Conscious intention and human action: Review of the rise and fall of the readiness potential and Libet’s clock

Edward J. Neafsey

Loyola University Chicago Stritch School of Medicine, Department of Molecular Pharmacology and Neuroscience, 2160 S. First Ave., Maywood, IL 60153, United States

ARTICLE INFO

Keywords:
Readiness potential
Bereitschaftspotential
Intention
Decision
Free will
Hard problem
Consciousness
Libet
Kornhuber
Neuroscience
Epiphenomenon

ABSTRACT

Is consciousness—the subjective awareness of the sensations, perceptions, beliefs, desires, and intentions of mental life—a genuine cause of human action or a mere impotent epiphenomenon accompanying the brain’s physical activity but utterly incapable of making anything actually happen? This article will review the history and current status of experiments and commentary related to Libet’s influential paper (Brain 106:623–664, 1983) whose conclusion “that cerebral initiation even of a spontaneous voluntary act…can and usually does begin unconsciously” has had a huge effect on debate about the efficacy of conscious intentions. Early (up to 2008) and more recent (2008 on) experiments replicating and criticizing Libet’s conclusions and especially his methods will be discussed, focusing especially on recent observations that the readiness potential (RP) may only be an “artifact of averaging” and that, when intention is measured using “tone probes,” the onset of intention is found much earlier and often before the onset of the RP. Based on these findings, Libet’s methodology was flawed and his results are no longer valid reasons for rejecting Fodor’s “good old commonsense belief/desire psychology” that “my wanting is causally responsible for my reaching.”.

1. Introduction

Is consciousness—the subjective awareness of the sensations, perceptions, beliefs, desires, and intentions of mental life—a genuine cause of human action or a mere epiphenomenon, an utterly impotent side effect or “loose end” (Wegner, 2002) of the brain’s neuronal activity that has as much to do with human action as “the steam-whistle which accompanies the work of a locomotive” (Huxley, 1874) or as the “turn signals are to the movements of motor vehicles” (Wegner, 2004) or as “a shadow …upon the steps of the traveller whom it accompanies” (James, 1879)—an extraneous something “bypassed by neural events” (Nahmias, 2014) that do all the real work? This question has a long history in philosophy (Gallagher, 2006; Robinson, 2019), and, not surprisingly, neuroscience has contributed to this debate. This review will discuss the history of experiments and criticism of the conclusions and especially the experimental methods of one particularly notable and highly cited neuroscience paper by Benjamin Libet and his collaborators (Libet, Gleason, Wright, & Pearl, 1983), which concluded that the “brain decides” to move long before “I decide” to move and thus raised serious questions about the efficacy and significance of human conscious voluntary decisions or intentions. The history will be
reviewed in two sections. The first will treat early (up to 2008) challenges to Libet’s conclusions. The second will treat more recent (2008 on) challenges to his conclusions and will emphasize two especially noteworthy experimental findings. The first finding is a substantial change in how neuroscientists understand what the readiness potential (RP) is and, more importantly, what it is not. And the second finding is a new method of measuring intention to move using “tone probes” that also radically changes the way Libet’s work and conclusions are interpreted. In fact, I consider the main contribution of this review to the literature is that it brings discussion of these two developments (what the RP is and is not; how to measure intention) together in one place. Before discussing Libet’s paper, however, it is necessary to discuss the “readiness potential,” which was the method Libet et al. (1983) used to measure brain activity related to movement.

1.1. The Readiness Potential

Kornhuber and Deecke (1965) (in English, Kornhuber & Deecke (2016)) asked subjects to make self-paced movements of their hand or foot, with about 15 s between the movements. The scalp electroencephalogram (EEG) was also recorded on tape while the subject was making the movements. After the experimental session, the tape was played backwards so that EEG activity before the movement could be averaged over fifty or even hundreds of movements. As seen in Fig. 1A and as described in their words, “Voluntary hand or foot movements are preceded by a slowly increasing surface-negative cortical potential of 10–15μV, called readiness potential [dark blue line labeled RP in Fig. 1A, bereitschaftspotential (BP) in original German]. This potential is maximal over the contralateral precentral region, but shows bilateral spread and is larger over the frontal than over the occipital areas. The readiness potential increases with intentional engagement and is reduced by mental indifference of the subject.” And, “the bioelectrical process seems to belong to those brain processes that appear as readiness to act in consciousness/conscious awareness.” Eleven years later Deecke, Grözingter, and Kornhuber (1976) further described the RP and concluded that it “may be attributed to an early preparatory process prior to the movement.” They also noted that “over the precentral region, the initial bilateral symmetry later gives way to a slight contralateral preponderance of negativity” [cyan line labeled L/R Precentral in Fig. 1A]. This contralateral potential subsequently became known as the lateralized readiness potential (LRP). And, as reviewed by Shibasaki and Hallett (2006), the RP is now considered to have two components: an early component (Early BP, BP1, NS1, Type I RP) that is largest at the midline recording site Cz and a later component (Late RP, LRP, BP2, NS’, NS2, Type II RP) that is maximal contralateral to the movement performed. From studies using both current source density analysis and chronically implanted subdural epicortical electrodes, Shibasaki and Hallett concluded that “it is the current consensus that early BP starts first in the SMA [midline Supplementary Motor Area], including pre-SMA and SMA proper, and then shortly thereafter in the lateral premotor cortices bilaterally, and about 400 ms prior to the movement onset the late BP (NS’) starts in the M1 and premotor cortex, mainly contralaterally.”

1.2. Libet’s Experiment

Now on to Libet’s experiment (Libet et al., 1983), which is depicted in Fig. 1B. The five subjects of the experiment had EEG electrodes attached to the scalp at the vertex (point Cz for EEG recording) to allow the RP to be recorded. They were then instructed to watch a screen with a dot quickly rotating around a clock face and, after waiting for the dot to go around at least once (2.56 s), then make a voluntary hand movement whenever they wished. They were asked to not plan the movement ahead of time but just act spontaneously. After making the movement they reported the position of the dot (10 s, 40 s, etc.) on the screen at the moment they made a voluntary hand movement whenever they wished. They were asked to not plan the movement ahead of time but just act spontaneously. After making the movement they reported the position of the dot (10 s, 40 s, etc.) on the screen at the moment they experienced or were aware of the “urge” or “intention” or “decision” to move; Libet termed this the “W time.” Each subject performed 40 such movements in each of six experimental sessions, and the EEG during the several seconds before each movement was averaged by a computer over the 40 trials, allowing the readiness potentials (such as blue tracing “RP SB6a” in Fig. 1B) to become apparent. As seen in the boxplot of average onset times of the RPs for each subject in Fig. 1B, these RPs (filled blue circles) began more than 0.4 s before each movement, with some beginning much earlier. What was striking was that the onsets of the “W times” (filled red circles) reported by the same subjects were all only about 0.2–0.3 s before the movement at time 0, long after the start of the RP. Libet concluded that “cerebral initiation of a spontaneous, freely voluntary act can begin unconsciously, that is, before there is any (at least recallable) subjective awareness that a ‘decision’ to act has already been initiated cerebrally.” This introduces certain constraints on potentiality of conscious initiation and control of voluntary acts. Or, more succinctly, “cerebral activity initiates the voluntary act before reportable conscious intention” appears.” And, “it would appear that some neuronal activity associated with the eventual performance of the act has started well before any (recallable) conscious initiation or intervention could be possible. Put another way, the brain evidently ‘decides’ to initiate or, at the least, prepare to initiate the act at a time before there is any reportable subjective awareness that such a decision has taken place.”

1.2.1. Libet’s Impact: 3380 Citations, Everywhere

Libet’s findings have been replicated by many other labs, as will be described below. And, not surprisingly, his conclusions have had a huge and lasting impact and have figured prominently in neurophilosophical debates about human free will and human

---

4 Anscombe (1957) (pp. 26–33) would probably not use the word “intention” in reference to the isolated, purposeless, spontaneous, impulsive movements of the Libet task, since the only answers that such subjects could give to her question “Why are you moving your hand?” would be things like “to follow the instructions I received” or “to earn my stipend” or “just an impulse” or “for no reason,” rather than any meaningful reason for the movements themselves; instead she would likely use the word “voluntary” for such “commanded” movements. Also see Gallagher (2006).
Consciousness and Cognition 94 (2021) 103171

responsibility. If the “brain decides” long before “I decide,” does this mean that free will is an illusion and consciousness is an “epiphenomenon” that, as mentioned above, has as much to do with human action as “the steam-whistle which accompanies the work of a locomotive” (Huxley, 1874) or as “turn signals are to the movements of motor vehicles” (Wegner, 2004)? It must be said, however, that Libet himself did not support such interpretations of his experiment, arguing in his original 1983 paper that “There could be a conscious ‘veto’ that aborts the performance even of the type of ‘spontaneous’ self-initiated act under study here,” and in 1999 he wrote that “we must recognize that the almost universal experience that we can act with a free, independent choice provides a kind of prima facie evidence that conscious mental processes can causatively control some brain processes” (Libet, 1999). However, Libet’s cautions notwithstanding, the genie was out of the bottle, and his results and conclusions had a life of their own and became a key element of “folk neuroscience” whose influence extended far beyond neuroscience and into philosophy (PhilPapers website searching for all matches of libet yields 245 hits), law (e.g., Greene and Cohen (2004), Sinnott-Armstrong and Nadel (2010), Morse and Roskies (2013)), and popular culture. For example, a Google search using libet “free will” yields 77,100 hits, and a YouTube search using libet experiment yields 1258 hits. And, using Wikipedia’s April 2021 article on the “Neuroscience of Free Will” (Wikipedia-contributors, 2021) as another index of impact on popular culture, Libet’s experiment is the first experiment mentioned and is discussed in detail on more than 2 pages of the 18 pages (11%) of text of the article. And, on the question of epiphenomenalism, the psychologist Daniel Wegner’s (2002) book The Illusion of Conscious Will strongly advocates epiphenomenalism, asserting that conscious will is a mere “feeling that occurs to a person” and that the “brain creates both the thought and the action, leaving the person to infer that the thought is causing the action.” Although Wegner did not base his conclusions on Libet’s experiment, he cited Libet’s work as consistent with his conclusions, as did Sam Harris, who obviously had Libet’s work in mind when he wrote in Free Will that “One fact now seems indisputable: Some moments before you are aware of what you will do next—a time in which you subjectively appear to have complete freedom to behave however you please—your brain has already determined what you will do” (Harris, 2012). So Libet’s experiment has had an enduring and persistent connection with epiphenomenalism and doubts about free will.
2. Early (up to 2008) Challenges to Libet’s Conclusions

2.1. Open Peer Commentaries on Libet (1985) in Behavioral and Brain Sciences

In 1985, just two years after Libet et al. (1983), Libet published a “target article” (Libet, 1985) in Behavioral and Brain Sciences followed by twenty-four Open Peer Commentaries. The commentaries contained three key criticisms that have become more and more telling as the years have passed.

2.1.1. The Meaning of the RP

Three commentaries (by Eccles, Ringo, and Stamm) questioned the origin and meaning of the RP. Eccles (1985) presciently argued against Libet’s interpretation of the RP as an indicator of the brain’s movement initiation process by pointing out that “Since the RP as observed is formed by the averaging of a large number (fifty to hundreds) of recordings of scalp potentials with zero time given by the onset of the electromyogram, it is a mistake to assume tacitly that the averaging eliminates the random fluctuations [in cortical activity]. If there is a tendency for the initiation of the movements to occur during the excitatory [negative] phases of the random spontaneous activity, the earlier phase of the RP may be no more than the averaging of the premonitory spontaneous activity. If that is so, the RP does not signify that cortical activity initiates the movement.” And Ringo (1985) and Stamm (1985) both voiced similar concerns about the origin and meaning of the RP. This same criticism of Libet’s assumption that the RP identifies brain activity leading to movement has been repeatedly made since then (see below) and was recently reiterated by the neuroscientist and philosopher Adina Roskies (2011), who noted it was entirely possible that in a given single trial “Any individual-RPs that occur but are not followed by a finger movement will be unrecorded,” which “would drastically change the interpretation of the RP as a causal precursor to motor activity.” And an even stronger questioning of the meaning of the RP has been raised by the experiments of Schurger, Sitt, and Dehaene (2012), described below.

2.1.2. The Time Course of Intention

Two commentaries (by Marks and Ringo) argued that “urges” or “intentions” are not sudden, all-or-nothing events that can be simply marked by a single time point on the rotating dot clock but rather are elements of a more gradually developing process in the time before the movement. Marks (1985) wrote that he “would like to be able to query the subject, ‘Do you think you are likely to want to move your wrist within the next few tenths of a second?’ Of course, as a control measure I would ask the same question of the subject at other, randomly chosen, points in time, points at which no RP had been in evidence in recent moments. Were all of this possible I strongly suspect that subjects would be much more likely to acknowledge an intent to act at ‘test’ moments—that is, during the supposed ‘unconscious interval’ between the occurrence of the readiness potential and the first awareness of an intent to act—than at ‘control’.” And Ringo (1985) wrote “that the subjects may be reporting the ‘peak’ of an urge that actually has an extent in time. That is, perhaps we should not imagine the production of an instantaneous urge that is then sent out to the appropriate motor control areas and generates activity (from which idea we would expect the urge to precede the RP); instead, the urge may have a start, a rise, and a peak.” And, more recently, Roskies (2011) wrote that “The relative timing of conscious intent to move and the initiation of movement are the components one would want to assay if one were interested in the efficacy of conscious will. However, a closer look at Libet’s experimental design suggests that these are not the states that he is measuring. Instead, Libet’s experiment with the clock face probes the relative timing of a meta-state, consciousness of conscious intent, and the initiation of movement (assuming the worries above are discounted). There is good reason to think that consciousness of conscious intent may occur sometime after conscious intent, and thus the fact that this occurs after the RP has begun is compatible with conscious intent occurring prior to the RP.” (Also see Guggisberg, Dalal, Schnider, & Nagarajan (2011) for a similar distinction between introspection [a meta-state] and primary consciousness). And, indeed, and as will be described below in more detail, when Matsuhashi and Hallett (2008) developed the “tone probes” method to measure the onset of intentions or urges, they found exactly what these two commentators and Roskies predicted, namely a much earlier and more gradual onset of intention, which has been confirmed by Verbaarschot’s lab in their two studies using tone probes (Verbaarschot, Haselager, & Farquhar, 2016; Verbaarschot, Farquhar, & Haselager, 2019).

2.1.3. Meaningless Spontaneous Movements as a Model for Volitional Action

A number of commentators had problems with the spontaneous movement task as a model for a voluntary movement. Breitmeyer (1985) wrote “in what sense can the voluntary acts as operationally defined by Libet be paradigmatic of volitional action generally, particularly when he draws certain weighty religio-ethical implications from his findings? As Libet admits, his experimentally reduced acts of finger/wrist flexion occur in the absence of any larger meaning. Hence they are as limited in application to our understanding of volitional action as use of nonsense syllables is to our understanding of memory. By what rules do we proceed from these experimental findings to human volitional action (or memory) occurring inextricably within a rich, varied, and meaningful context?” And Bridgeman (1985) wrote “the subjects’ wills were not as free as the Libet article implies, for the small, sharp movements that they were instructed to make were not freely willed but were requested by the experimenter. The will of a subject was no more free in this design than in reaction-time experiments; the only difference between this experiment and the latter paradigms is that the instruction and the movement are decoupled in time. While performing the task, the subjects do nothing more than obey the instructions.” And Jung (1985) wrote “These simple movements are made voluntary, but the will acts here only as a trigger. Willed intention is more important in goal-directed and complex movements such as writing.” And Näätänen (1985) wrote that Libet “seems to ignore the fact that the specific nature of the movement was determined in detail by the instructions, practice, and preceding repetitions, and that hence the only decision of the subject involved the timing of this preplanned movement. Moreover, even the decision to perform this movement
can be regarded as already having been made (consciously) by him at the beginning of the experiment: The subject knows and has agreed that he is going to produce quite a large number of these movements sooner or later, within some reasonable time, before he can leave (and receive his payment), and that it is only the timing of each single movement of this specified type that is under his control—and even that not fully but within certain quite wide limits. Consequently it appears to be somewhat questionable to describe this motor act as ‘spontaneous’ or ‘fully endogenous’ and occurring with ‘no preplanning.’” And, more recently, Roskies (2011) made the same point when she wrote that Libet’s experiments are “irrelevant to the philosophically interesting question of whether we have free will” and “even if the data does suggest that in spontaneously deciding to move our fingers our movements are not governed by our conscious will, this is entirely consistent with the supposition that in other types of cases—those for which we want to hold people morally responsible—awareness of intentions does precede our actions.” And, as will be described more fully below, Maoz, Yaffe, Koch, and Mudrik (2019) recently reported that there are no RPs at all before deliberate choice movements, further questioning the Libet task’s validity.

2.2. Keller and Heckhausen

Keller and Heckhausen (1990) found that “RPs beginning approximately 500 ms before movement onset can be obtained with unconsciously as well as consciously performed spontaneous motor acts.” Their subjects were silently counting backwards from 3521 in steps of 3, and, when EMG activity triggered EEG potentials, the subjects were asked if they were aware of the movement and, if so, had it been planned or was purely spontaneous and if there was any kind of urge to act before the movement. Nearly all subjects made some unconscious movements that, when averaged, showed RPs. This is an important fact because it weakens the connection between the RP and voluntary movement or intention. This finding was recently confirmed by Takashima, Cravo, Sameshima, and Ramos (2018) who reported virtually identical early RPs (beginning 2 s before movement) before both “automatic” (without awareness) movements and consciously “willed” movements.

2.3. Haggard and Eimer

Haggard and Eimer (1999) found that there was no difference in RPs “between a fixed movement condition, where subjects made voluntary movements of a single finger in each block, and a free movement condition, in which subjects chose whether to respond with the left or the right index finger on each trial,” implying the RP is not related to a specific movement but to some more general preparation for movement. In addition, they found that the “RP tended to occur later on trials with early awareness of movement initiation than on trials with late awareness, ruling out the RP as a cause of our awareness of movement initiation,” since, if they are causally related, a late onset RP should logically go with a late onset awareness—but this did not happen. And, interestingly, they reported that “our RPs begin considerably earlier than those reported by Libet et al. (1983)” and “no clear baseline could be found within the ~2600-ms premovement epoch.”

2.4. Trevena and Miller

Trevena and Miller (2002) found that “Although the Readiness Potential was usually present before all of the decisions to move, consistent with the findings of Keller and Heckhausen (1990) and Libet et al. (1983), we found that many reported decision times [using Temporal Order Judgment Methodology] were before the onset of the Lateralized Readiness Potential, which measures hand-specific movement preparation. (The earliest reliable onset time for the decision to move was “about 400 ms before the movement” in their Experiment 1 and 500 ms before the movement in their Experiment 2, considerably earlier than Libet’s W times.) These findings are consistent with the conclusion that the LRP always started after the conscious decision to move. We conclude that even though activity [the early RP] related to movement anticipation may be present before a conscious decision to move, the cortical preparation necessary for the movement [itself] to happen immediately may not start until after the conscious decision to move.” Additionally “an RP may be generated by some nonmotoric processes involved in considering a movement that will occur at some time in the future and thus weaken the claim that the early onset of RP indicates that the brain starts preparing a movement before the participant has consciously decided to make it.” And “we conclude that the results of Libet et al. (1983) do not unambiguously demonstrate that movement preparation begins unconsciously. In particular, the distinction between the onset of the RP and the LRP before a spontaneous voluntary movement seems crucial. Our finding that reported decision times are always after the onset of the RP but often before the start of the LRP suggests that actual preparation for movement—as opposed to contemplation of it as a future possibility—may not begin until after a conscious decision to initiate the movement immediately.” Lastly, similar to Haggard and Eimer (1999), they reported their RPs started much earlier than those in Libet’s experiment, with negativity “present even from the start of the recording epoch” and “the RP …therefore present for at least 2000 ms before the movement.”

2.5. Herrmann et al.

Herrmann, Pauen, Min, Busch, and Rieger (2008) used magnetoencephalography (MEG) to record event-related magnetic fields before subjects performed left or right hand movements that were cued by stimulus pictures shown just before the movement. They concluded that “Because the [early] RP sets in before the stimulus is presented and participants react appropriately, the [early] RP cannot determine which of the two alternatives available (right-hand vs. left-hand movement) is executed. Rather the [early] RP seems to reflect a general expectation or an unspecific motor preparation,” And, finally, “only if Libet’s data show
that the unconscious [early] RP predetermines a specific movement, can it be argued that the conscious decision concerning this movement is only an illusion and freedom is put at risk."

2.6. Wegner’s Epiphenomenalism

Wegner (2002) published *The Illusion of Conscious Will* in 2002. Although his conclusion that conscious will was an illusion was not based on Libet et al. (1983), he writes that his conclusion was “in line with facets of several existing theories” (Wegner, 2004), including Libet’s work, so Libet helped provide a background theory into which Wegner’s ideas fit well. The “good fit” can be seen in Fig. 2, which superimposes Wegner’s (2003) summary figure on top of Libet’s results from Fig. 1B. Note that Wegner’s “Actual causal path” arrow starts from the “Unconscious cause of action” box and ends in the “Action” box, while, in contrast, the “Thought” box (conscious will) gives rise to the “Only apparent cause” arrow leading to the “Action” box, i.e., epiphenomenalism. The fit of this scheme with Libet’s “unconscious” brain cause of movement that precedes W is obvious.

Wegner’s diagram can be considered a slightly more complicated version of Kim’s diagram of how Nonreductive Physicalism fails to accomplish mental causality and turns into epiphenomenalism (Kim, 2005). This is illustrated in the inset box at the upper left. In this box a physical event such as a movement is indicated by p*, which has a physical cause (p), indicated by the horizontal arrow from p to p*, and, according to Nonreductive Physicalism, a mental cause (m), indicated by the diagonal arrow from m to p*. The vertical lines with open arrows from p to m and p* to m* indicate a “supervenience” relation (no change in m without a change in p, a form of property dualism). (Note that the p, m, and p* have also been added to Wegner’s boxes to make the parallels clear.) Nonreductive Physicalism holds that the mental is not reducible to the physical, so it is possible for a physical event (p*) to have two causes, one mental (m) and one physical (p). Kim rejected that on the basis of the causal exclusion principle (“If an event e has a sufficient cause c at t, no event at t distinct from c can be a cause of e [unless this a genuine case of causal overdetermination”), so m cannot be a cause of p* [indicated by large red “X”]. And so Kim concluded that Nonreductive Physicalism, just like Cartesian dualism, ends up “not able to explain how mental causation is possible” and, “instead of saving mental causation, it ends up relegating mental causation to the status of epiphenomena” because the mental has lost its “causal powers.”

2.7. Summary

These early challenges to Libet’s conclusions included the *Behavioral and Brain Sciences* commentators questioning what the RP really means, whether Libet’s clock is a good measure of intention, and whether spontaneous movements are an appropriate way to study volitional action. In addition, Keller and Heckhausen (1990) found RPs before involuntary movements, meaning the RP was not specific for voluntary movements. And Hagyard and Eimer (1999) and Herrmann et al. (2008) both found identical early RPs before movements of either hand, suggesting the early RP is related to a more general process of anticipation and not to preparation of a specific movement, consistent with the results of Trevena and Miller (2002). And Libet was cited in support of Wegner’s (2002) epiphenomenal conscious will.

3. Recent (2008 on) Challenges to Libet’s Conclusions

Two of these just described early challenges (the meaning of the readiness potential and how to measure intention) have become more acute in recent years.

3.1. What Is the Real Explanation of the Readiness Potential?

The challenges related to the meaning of the readiness potential have come from the laboratories of Susan Pockett, Aaron Schurger, Stefan Schmidt, Prescott Alexander, Rolf Verleger, and Uri Maoz, as illustrated in Fig. 3 below.

3.1.1. Pockett’s Lab

Pockett and Purdy (2010) recorded RPs in six subjects performing the Libet task. Each subject performed 390 spontaneous finger movements in the 30 min recording session, and “robust RPs were evident when all 390 trials for that subject were averaged.” On most trials (75%) “it was impossible to tell whether or not an RP was present in the noise. But … in our hands approximately 12% of individual trials definitely did show RPs. More importantly for our initial question, another 12% of individual trials had low “noise” levels but almost certainly did not show RPs.” And “for each individual subject we averaged 50 epochs that had been individually

---

5 “The thesis that bits of matter and their aggregates exhaust the content of the world” (Kim, 2005).
6 It should be said that Nahmias (2018), among others, rejects Kim’s application of the causal exclusion principle to eliminate mental causation in Nonreductive Physicalism, arguing that an interventionist theory of causation allows that “psychological variables (e.g., beliefs or intentions) can be picked out as the cause of effects (such as decisions or actions) over the neural variables that realize them (or on which the psychological variables supervene).” This is because (at least plausibly) the psychological variables could be realized by different neural variables, so interventions on the neural variables might not alter the effects, whereas interventions on the psychological variables would. This currently remains a hotly disputed topic (Moore, 2016; List & Menzies, 2009; List & Menzies, 2017), not least because the causal exclusion argument also threatens the status of the properties of all the special sciences (Fodor, 1974; Block, 2003; Baumgartner, 2009; Moore, 2010).
apparently negative RP emerges through an unequal ratio of negative and positive potential shifts [as Eccles (1985) predicted]. These

3.1.3. Schmidt

accumulator (red line) to the shape of the RP (blue line) in the period before the movement. And subsequently Schurger (2018) further

results suggest that ongoing negative shifts of the SCPs facilitate self-initiated movement but are not related to processes underlying

preparation or decision to act.” They concluded that “the early part of the RP [more than 500 ms before movement] appears to be an averaging artifact reflecting the ratio (2:1) of negative and positive epochs rather than a sign for a decision or a preparation process.” And “the RP does not indicate a ‘will’ that independently initiates an action or a ‘will’ that causes the RP to rise. In contrast, negative deflections of SCPs are linked to a higher probability of button press occurrences, since they might more readily lead to an impulse to act than positive deflections. In this view, we further suggest that the RP in principal cannot be used to solve the

Fig. 2. Wegener’s (2003) summary diagram superimposed on top of Libet’s results from Fig. 1B.

scored as not containing RPs [red tracing in Fig. 3A not showing an RP] and 50 epochs scored as definitely containing RPs [blue tracing in Fig. 3A with an RP]. …This demonstrates that a significant subset of finger movements generated in this session by this subject were not preceded by RPs.” And their subjects “did appear to be paying attention and making voluntary finger movements throughout the experiment.” So voluntary movements can take place without RPs, weakening the link between the RP and voluntary movement and intention; a similar lack of RPs before voluntary movements was also seen in subjects with parietal cortex lesions by Sirigu et al. (2004).

3.1.2. Schurger’s Lab

Schurger et al. (2012) recently proposed that the readiness potential does not result from a “specific movement preparation” process but rather from averaging random “ongoing spontaneous fluctuations in neural activity.” In their words, “We used a leaky stochastic accumulator to model the neural decision of “when” to move in a task where there is no specific temporal cue, but only a general imperative to produce a movement after an unspecified delay on the order of several seconds. According to our model, when the imperative to produce a movement is weak, the precise moment at which the decision threshold is crossed leading to movement is largely determined by spontaneous subthreshold fluctuations in neuronal activity. Time locking to movement onset [by averaging] ensures that these fluctuations [only] appear in the average as a gradual exponential-looking increase in neuronal activity.” Fig. 3B (adapted from their Fig. 1C) shows how good the fit is of the output of their modeled stochastic (random) accumulator (red line) to the shape of the RP (blue line) in the period before the movement. And subsequently Schurger (2018) further argued that the readiness potential might actually reflect the stochastic (random) noise input to the accumulator rather than its output. If, then, the readiness potential arises from averaging the random output of a leaky stochastic accumulator or its random noise input, as Schurger has shown to be plausible, then the early readiness potential, as such, is not real, does not really exist, and hence can do nothing, much less generate a movement. So a timing difference between a meaningless RP generated by averaging random noise and a subject’s W time cannot be used to conclude anything about the timing of brain activity and conscious decisions. And, as mentioned above, this is almost exactly what Eccles, Ringo, and Stamm said might be happening back in 1985.

3.1.3. Schmidt’s Lab

In 2013 Stefan Schmidt’s lab published a paper (Jo, Hinterberger, Wittmann, Borghardt, & Schmidt, 2013) which argued, similar to Schurger, that “in the Libet experiment, spontaneous fluctuations of the slow electro-cortical potentials (SCPs) [such as those seen in the dark blue line in the tracing seen at the lower left of Fig. 3C (adapted from Fig. 1 of Schmidt, Jo, Wittmann, & Hinterberger (2016))] account for a significant fraction of the readiness potential. The individual potential shifts preceding self-initiated movement were classified as showing a negative or positive shift.” And, as seen in Fig. 3C, “The negative [upper traces in Fig. 3C] and positive [lower traces in Fig. 3C] potential shifts were analyzed [separately] in a self-initiated movement condition [blue tracings before movement at time 0] and in a no-movement condition [red tracings before presentation of a tone stimulus at time 0]. Comparing the potential shifts between both conditions, we observed no differences in the early part of the potential. This reveals that the apparently negative RP emerges through an unequal ratio of negative and positive potential shifts [as Eccles (1985) predicted]. These results suggest that ongoing negative shifts of the SCPs facilitate self-initiated movement but are not related to processes underlying preparation or decision to act.”

And “the RP does not indicate a ‘will’ that independently initiates an action or a ‘will’ that causes the RP to rise. In contrast, negative deflections of SCPs are linked to a higher probability of button press occurrences, since they might more readily lead to an impulse to act than positive deflections. In this view, we further suggest that the RP in principal cannot be used to solve the

Consciousness and Cognition 94 (2021) 103171
A

Pockett and Purdy, 2010
Adapted from Fig. 1

"RPs appear NOT to be NECESSARY for voluntary movements"

Blue line is RP from average of 50 single trials 'eye-scored' as having an RP
Red line shows ABSENCE OF RP in average of 50 trials 'eye-scored' as without an RP

B

Shurger et al, 2012
Adapted from Fig. 1C

The early RP may be "largely determined by spontaneous subthreshold fluctuations in neuronal activity" that ONLY APPEAR to be "a gradual exponential-looking increase" preparing for a movement, i.e., "an ARTIFACT of AVERAGING."

Red line is simulation by 'leaky stochastic accumulator'
Accum Output = Integrated (Drift + Stochastic Noise)
Blue line is actual RP

C

Jo et al, 2013
RPs from Fig. 2

Early (>500msec pre-movement RPs AND pre-tone 'RPs' overlap) LRP (blue)
Early late

RP (blue) and RP-like (red) from positive slope SCPs
RP (blue) and RP-like (red) from negative slope SCPs
LRP (blue)

230 sec of EEG with slow cortical potentials (dark blue line) and movements (vertical lines); adapted from Figure 1 of Schmidt et al., 2016.

D

Alexander et al., 2016
RPs from Fig. 3

"...robust RPs occurred in the ABSENCE OF MOVEMENT"

RP (decide+move)
RP (decide only)

E

Verleger et al., 2015
RPs from Fig. 2

"BPs [RPs] had earlier onsets when the minimum interval was larger..."

F

Maoz et al, 2019
RPs from Fig. 3

"While we found the expected RPs for arbitrary decisions, they were STRIKINGLY ABSENT for DELIBERATE ones"

Arbitrary Movements: RP
Deliberate Movements: NO RP

Time (sec) Before Movement at Time 0

(caption on next page)
question of free will because it only reflects general preparation processes as it is correlated with an increase in the likelihood of an action.”

3.1.4. Alexander’s Lab

Alexander’s lab (Schlegel et al., 2013) replicated Haggard and Eimer’s 1999 study. They confirmed the earlier finding of no correlation between the RP onset times and the W times but failed to confirm the earlier correlation between LRP and W; “we crucially found no within-subject covariation between LRP onset and W. These results suggest that the RP and LRP reflect processes independent of will and consciousness.” This conclusion has significant implications for our understanding of the neural basis of motor action and potentially for arguments about free will and the causal basis of consciousness.” In other words, “Our data do not support the existence of a causal relationship between either the RP or LRP and W.” And in another experiment they found “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” (Schlegel et al., 2015), further disconnecting the RP from conscious willing. Even more importantly, in a subsequent study Alexander et al. (2016) used a novel task in which subjects chose one of four letters on the screen and then reported the Libet “clock time” for their decision. On some trials they merely decided on a letter, on others they decided on a letter and moved. RPs were averaged using the clock time as zero. As seen in Fig. 3D, they found the typical RP before movement [blue tracing of “decide + move” trials] but also found that “robust RPs occurred in the absence of movement [purple tracing of “decide only” RP] and that motor-related processes did not significantly modulate the RP. This suggests that the RP measured here is unlikely to reflect preconscious motor planning or preparation of an ensuing movement, and instead may reflect decision-related or anticipatory processes that are non-motoric in nature.” Importantly, the “decision only” RP matched both the amplitude and scalp distribution of the “true RP.” This is a major finding in the history of research on the RP because it demonstrates that, in the absence of a conscious intention to move, an RP does not cause a movement. These results were consistent with those of Trevena and Miller (2010), who reported a similar finding of an EEG negativity occurring before a decision not to move. In their summary Alexander et al. (2016) write, “Once an event-related potential is discovered, it is tempting to study its properties and relationships under the assumption that it reflects neural processing that is directly related to the original task that elicited it (e.g., that an ERP evoked by a movement task reflects motor-related processes). Our results show the usefulness of studying ERPs such as the RP outside of the paradigm in which they were initially discovered and defined. The current study shows that, although the RP has historically been considered a motor-related potential, the RP does not primarily reflect processes unique to motor execution or preparation, and may not even be primarily generated by the neural activity involved in making a free choice. Instead, it may reflect more general processes such as anticipation or those proposed by Schurger et al., 2012.” The impotence of the RP is further indicated by its complete vulnerability to “veto” by the subject until the “point of no return” about 200 ms before the movement actually occurs (Schultze-Kraft et al., 2016). Lastly, Alexander’s finding of a “robust RP ... in the absence of movement” also clearly disagrees with the conclusion of Travers, Khalighinejad, Schurger, and Haggard (2020) who rejected Schurger’s “purely stochastic model of RP generation” based on their finding of “no evidence of genuinely RP-like events at any time other than immediately prior to self-initiated actions” because the RP-like events seen without movements were “a poor match for the spatial profile” (scalp distribution) of the actual RP. However, as seen in the small head plots in Fig. 3D, in Alexander’s study the scalp EEG spatial profile of the decide-only RP is a good match to the spatial profile of the decide + move RP.

3.1.5. Verleger’s Lab

Verleger, Haake, Baur, and Śmigasiewicz (2016) recorded RPs from subjects making self-paced key presses at 1, 2, 3, or 5 s intervals. As seen in Fig. 3E (adapted from their Fig. 2), RPs preceding movements spaced farther apart had earlier mean onset times of −1.0, −1.65, −2.26, and −3.6 s, respectively. In fact, the relationship between mean onset times and movement intervals was almost perfectly linear (RP Onset = −0.65*Interval −3; p = 0.0009, R² = .9972), as seen in the small inset plot in the lower right of Fig. 3E. (Note that RPs with such an early onset were also seen by Haggard & Eimer (1999), Trevena & Miller (2002), Schurger et al. (2012), Alexander et al. (2016).) To address whether the RP was associated with some “internal timing” process they also did experiments where subjects were asked to count seconds while they waited to move (internal timing) or where they could just listen to a clock ticking (external timing). No difference was seen in RP amplitudes in these last experiments, suggesting the RP was not related to an internal timing process. In their words, RPs “vary in accordance with the temporal constraints on the intervals between movement, but ... the process reflected by BPs is not the timing mechanism itself.” Verleger’s results demonstrating RPs with very early onset times that are perfectly correlated with the intervals between movements are very strange and surprising, since it makes no sense for the brain to be preparing for such a trivial movement so long in advance. And, if Verleger’s results are extrapolated to even longer intervals, it makes even less sense. If the interval between movements was 10 s, the RP would start at 6.5 s before, for 30 s intervals, the RP would start at 20 s before, and for 60 s intervals, the RP would start at 40 s before. This seems absurd. Such early RPs, however, do make sense if they are “artifacts” (Jo et al., 2013) of
averaging random “stochastic noise” (Schurger et al., 2012) or “slow cortical potentials” (Schmidt et al., 2016) that are always present (no matter what the interval between movements or when the average starts) and that have no necessary relation to movement at all (Alexander et al., 2016)—or anything else for that matter.

3.1.6. Maoz’s Lab

Maoz et al. (2019) published a study in which they recorded RPs before response choice movements (left or right hand) in the same subjects when they made either arbitrary, meaningless choices (similar to the original Libet paradigm, see Section 2.1.3) or deliberate, meaningful choices. In the deliberate-decision trials the choice was which of two non-profit organizations would receive a monetary donation of $1000. In the arbitrary-decision trials both non-profit organizations received an equal donation of $500, irrespective of the subject’s keypresses. The choices on a particular trial were also classified as easy or hard, depending on the compatibility of the two non-profit organizations. As seen in Fig. 3F (adapted from their Fig. 3), they found clear RPs before both easy and hard arbitrary choice movements (blue traces) but no obvious RPs before either easy or hard deliberate choice movements (red traces). They explained their results by postulating “different neural underpinnings of arbitrary and deliberate decisions...in line with a recent study using a drift–diffusion model (DDM) to investigate the RP (Schurger et al., 2012).” And they concluded that “RPs represent an artificial accumulation of random fluctuations rather than serving as a genuine marker of an unconscious decision to initiate voluntary movement. Hence, our results challenge RP-based claims of Libet and follow-up literature against free will in arbitrary decisions and much more so the generalization of these claims to deliberate decisions.”

3.2. How Should Intention Be Measured?

Is Libet’s W time determined by the moving dot clock a good measure of intention? Recently Banks and Isham (2009) reported that the Libet clock W times reported by their subjects could be shifted linearly closer to the time of the actual button press when an auditory beep signaling the button press was delayed by 5, 20, 40, or 60 ms after the button press, implying that “participants’ report of their decision time is largely inferred from the apparent time of the response” rather than indicating “perception of a hypothetical brain event [such as the RP] prior to the response.” And, even more fundamentally, is awareness of intention an abrupt, all-or-none, single event, as assessed by Libet’s W time? Or is intention a more gradual, graded process? Miller and Schwarz (2014) recently reviewed this question and argued in favor of intention as a gradual, graded process and in support quoted Haggard’s statement that “conscious intentions clearly come by degrees: one can be barely conscious that one is going to take the next step when walking but intensely aware of pulling a trigger” (Haggard, 2008). And Miller and Schwarz (2014) also noted the important development of a new method for measuring intention with “tone probes” by Matsuhashi and Hallett (2008).

3.2.1. Matsuhashi and Hallett “Tone Probes”

Matsuhashi and Hallett (2008) assessed the presence of a conscious intention to move by using “tone probes” to “ask” the subject whether he or she is aware of an intention to move (recalling the idea of Marks (1985) in his Behavioral and Brain Sciences commentary in Section 2.1.2 above). Rather than Libet’s method in which the subject reports the position of the dot on the clock after making the movement, the subject in the Matsuhashi task received the following instructions.

Please quickly extend your index finger, following the instructions below:

(a.) The interval between your movements should be about 5–10 s. However, do not count or keep time. Just wait for a while. We will let you know if your intervals are too long or short. As soon as you think about the next movement, immediately extend your index finger as briskly as possible.

(b.) You will hear tones throughout the experiment. If you hear the tone while you are waiting and not thinking about the next movement, just ignore the tone and do your movement at your own will.

(c.) If you hear the tone after you have started thinking about the next movement or making the movement, stop the movement and relax. Wait for another 5–10 s without counting and make the next movement.

(d.) If you hear the tone after you have extended your finger, the tone should be ignored.

The onset of intentions in each subject was determined by comparing the timing distributions of tones and movements. In their words, “To determine the intention times, the distribution of relative times between movements and tones was constructed. If the subject completely ignored the randomly presented tone, the distribution [of tones] should be uniform before the movement onset. However, in this study design, tones that happened in a certain period before the movement onset [when the subject has intentions to move] would cause cancellation of the following action and would not contribute to the constructed tone distribution, making a dip in this otherwise uniform distribution. The onset of this “dip” or gap or decrease in tones followed by movements is, therefore, the onset of the intention to move. In Fig. 4A a row of small black dots beginning just below the large “A” illustrates...
the distribution of tone probes followed by movements in one subject; note that at about 2 s before movement the dots almost stop before reappearing just before the movement. This gap corresponds to tone probes that the subject judged occurred when he or she detected an intention to move and therefore aborted the intended movement, and thus the beginning of the gap is the onset of intention.

Matsuhashi and Hallett recorded the EEG of fifteen subjects making self-paced movements while having tone probes presented. As just mentioned, in Fig. 4A a row of small black dots beginning just below the large “A” illustrates the distribution of tone probes followed by movements in one subject. And note in Fig. 4A that in five subjects the onset times of intentions (T, filled red circles) preceded (red lines) the onset times of their readiness potentials (BP1 (early RP), filled blue circles), in marked contrast to the Libet clock task where all Ws occurred long after the onset of the readiness potential. And, they concluded, “statistically, the onset of BP1 (early RP) is earlier than T; however, some of the subjects [5/15] had a time T that preceded BP1 onset, suggesting that BP onset does not relate directly to the thought of movement initiation. The lack of positive correlation between T and BP1 also puts the causal relationship into doubt.”

3.2.2. Verbaarschot’s Lab

Verbaarschot et al. (2016) used Matsuhashi tone probes to assess intention in subjects whose EEG was being recorded, using these instructions:

Upon the presentation of this auditory probe, participants should: (1) veto their act if they were intending to act at the time they heard the beep and wait until the current image disappears from the screen, or (2) otherwise ignore the probe.

However, they used a different behavioral task than Matsuhashi and Hallett. Instead of asking the subjects to produce self-paced movements every 5–10 s, on each trial the subjects viewed a picture on the screen and then pressed a switch to change to a new picture when they wanted (pressing the switch was the movement used for averaging the EEG and also added a more natural motive or reason for the movement to the task (see Section 2.1.3 above).) As seen in Fig. 4B, they also had their subjects report Libet “W times” that are plotted on the boxplot labeled “W” just before the movement; importantly, these W times closely matched those originally reported by Libet. However, in 10 of the 12 subjects the onset of intention (boxplot labeled “I,” filled red circles in Fig. 4B) based on tone probes preceded (red lines) the onset of the readiness potential (boxplot labeled “RP,” filled blue circles in Fig. 4B), an even more dramatic reversal of the Libet pattern than that seen by Matsuhashi and Hallett in Fig. 4A. These intention (I) onsets also obviously preceded the W times. And in their words (with my comments in brackets), “the onset of intending is found up to 2 s prior to action. [inspection of Fig. 4A actually shows 6/12 onsets of intention earlier than 2 s] This ‘probed’ awareness has its onset around the same time [the median onset of I (thick black line in the pink box) is clearly before the median onset of the RP (thick black line in the blue box)] as the brain starts preparing the act as measured using EEG. The average onset of intending measured using the Matsuhashi task did not differ significantly from the [mean] RP [The mean onset of I (-2.17 s) was significantly earlier than the mean onset of RP (-1.48 s), as measured by a t-test for I vs. RP (t = -2.33, df = 22, p = 0.0145.) and alpha/beta ERD (event-related desynchronization) onset, suggesting that these processes have their onset around the same point in time.” [preceding comments in red suggest intending is earlier.]

In another study Verbaarschot et al. (2019) also used tone probes to assess intention in subjects whose EEG was being recorded, but the voluntary movements took place in the context of playing one of two video games. The exact instructions for the tone probes were:

When at the moment a probe is presented, the player.

a. Experienced an intention to act, they should cancel (veto) their action and wait for the next trial to begin.

b. Did not experience an intention to act; they should ignore the beep and continue the game.

The first video game was called “Free Wally” with movements that were “deliberate actions to achieve a goal” (choosing, over a number of trials, when Wally the whale will shoot water at the hunters approaching up the hill where Wally was confined in a cage). This was an effort to achieve more “ecological validity” for the movements (again see Section 2.1.3 above), giving the subject “a choice of what action to perform, when to perform it and whether to execute it, incorporating all elements of an intention” (Brass & Haggard, 2008). The second video game was called the “Object Game” that was “designed to measure spontaneous self-initiated actions that are performed independently of the presented stimuli, mimicking the most well-known studies on intended action,” such as Libet’s task.

“Once every round (corresponding to a trial in the experiment) participants are free to press a button with their left or right hand whenever they want to.”

As seen in Fig. 4C, the “grand average” of the readiness potentials from all subjects before movement (digitized from Fig. 9 of their paper at 100 points/s using WebPlotDigitizer (Rohatgi, 2021)) for the Free Wally task (solid red tracing) and the Object task (solid blue tracing) took place in the interval from -4 s before the movement to 1 s after. These time series were analyzed statistically using R’s strucchange package to determine the location of “breakpoints” that define the onset times when the RPs deviated from their baselines (Bai & Perron, 2003; Zeileis, 2001; Verbesselt & Zeileis, 2014). The onset time breakpoint for the Free Wally grand average RP was at 1.58 s before the movement; the onset time breakpoint for the Object Task grand average RP was at 1.61 s before the movement. The 95% confidence limits for both onset time breakpoints are shown on the arrows pointing at these timepoints.

The onset of intentions was measured by tone probes delivered at pseudo random moments during the series of movements. The grand average percent of tones with movements (= “percent of tones ignored”) for all subjects was calculated for the fifty 100 ms bins in the 5 s before the movements in the two tasks (illustrated in their Fig. 8); these two grand average time series of the “percent of tones with movements” are shown in Fig. 4C (Free Wally: red lines connecting filled red circles; Object Task: blue lines connecting filled blue circles and with the area under the curve filled with a light blue color). A statistical analysis similar to that for the RP time...
series was carried out to determine the onset time breakpoints where the two time series of “percent of tones with movements” deviated from their baselines, showing “dips” in the distribution of percent of tones with movements. (At the top middle of Fig. 4C these dips can be better appreciated in the small inset graphs of the percent tones with movements during the full 5 s before movement intentions for Free Wally (red) and the Object Task (blue).) Note that if the percentage goes down, as in the dips, that means that intentions were present when the tone was presented and so the movement was canceled (tone not ignored). The onset time breakpoint for the grand average of onset times of Intentions in the Free Wally game was 2.3 s before movement and that for the Object Task was 2.2 s before the movement, both clearly well before the onset times for the RPs. The 95% confidence limits for both of the Intention onset time breakpoints are shown around the red and blue arrows pointing from “Intentions” to these onset time breakpoints on the plots in Fig. 4C.

3.2.3. Summary
By using “tone probes” the labs of Matsuhashi and Hallett and Verbaarschot and her coworkers have demonstrated that the onset of
the intention to move occurs long before Libet’s W times and often before the onset of the RP.\(^7\)

4. Discussion

4.1. Intention Before RP: Has the Ghost Returned?

If intentions precede the RP, does that mean that the “ghost in the machine” (Bryce, 1949) has returned and intentions are present without any brain activity? No. Even if the RP is plausibly only an artifact of averaging and even if tone probes have shown the onset of intentions takes place well before the onset of any RPs, that does not mean that nothing is going on in the brain when these intentions begin. The UCLA neurosurgeon Itzhak Fried and his coworkers recorded neuronal activity from depth electrodes implanted into the medial frontal lobe (SMA, pre-SMA, and ACC (anterior cingulate cortex)) during performance of the Libet clock task in “12 subjects with pharmacologically intractable epilepsy to localize the focus of seizure onset” (Fried, Mukamel, & Kreiman, 2011). Each depth electrode included nine microwires capable of recording single and multi-unit neuronal activity, and 760 units (254 single units and 496 multiunits) were recorded in the SMA, pre-SMA, and ACC of the 12 patients. As seen in Fig. 5A, they found “progressive neuronal recruitment over ∼1500 ms before subjects report making the decision to move …[with a] progressive increase or decrease in neuronal firing rate, particularly in the supplementary motor area (SMA), as the reported time of decision was approached.” Much of this early neuronal activity took place in the 1500 ms preceding movement, but there were a number of neurons whose firing rates changed even earlier. And, as illustrated in Fig. 5B, in experiments in monkeys done in the lab of Mark Churchland by Lara, Cunningham, and Churchland (Jul. 2018) SMA neurons showed “preparatory and movement-related activity that covaried with reach direction,” in marked contrast to the human early RP’s lack of any movement specificity. So there is early, movement-specific neuronal activity during these early intentions.

Fried, like Libet, found the W time was only about 0.2 s before the movement, but, as shown above in the studies from the labs of Matsumoshi and Hallett and Verbicaortocht, W time utterly fails to capture when intention actually begins. Related to such early intentions, Miller and Schwarz (2014) comment that “At the start of each trial, it seems plausible that participants would already have a weak yet conscious urge to move within the next few seconds, simply because they know that their task is to make such movements. …In this scenario, the fact that brain activity appears to emerge before the conscious decision—i.e., before W—is merely an artifact of the experimenter’s requirement that the observer impose an arbitrary criterion for making a binary judgment about an inherently gradual process that underlies decision making.” In other words, the mere presence of the subjects in the experimental situation indicates that some form of intention is already and always present; the actual intention to “move now” (Searle’s (1980) “intention in action”) arises from and “is caused by this [earlier, pre-existing] prior intention” (Searle, 1980) to move sometime (but not now).\(^8\) In a sense, given the Libet-type experimental situation, it is not possible for the subject to be in an “intentionless” state from which a new, fully-formed intention arises, as when Athena was born as a fully formed adult from the head of Zeus. This makes it impossible, in principle, to even address the question of timing of mental and physical processes in a Libet-type experiment. And, as shown by tone probes, even the final intention to move now is not instantaneous or abrupt.

Lastly, as noted by Miller and Schwarz (2014), this same fact about intention being always and already present in experimental subjects also applies to the fMRI study by Soon, Brass, Heinze, and Haynes (2008) who found very early prefrontal activity as long as 10 s before the conscious decision times of their subjects. This early activity “predicted” whether the left or right index finger would be moved (57% accurate vs. 50% for chance)\(^8\) but this activity so long before movement likely had just as much to do with the intention NOT to move my left (or right) finger now that must also be present, especially in the frontal areas where brain damage leads to loss of frontal cortical inhibitory control over behavior (Malmo, 1942; Pribram, Ahumada, Hartog, & Ross, 1964). Or, as suggested by Koenig-Robert and Pearson (2019), the early activity could be viewed “not in terms of unconscious decision processes …but rather by a process in which a decision (which could be conscious) is informed.” Guggisberg and Guggisberg (2013) expressed a similar view that “intention consciousness does not appear instantaneously but builds up progressively …[and] early neural markers of decision outcome are not unconscious but simply reflect conscious goal evaluation stages which are not final yet and therefore not reported with the clock method.”

\(^7\) Using a visual “probe” Parés-Pujolràs, Kim, Im, and Haggard (2019) also reported a “gradual, rather than a fixed-threshold, categorical model of intention awareness.” This “latent awareness” was correlated with an RP-like EEG negativity.

\(^8\) Mele (2009) calls them “occurrent” and “standing” intentions, Pacherie and Haggard (2010) term them “immediate” and “prospective” intentions, and Nahmias (2014) calls them “distal” intentions and “urges.” Mele’s (2009) analysis of intentions is a key element in his book’s criticism of Libet and Wegner.

\(^9\) Very good odds for gambling in Las Vegas but not so good for whether you can make it across the tracks before the train arrives. And, of course, the subject could always change his or her mind (Nahmias, 2014). And Lages and Jaworska (2012) concluded that “it seems possible that the multivariate pattern classification in Soon et al. (2008) …was compromised by individual response bias in preceding responses and picked up neural correlates of the intention to switch or stay during a critical time window.” This “compromised” classification suggests there is no neural activity signal at 10 s prior to the movement that is specific for the upcoming movement but rather some kind of background, more or less stable neural “state” that lasts for a few minutes of switch or stay that has some modest predictive power. Such a state could, therefore, “predict” the movements during those few minutes.
movement, by Libet intention clearly suggest that intention is not an all-or-none phenomenon but a gradual process that begins much earlier than estimated.

Recent research on RPs has also highlighted several anomalies that challenge the idea that RPs are a direct indicator of voluntary intention. For example, Matsuhashi and Hallett (2008) found that tone probes were a more sensitive way to measure the presence of intention, forcing subjects to attend to even the slightest inkling. The results from the labs of Matsuhashi and Hallett (2008) and Verbaarschot et al. (2016, 2019) using tone probes to measure intention means nothing because the RP's relation to upcoming movement is an illusion.

The first and perhaps most important anomaly is the RP's dependence on averaging EEG potentials whose noise, when averaged, can reproduce the RP's waveform. This was the point of attack for Eccles (1985), Ringo (1985), Stamm (1985), Schurger et al. (2012), Schmidt et al. (2016), and Maoz et al. (2019). The second anomaly is that an RP is also seen before involuntary or unconscious movements (Keller & Heckhausen, 1990) and even before decisions that involve no movement at all (Alexander et al., 2016). The third anomaly is the early RP's lack of movement specificity, since very similar RPs occur before completely different movements, such as right hand vs. left hand (Haggard & Eimer, 1999; Herrmann et al., 2008). Related to this is that the RPs do not differ before movements with completely different motives and intentions, as seen in the RPs in the Free Wally and Object Tasks (Verbaarschot et al., 2019). The fourth anomaly is the onset time of the RP, which, for the exact same movement, has an almost perfect linear relationship to the interval between movements (Verleger et al., 2016). And the last anomaly is the absence of the RP before deliberate choice movements (Maoz et al., 2019).

All of these facts argue against the early RP having anything to do with preparation for a specific movement or the voluntary intention to move and make any comparison of RP onset times and W times pointless. Whether the RP starts before (Libet) or after (tone probes) intention means nothing because the RP's relation to upcoming movement is an illusion.

5. Conclusions

5.1. The RP Is Not What It Seemed To Be

The “paradigm” (Kuhn, 1970), that the early RP indicates brain activity preparing for movement was and is beset by several important “anomalies.” The first and perhaps most important anomaly is the RP’s dependence on averaging EEG potentials whose noise, when averaged, can reproduce the RP’s waveform. This was the point of attack for Eccles (1985), Ringo (1985), Stamm (1985), Schurger et al. (2012), Schmidt et al. (2016), and Maoz et al. (2019). The second anomaly is that an RP is also seen before involuntary or unconscious movements (Keller & Heckhausen, 1990) and even before decisions that involve no movement at all (Alexander et al., 2016). The third anomaly is the early RP’s lack of movement specificity, since very similar RPs occur before completely different movements, such as right hand vs. left hand (Haggard & Eimer, 1999; Herrmann et al., 2008). Related to this is that the RPs do not differ before movements with completely different motives and intentions, as seen in the RPs in the Free Wally and Object Tasks (Verbaarschot et al., 2019). The fourth anomaly is the onset time of the RP, which, for the exact same movement, has an almost perfect linear relationship to the interval between movements (Verleger et al., 2016). And the last anomaly is the absence of the RP before deliberate choice movements (Maoz et al., 2019).

All of these facts argue against the early RP having anything to do with preparation for a specific movement or the voluntary intention to move and make any comparison of RP onset times and W times pointless. Whether the RP starts before (Libet) or after (tone probes) intention means nothing because the RP’s relation to upcoming movement is an illusion.

5.2. Intentions Begin Much Earlier Than Libet’s W Times

The results from the labs of Matushashi and Hallett (2008) and Verbaarschot et al. (2016, 2019) using tone probes to measure intention clearly suggest that intention is not an all-or-none phenomenon but a gradual process that begins much earlier than estimated by Libet’s W time and in many cases before the onset of the RP. But is Libet’s clock time W intention the same as the intention detected by tone probes? Matushashi and Hallett (2008) told their subjects to make the movement “as soon as you think about the next movement,” to ignore the tone if they are “not thinking about the next movement,” and to stop the movement “if you hear the tone after you have started thinking about the next movement or making the movement.” So these instructions clearly identify intention to move with “thinking about the next movement.” In the two studies from Verbaarschot’s lab, the instructions explicitly said to “veto their act if they were intending to act at the time they heard the beep” so “intention to move” very clearly meant “intending to act at the time.” Both labs had similar results, with tone probe intentions beginning early and even sometimes before the onset of the RP, so the small differences in the language of the instructions given to the subjects (“thinking about the next movement” vs. “intending to act at the time”) do not seem significant and are both roughly equivalent to the variety of terms Libet’s study used for reporting the time of “conscious awareness of wanting to perform a given self-initiated movement,” which was “also described as an ‘urge’ or ‘intention’ or ‘decision’ to move” (Libet et al., 1983). So it would seem that the subjects in the different labs had the same concept of “intention” and that tone probes were a more sensitive way to measure the presence of intention, forcing subjects to attend to even the slightest inkling or trace of intention.
5.3. Summary

Rather than invalidating “folk psychology,” the Libet experiment itself now has had significant doubts raised about its own conclusions because of serious problems in its experimental methods of using the readiness potential to measure brain activity preparing for movement and of using the rotating dot clock to measure intentions. It will be hard to dethrone Libet from its place in “folk neurophilosophy,” but the time (Kihlstrom, 2017) may have come. It is ironic that the “obvious” conclusion drawn from Libet’s experiment that conscious intentions are an illusion will have to be replaced with the realizations that the readiness potential itself is an artifactual illusion and that intentions are a much more difficult ghost to “bust” (Reitman, 1984) than Libet imagined. In Manuel Vargas’s (2009) review of Alfred Mele’s Conscious Intentions: The Power of Conscious Will Vargas criticized Mele for writing that he did not care “to stipulate a starting point in the process” of movement initiation because, in Vargas’s opinion, “the business of when particular action processes properly start does matter a good deal.” And Libet’s experiment has been so influential because it seemed to stipulate a starting point in the brain’s activity that preceded the conscious urge or decision to move. But, as argued above, the RP cannot be used to establish the brain’s starting point and tone probes have shown that Libet’s clock drastically underestimates when conscious urges or decisions occur before a movement. The time gap between the RP’s “brain activity” and conscious intention seen in Libet-type experiments does not exist, so no explanation is needed. And thus Libet-type experiments cannot be used to attack Fodor’s (1987) “good old commonsense belief/desire psychology” and provide no reason not to believe that we live in a world where “my wanting is causally responsible for my reaching, and my itching is causally responsible for my scratching, and my believing is causally responsible for my saying” (Fodor, 1989), a world where a person is, in Frankfurt’s (1971) words, “free to will what he wants to will,” and a world where human agents sometimes act for reasons that give the actions meaning and significance (Taylor, 1977).

Funding

None.

Acknowledgments

In memory of the Rev. Joseph J. Peters, S.J., Ph.D. of Xavier University who introduced me to neuroscience and its questions. Thanks to the two anonymous reviewers for their helpful comments. Thanks to Dr. Phil Janicak for getting me started on this. And for Shonagh: always and forever.

References

Alexander, P., Schlegel, A., Sinnott-Armstrong, W., Roskies, A. L., Wheatley, T., & Tse, P. U. (Jan. 2016). Readiness potentials driven by non-motoric processes. Consciousness and Cognition, 39, 38–47.
Anscocome, G. E. M. (1957). Intention. Blackwell.
Armstrong, S., Sale, M. V., & Cunnington, R. (Dec. 2018). Neural oscillations and the initiation of voluntary movement. Frontiers in Psychology, 9. https://doi.org/10.3389/fpsyg.2018.02509.
Bai, J., & Perron, P. (2003). Computation and analysis of multiple structural change models. Journal of Applied Econometrics, 18(1), 1–22. https://onlinelibrary.wiley.com/doi/abs/10.1002/jae.659.
Banks, W. P., & Isham, E. A. (2009). We infer rather than perceive the moment we decided to act. Psychological Science, 20, 17–21.
Baumgartner, M. (2009). Interventionist causal exclusion and non-reductive physicalism. International Studies in the Philosophy of Science, 23(2), 161–178. https://doi.org/10.1080/02698590903006909.
Block, N. (2003). Do causal powers drain away. Philosophy and Phenomenological Research, 67(1), 133–150.
Brass, M., & Haggard, P. (2008). The what, when, whether model of intentional action. The Neuroscientist, 14, 319–325.
Breitmeyer, B. G. (1985). Problems with the psychophysics of intention. Behavioral and Brain Sciences, 8(4), 539–540.
Bridgeman, B. (1985). Free will and the functions of consciousness. Behavioral and Brain Sciences, 8(4), 540.
Deecke, L., Grözing, B., & Kornhuber, H. H. (Jul. 1976). Voluntary finger movement in man: cerebral potentials and theory. Biological Cybernetics, 23, 99–119.
Eccles, J. C. (1985). Mental summation: The timing of voluntary intentions by cortical activity. Behavioral and Brain Sciences, 8(4), 542–543.
Fodor, J. A. (1974). Special Sciences (Or: The Disunity of Science as a Working Hypothesis). Synthese, 28(2), 97–115.
Fodor, J. A. (1987). Psychosemantics: The Problem of Meaning in the Philosophy of Mind. MIT Press.
Fodor, J. A. (1989). Making Mind Matter More. Philosophical Topics, 17(1), 59–79.
Frankfurt, H. G. (1971). Freedom of the will and the concept of a person. Journal of Philosophy, 68(1), 5–20.
Fried, L., Mukamel, R., & Kreiman, G. (Feb. 2011). Internally generated preactivation of single neurons in human medial frontal cortex predicts volition. Neuron, 69, 548–562.
Gallagher, S. (2006). Where’s the Action? Epiphenomenalism and the Problem of Free Will. In S. Pockett, W. P. Banks, & S. Gallagher (Eds.), Does Consciousness Cause Behavior? (pp. 109–124). MIT Press.
Greene, J., & Cohen, J. (Nov 2004). For the law, neuroscience changes nothing and everything. The Atlantic. https://www.theatlantic.com/health/archive/2019/09/free-will-bereitschaftspotential/597736/.

10 @SamHarrisOrg from Sep 12, 2019 (https://twitter.com/samharrisorg/status/1172175513671987200?lang=en) includes the following tweet from Harris: “I have always regarded mentioning the Libet work in my book “Free Will” because it was never integral to the argument. When/if it is fully debunked, the case against free will remains unchanged. Free will makes no sense even if our actions arise exactly when we feel they do.” And Harris’s tweet is followed that same day by the following tweet from Daniel Dennett (@danieddennett) “The Libet results on free will and their many descendants are crumbling now, and there is more to come. A nice case of science exposing hidden dualist assumptions in neuroscience,” with a link to Bahar Gholipour’s “A Famous Argument Against Free Will Has Been Debunked” in The Atlantic describing Schurger’s experiments (https://theatlantic.com/health/archive/2019/09/free-will-bereitschaftspotential/597736/). So “the time may have come” sooner than first thought.
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 of the United States of America, 109, E2904–E2913.

Searle, J. R. (1980). The Intentionality of Intention and Action. Cognitive Science, 4(1), 47–70.

Shibasaki, H., & Hallett, M. (Nov. 2006). What is the Bereitschaftspotential? Clinical neurophysiology, 117, 2341–2356.

Sinnott-Armstrong, W., & Nadel, L. (2010). Conscious Will and Responsibility: A Tribute to Benjamin Libet. Oup Usa.

Sirigu, A., Dapратi, E., Ciancia, S., Giraux, P., Nighoghossian, N., Posada, A., & Haggard, P. (Jan 2004). Altered awareness of voluntary action after damage to the parietal cortex. Nature Neuroscience, 7(1), 80–84.

Soon, C. S., Brass, M., Heinze, H.-J., & Haynes, J.-D. (May 2008). Unconscious determinants of free decisions in the human brain. Nature Neuroscience, 11, 543–545.

Stamm, J. S. (1985). The uncertainty principle in psychology. Behavioral and Brain Sciences, 8(4), 553–554.

Takashima, S., Cravo, A. M., Sameshima, K., & Ramos, R. T. (Aug. 2018). The effect of conscious intention to act on the Bereitschaftspotential. Experimental Brain Research, 236, 2287–2297.

Taylor, C. (1977). What is human agency? In T. Mischel (Ed.), The Self: Psychological and Philosophical Issues (pp. 103–135). Rowman & Littlefield.

Travers, E., Khalighinejad, N., Schurger, A., & Haggard, P. (Feb. 2020). Do readiness potentials happen all the time? NeuroImage, 206, 116286. https://doi.org/10.1016/j.neuroimage.2019.116286.

Trevena, J., & Miller, J. (Mar. 2010). Brain preparation before a voluntary action: Evidence against unconscious movement initiation. Consciousness and Cognition, 19, 447–456.

Trevena, J. A., & Miller, J. (Jun. 2002). Cortical movement preparation before and after a conscious decision to move. Consciousness and Cognition, 11, 162–190.

Vargas, M. (2009). Review of Mele, Effective Intentions: The Power of Conscious Will. Notre Dame Philosophical Reviews, 2009(9). https://ndpr.nd.edu/reviews/effective-intentions-the-power-of-conscious-will/.

Verbaarschot, C., Farquhar, J., & Haselager, P. (Oct. 2019). Free Wally: Where motor intentions meet reason and consequence. Neuropsychologia, 133, 107156.

Verbaarschot, C., Haselager, P., & Farquhar, J. (Jul. 2016). Detecting traces of consciousness in the process of intending to act. Experimental Brain Research, 234, 1945–1956.

Verbesselt, J., & Zeileis, A. (2014). Tutorial I: Detecting a breakpoint in a time series. R-forge. https://r-forge.r-project.org/scm/viewvc.php/checkout/tutorial/TutorialExplainingStrucChangeBasics.pdf?root=bfast.

Verleger, R., Haake, M., Baur, A., & Smigasiewicz, K. (2016). Time to Move Again: Does the Bereitschaftspotential Covary with Demands on Internal Timing? Frontiers in human neuroscience, 10, 642.

Wegner, D. M. (2002). The Illusion of Conscious Will. MIT Press.

Wegner, D. M. (2003). The mind’s best trick: How we experience conscious will. Trends in Cognitive Sciences, 7(2), 65–69.

Wegner, D. M. (2004). Precis of The Illusion of Conscious Will. Behavioral and Brain Sciences, 27(5), 649–659.

Wikipedia-contributors, 2021. Neuroscience of free will. [Online; accessed 28-April-2021]. URL https://en.wikipedia.org/wiki/Neuroscience_of_free_will.

Zeileis, A., Leisch, F., Hornik, K., Kleiber, C., 2001. Strucchange: An r package for testing for structural change in linear regression models. Technical Reports 2001, 26, Technische Universität Dortmund, Sonderforschungsbereich 475: Komplexitätsreduktion in multivariaten Datenstrukturen. https://EconPapers.repec.org/RePEc:zbw:shfbib:200126.