet and colleagues were specific about their use of “W” to refer to subjects’ reported *time* of initial awareness of consciously willing 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 at which conscious processes related to this event began.

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Libet's data revealed that, on average, the RP begins several hundred milliseconds before W_T. This finding has called into question the ability of conscious choice to influence the timing of the movement in Libet's paradigm, since pre-conscious neural activity indexed by the RP began reliably before subjects were consciously aware of willing to move. One possible implication of Libet's result is that the unconscious neural processes indexed by the RP are the cause of both the movement and the accompanying feeling of consciously and volitionally choosing to generate that movement. Libet interpreted his result as placing "certain constraints on the potentiality for conscious initiation and control of voluntary acts," but he concluded that his finding did not rule out either the possibility of a conscious 'veto' power, as W_T is still before movement onset, or the possibility that acts preceded by conscious deliberation (rather than the spontaneously willed acts in Libet's paradigm) might be initiated and controlled consciously.

More recently, Haggard and Eimer (1999) investigated whether the onset of the RP covaries with W_T. Relying on an insight first noted by John Stuart Mill (1843), they reasoned that, if the neural processes that the RP reflects cause the sense of conscious will, then the timing of the RP and W_T should covary. However, they found no temporal covariation between the RP and W_T. This result was replicated by Schlegel et al. (2013), suggesting that W may be independent of the neural processes indexed by the RP. Haggard and Eimer additionally investigated the correlation between the lateralized readiness potential (LRP) and W_T. The LRP is measured as the difference between potentials to the left and right of the vertex and reflects the lateralization of motor-related neural activity that precedes movement (Eimer, 1998). Haggard and Eimer did find a correlation between the LRP and W_T and suggested that the neural processes indexed by the LRP could potentially cause the feeling of conscious willing. However, Schlegel et al. (2013) failed to replicate that finding. The lack of correlation in these studies suggests that the neural processes underlying the RP and LRP may not cause W.

While Libet's study and those following it provide tantalizing evidence regarding the role of conscious volition and associated neural processes in the production of action, the gold standard method for assessing causal relations requires manipulation. If endogenously initiated volitional movement can occur in the absence of W, then conscious intention is not a cause of volitional action in all cases. Additionally, the presence of an RP preceding such movements would provide further evidence that the RP reflects neural processes that are independent of conscious will. Thus, we can test causal relations by manipulating W. But conscious intention is difficult to manipulate. To be clear, by "conscious intention" we simply mean the reportable experience of deciding consciously to execute a movement. While the ideal would be to observe spontaneous, endogenously initiated actions in the absence of conscious intention, this may not be possible to achieve in an experimental context. However, hypnosis provides a possible mechanism by which movements can be elicited outside of reportable awareness or intention.

Hypnosis, as used here, consists of two stages: hypnotic induction and 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 during hypnosis that is to be followed after waking from the hypnotic state. Although the neural basis of hypnosis is still unknown (Kihlstrom, 2013), several recent studies have validated its ability to produce striking alterations in consciousness and cognitive processes (Cojan et al., 2009; McGeown et al., 2012; Raz, Fan, & Posner, 2005; Raz, Shapiro, Fan, & Posner, 2002; Wheatley & Haidt, 2005). Thus, in this experiment we used hypnosis to test whether endogenously initiated movements can still occur when the feeling of conscious will is removed experimentally. We find that non-conscious volitional actions can occur, and that the RP and LRP are present even when an action occurs in the absence of conscious will.

2. Methods

The experiment consisted of five phases: EEG preparation, first hypnotic induction, first task phase (with post-hypnotic suggestion), second hypnotic induction, and second task phase (without post-hypnotic suggestion). For the first 14 subjects the phases followed the order above, 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) that was administered for screening purposes in a large group setting (Shor & Orne, 1962).

For the first task phase, subjects sat 50 cm from a computer monitor on which a series of 20 s, silent nature videos were displayed (width × height: 14.47 × 10.88° visual angle). A fixation point was displayed at the center of each clip and a red arrow appeared on the left or right side of the screen to indicate the hand with which subjects should respond (Fig. 1). Subjects' hands rested palm up on a pillow positioned on their lap, out of view under the table on which the display monitor sat. Each hand held a stress ball loosely. We used a self-paced squeeze task similar to those used previously to investigate RPs (Ball et al., 1999; Deecke et al., 1976). 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 one block each for left and right hand responses, each block consisting of 40 randomly selected clips with a 3 s pause in between each clip. A longer break of around a minute (at the subject's discretion) occurred in between the blocks. The order of left/right blocks was randomized and the arrow was on screen throughout the entirety of each block. The second task phase was identical except that the red arrow was replaced with a blue semicircle to indicate the response hand. We used a blue semicircle rather than the previous red arrow to minimize the possibility of lingering effects from the post-hypnotic suggestion. Phillip Glass's soundtrack to the film *Dracula* was played in 20 s clips along with the videos. The video and music clips were used to engage subjects' attention and thereby

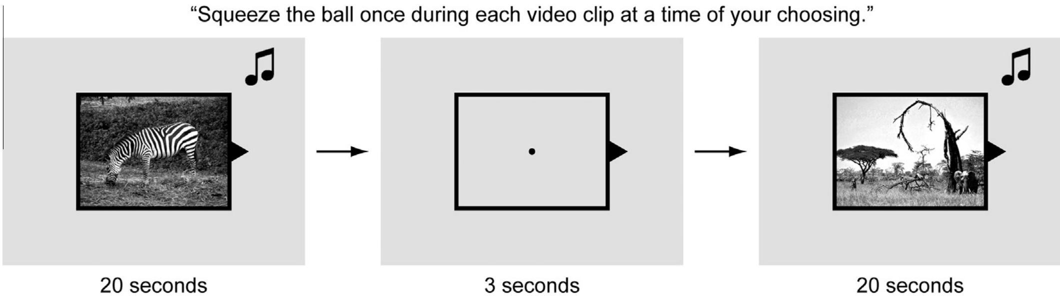

Fig. 1. Trial schematic. During each block, 20 s video clips were interleaved with 3 s rest periods. Left or right facing arrows (post-hypnotic movement condition) or semicircles (conscious movement condition) indicated the hand to use when squeezing the ball and were on screen for the entire block of 40 clips. There were four blocks total: post-hypnotic left/right movement and conscious left/right movement.

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 left or right 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 notice themselves squeezing the stress ball during the movie clips. According to the cover story, the experimenter would be calibrating the electromyography (EMG) electrodes on their forearms during each clip of the first task phase, and 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 muscles to contract. Subjects were also 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 waking from the second induction (now no longer under the influence of hypnosis), subjects were given instructions for the second task phase. These instructions were identical to those used as the post-hypnotic suggestion during the first induction. While not directly relevant to our hypothesis, this task phase allowed us to compare RPs that precede movements that lack a feeling of conscious will (volitional movement after post-hypnotic cue) to those preceding normal, intentional movements.

Following each task phase, subjects were given a sheet of paper and instructed to "write down whatever you can recollect from the hypnosis session." Any subjects who mentioned the post-hypnotic suggestion from the first induction were excluded from the analysis. Some subjects did report that their forearm moved because of the EMG calibration, but the subjects who were included in our analysis were not conscious of willing or intending the movement, as they were in the normal case. A further funnel debriefing interview was conducted with each subject after the experiment, to further evaluate whether subjects suspected anything about the experimental manipulation (see Supplementary Text). A limitation of this design is that the order of task phases could not be counterbalanced, since having subjects perform the intentional movement task first would likely alert them to the purpose of the hypnosis.

19 subjects (14 female) participated in the experiment after giving informed, written consent according to the policies of Dartmouth College's Committee for the Protection of Human Subjects. Because of our conservative inclusion criteria, 15 subjects (11 female) who did not experience amnesia for the post-hypnotic suggestion were excluded from further analysis. Thus, 4 subjects (3 female) passed our stringent criteria for analysis.

EEG data were recorded from 64 scalp locations according to the 10–10 system (Chatrian, Lettich, & Nelson, 1985) as well as from left and right mastoids. Electrooculographic (EOG) data were recorded from above and below the right eye. EMG data were recorded from two pairs of electrodes placed in series over the flexor digitorum superficialis and/or flexor carpi radialis muscle of each forearm (one pair of electrodes for each forearm). All recordings were collected at 2048 Hz using BioSemi ActiveTwo Ag/AgCl electrodes. Data were re-referenced offline to the average of the mastoid channels. The data were preprocessed twice, once using a 0.016–70 Hz bandpass filter to identify epochs containing eye-blink or eye movement artifact and once using a 0.016–15 Hz bandpass filter for averaging. Epochs were defined from 2000 ms before to 500 ms after movement onset as indicated by the EMG data and were baseline corrected using the mean signal from the first 100 ms of the epoch. EMG onset was defined manually for each trial as the point at which the signal first deviated visibly from the baseline period. EMG time-to-peak was likewise defined manually as the time between EMG onset and the time at which the EMG burst reached its peak value. Only trials with visually detectable EMG bursts 2000 ms or more after clip onset were included in the analysis (mean 45.62% [SD 23.45] of epochs excluded per subject).

The RP was measured using data from electrode Cz and was calculated for each subject by averaging the signal during the epoch described above for all trials that showed an accompanying EMG burst. The LRP was measured as the difference in signal from electrodes C3 and C4 using the double subtraction method (Eimer, 1998). For within-subject *t*-tests, mean RP and LRP amplitudes were calculated as the mean signal amplitude from the end of our baseline calculation period (1900 ms before EMG onset) to EMG onset time. These within-subject tests were unpaired *t*-tests comparing mean amplitude between hypnotically initiated and consciously initiated trials.

3. Results

Four of our subjects passed our stringent inclusion criteria, indicating via debriefing statements collected after the experiment that they believed our cover story and did not experience feelings of conscious will related to the post-hypnotically initiated volitional movements. Thus in each of these four subjects, volitional movements were elicited in the absence of conscious feelings of will.

It is possible that the movements initiated under post-hypnotic suggestion were not characteristic of normal volitional action. For instance, even though we instructed subjects to move at a time of their choosing, the post-hypnotic suggestion could have altered subjects' movements to become like the automatic, stereotyped actions of cued paradigms such as go/no-go tasks (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). If this was the case, subjects' response latencies and response latency variances would be expected to decrease under the influence of the post-hypnotic suggestion (i.e. their actions would become mere stereotyped reactions to the response cue). To evaluate this possibility, we compared the mean and variance of subjects' EMG onset times between hypnotically initiated and consciously initiated movement conditions. Because of the small number of subjects who passed our inclusion criteria, random-effects analyses are not appropriate for our data. Instead, the analyses we report were carried out on each subject individually. Caution should therefore be used in interpreting our results in terms of the general population. Within-subject *t*-tests showed that, indeed, EMG onset times differed systematically between the post-hypnotic and conscious conditions in three out of the four subjects (Table 1; see Tables S1 and S2 for analyses of movement amplitude and time-to-peak). However, in these subjects we observed an increase rather than a decrease in response latencies, suggesting that this difference did not arise because the post-hypnotically induced movements resembled reactions to a cue. Likewise, *F*-tests for equal variance showed that the onset variances differed in two out of four subjects, but these differences represented mean increases rather than decreases in onset variance in the post-hypnotically induced responses. These results argue against the possibility that the movements induced by post-hypnotic suggestion became automatized reactions to the cue.

Further evidence for non-conscious volitional action is provided by our observation of RPs in each of our subjects during the post-hypnotically initiated movement condition (Fig. 2). While the presence of the RP is sufficient to support the volitional nature of the movements, further support is provided by subsequent within-subject *t*-tests that showed no difference in RP or LRP amplitudes in any of our subjects between post-hypnotically initiated and consciously initiated movements (Table 2). Note, however, that these were fixed-effects analyses performed on each subject individually. Thus, our EEG data support the existence of antecedent neural activity over motor cortex that would be expected for volitional but not cued movements. The presence of typical RPs and LRPs without subsequent feelings of conscious will suggests that the neural processes underlying both the RP and LRP are independent of W.

4. Discussion

In the present study we demonstrate evidence for the existence of non-conscious volitional action. We used hypnosis, specifically post-hypnotic suggestion, in four subjects to elicit self-timed, endogenously driven movements that occurred without an accompanying sense of conscious will. Behavioral data show that these post-hypnotically initiated movements

Table 1
Analysis of latency of EMG onset from beginning of trial. Comparison between hypnotically and volitionally initiated movements. Asterisks indicate significant differences.

Subject	Hypnotic		Volitional	
	Mean EMG Onset (ms)	S.E.	Mean EMG onset (ms)	S.E.
1	3404.	712.	4900.	1045.
2	14231.	546.	10989.	312.
3	7973.	225.	5475.	347.
4	8732.	441.	3714.8	394.
	t-test of mean onset latency		*F*-test for equal onset variance	
	t (df)	*p*	F (df_1,df_2)	*p*
1	−1.21 (43)	.233	0.531 (23,20)	.146
2	5.51 (126)	<.001*	2.10 (51,75)	.003*
3	6.31 (124)	<.001*	0.684 (77,47)	.138
4	7.79 (125)	<.001*	2.07 (78,47)	.008*

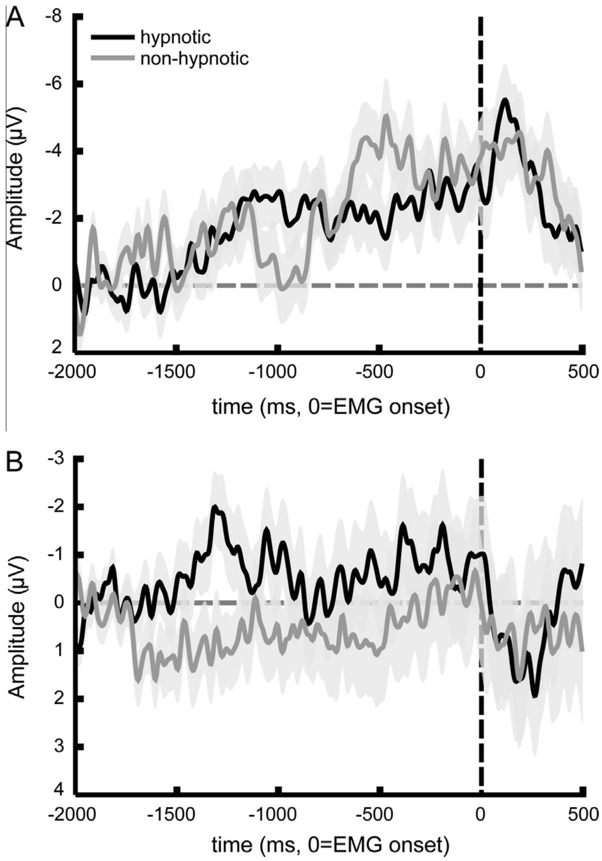

Fig. 2. Both RPs and LRPs occur during post-hypnotically initiated movements. Within-subject *t*-tests showed no differences in any subject in RP or LRP amplitude between post-hypnotically and consciously initiated movements. Data were pooled across all subjects before computing the average waveforms presented here. Shaded regions are standard errors of the mean across all trials. (A) Mean RP at Cz across all trials that passed our criteria for analysis. Black trace is RP elicited during post-hypnotically induced movements. Gray trace is RP elicited during normal, consciously induced movements. 203 trials were averaged to produce the waveforms for the post-hypnotic condition, and 162 were averaged to produce the non-hypnotic waveforms. (B) Grand mean LRP across C3 and C4. Black and gray traces are as in panel A.

Table 2
RP/LRP amplitude analysis. Comparison between hypnotically and volitionally initiated movements.

Subject	Hypnotic Mean amplitude (S.E.) (μV)	Volitional	*t* (df)	*p*
	RP			
1	−2.05 (2.08)	−4.79 (2.75)	0.786 (27)	.439
2	−1.43 (0.991)	−1.51 (0.877)	0.0631 (101)	.950
3	−1.51 (0.933)	−2.69 (1.30)	0.751 (119)	.454
4	−1.60 (0.947)	−1.03 (1.21)	−0.373 (110)	.710
	LRP			
1	−3.34 (2.84)	−1.41 (1.68)	−0.469 (27)	.643
2	−0.0271 (0.627)	0.281 (0.424)	−0.422 (101)	.674
3	−0.467 (1.39)	2.07 (2.07)	−1.05 (119)	.296
4	−0.157 (0.657)	−0.216 (1.12)	0.0488 (110)	.961

did not resemble automatic reactions to an exogenous cue. The presence of RPs preceding these movements is consistent with volitional but not cued movements.

The central issue addressed in this study 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 the neural correlate of conscious will, really does cause the bodily movements that it is subjectively felt to cause. Previous work has found that the experience of conscious will can be manipulated by exogenous factors, suggesting the possibility that conscious will may be illusory rather than causal of subsequent action (Banks & Isham, 2009; Lau, Rogers, & Passingham, 2007; Pockett, Banks, & Gallagher, 2009; Pockett

& Purdy, 2010; Rigoni, Brass, & Sartori, 2010; Wegner & Wheatley, 1999). Given that conscious willing must itself be caused by previous neural events, another reasonable question to ask is whether the readiness potential is a signature of neural activity that causes willing and/or movement itself. These questions are the focus of the present experiment.

In discussions of will it is useful to distinguish distal acts of willing (e.g. willing to take part in an experiment and what it entails) from proximal acts of willing (e.g. 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 whether 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 (1992) 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. Thus neither our data nor Libet's can be used to support or rule out any possible role for free will in cases such as when one intends to perform a future action or complex series of actions. Nonetheless, our findings do help us understand the kinds of actions that subjects performed in our experiments.

Since both an RP and LRP occur even when subjects perform a motor act without being conscious of having commanded it (due to the post-hypnotic suggestion, they perceive that the ball squeezes happened due to external forces), the RP and LRP may be unrelated to the subjective experience of intentional movement. While the exact nature of the neural processes reflected by the RP remains unclear, we can conclude that those processes are not specific to conscious willing. Below we discuss the implications of our findings for the scientific and philosophical debate surrounding free will and the RP and LRP.

4.1. Is proximal conscious will necessary for non-reflexive, 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. Is conscious proximal will necessary for the execution of non-reflexive actions that have not been cued exogenously? Our finding here, namely 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 is not always the case. A caveat to this finding, however, is that the post-hypnotic suggestion necessarily circumvented, at least in part, normal action processing. Thus, the conditions created by post-hypnotic suggestion resulted in alterations to cognitive and/or motor pathways as they operate in typical conditions. Subjects' reports illustrate this point, as under normal circumstances people are unlikely to misattribute squeezing a stress ball to an external force. Furthermore, our EMG data suggest that in some subjects there were indeed differences in the force, time-to-peak, and temporal distribution of squeezes between post-hypnotic and conscious conditions. We cannot be clear about how conscious proximal will was extinguished and the effect that intervention 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 percentage of subjects who passed our stringent criteria for inclusion, caution should be exercised in interpreting our results. Nonetheless, these data establish that there are individuals in whom volitional action and an accompanying RP can occur in the absence of conscious willing.

4.2. Is proximal conscious will sufficient for non-reflexive, uncued actions?

We know that the human brain supports multiple neural pathways that can lead to action. Thus it may be expected that actions, even complex actions, can occur without immediate conscious intervention. However, finding such a situation still does not address whether conscious proximal will can be *sufficient* for action, even though it may not always be necessary. Cojan et al. (2009) showed that subjects can be paralyzed through hypnosis, suggesting the possibility that under at least some circumstances it is not sufficient. 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 never effectual, or 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, 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.

4.3. 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 moment W_T that subjects report as the time at which they became conscious of their proximal will. However, his paradigm leaves to conjecture the exact relationship between the RP, will, and movement. Libet himself suggested the possibility that the neural processes that generate the RP cause the subsequent conscious proximal will (Libet et al., 1983; pg. 640). Our earlier findings (Schlegel et al., 2013) replicated the finding of Haggard and Eimer (1999) that the timing of the RP and W_T do not correlate, and we additionally found the same lack of correlation between the LRP and W_T. The present experiment shows that there exist situations in which readiness potentials can occur with no conscious willing of an action. These results suggest that, in fact, there may be no relationship between readiness potentials and proximal will. They may instead reflect independent processes.

4.4. What is the RP?

The present and previous studies (Haggard & Eimer, 1999; Schlegel et al., 2013) provide evidence that the RP is independent of both conscious will and motor actions. If the neural processes underlying the RP do not cause conscious proximal will or movement itself, then what is the RP and how does it relate to the Libet paradigm? One hypothesis is that the RP reflects one or more general processes, such as anticipation or preparation, that accompany actions in the Libet paradigm but are not measured explicitly. This view is supported by the observation that the RP occurs in a variety of tasks (Brunia & Van den Bosch, 1984; Deecke et al., 1976; Ikeda, Lüders, Burgess, & Shibasaki, 1993) and resembles closely a number of other event related potentials (ERPs) such as the stimulus preceding negativity (SPN) (Damen & Brunia, 1987) and the contingent negative variation (CNV) (Walter et al., 1964) that seem largely to reflect anticipation (van Boxtel & Böcker, 2004). An alternative model proposed recently by Schurger, Sitt, and Dehaene (2012) is that the RP (or at least its earlier components; (Jo, Hinterberger, Wittmann, Borghardt, & Schmidt, 2013)) reflects a random-walk process that can lead conditionally to movement once it crosses a threshold.

Given our own and Libet's data, it is reasonable to conclude that proximal conscious willing is not a necessary cause of action in the kinds of cases our experiment tested. But it is important to acknowledge that there are other scenarios where conscious willing might cause movement, as described above. The findings here are restricted to 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 move beyond the Libet tradition to test whether distal conscious intentions and willing play a causal role in subsequent actions.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.concog.2015.01.002.

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