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# On Reporting the Onset of the Intention to Move

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## On Reporting the Onset of the Intention to Move

*Uri Maoz, Liad Mudrik, Ram Rivlin, Ian Ross, Adam Mamelak, and Gideon Yaffe*

### 1. Introduction

In 1965, Hans Kornhuber and Luder Deecke made a discovery that greatly influenced the study of voluntary action. Using electroencephalography (EEG), they showed that when aligning some tens of trials to movement onset and averaging, a slowly decreasing electrical potential emerges over central regions of the brain. It starts 1 second (s) or so before the onset of the voluntary action<sup>1</sup> and continues until shortly after the action begins. They termed this the *Bereitschaftspotential*, or readiness potential (RP; Kornhuber & Deecke, 1965).<sup>2</sup> This became the first well-established neural marker of voluntary action. In that, the RP allowed for more objective research on voluntary action rather than its previous dependence on subjective introspection.

Two decades later, the RP captured the attention of the wider neuroscience community as well as of philosophers, legal scholars, and laypeople. This is because it was associated with a key question in the debate on free will: Is human voluntary action caused by the conscious intention to act? Or does the conscious experience only follow unconscious neural activity, which is the true origin of that action, and over which humans have only-limited immediate control?

### 2. The Libet and Follow-Up Experiments— Readiness Potential and Intention

What associated the RP with free will was the seminal empirical work of Benjamin Libet and colleagues. Initially they found that endogenous acts that

are spontaneously capricious in origin (e.g., flexing the wrist or a finger at a time of one's choice, for no reason or purpose and with no consequences) are also preceded by an RP (Libet, Wright, & Gleason, 1982). They were then surprised by the relatively early onset of RP—over 1 s (one second) before movement onset. And they wanted to know how long before action onset people became aware of their urge or intention to move.<sup>3</sup> One possibility was that subjects' awareness of the intention to move also appeared early before movement onset, potentially reflecting a long lag between the time they decided to act and the moment they executed the action. Alternatively, it could be that subjects' awareness actually followed—rather than co-occurred with or preceded—the onset of the RP, in which case one may speculate that this awareness is not part of the causal chain leading to action.

These competing hypotheses were put to an empirical test in what is now commonly known as the Libet experiment (Libet, Gleason, Wright, & Pearl, 1983). But how does one measure the onset of intention? Lacking a reliable neural marker, Libet's solution was to use introspection:<sup>4</sup> subjects were instructed to flex their right wrist or finger whenever they felt like doing so and report the position of a rotating spot on a clock when they first felt the urge to move. The authors termed this reported time of urge onset *W* time (*W* apparently stands for “wanting” to move). They then famously found that while *W* time begins about 200 milliseconds (ms) before movement onset, on average, the RP starts at least 550 ms prior to movement onset.

Since their publication, Libet's results have fostered ongoing discussions, debates, and criticism and have inspired many further experiments.<sup>5</sup> For instance, Keller and Heckhausen (1990) replicated the original Libet results, and also compared the RP generated there to RPs generated before hand movements that were initiated unconsciously—that is, while the subjects were occupied by another, attention-grabbing but unrelated cognitive task. They found the latter RPs to be significantly smaller and of more lateral origin, and suggested that the Libet task, which instructs subjects to time and report urges to move, led normally unconscious processes to become conscious due to attentional amplification.

Haggard and Eimer (1999) independently replicated the original Libet results as well. They too expanded on them, first by allowing subjects to decide both when and which hand to move, and second by computing the lateralized readiness potential (LRP; a variant of the RP that distinguishes between the neural signals that precede left versus right hand movements and generally begins in closer temporal proximity to movement onset). Their aim was to test whether RP was part of the causal chain leading to the intention to act. So they investigated whether earlier *W* times are accompanied by earlier RP onsets,

and they failed to find such a correlation. They did, however, find that LRP onset co-varied with *W* time, leading them to suggest that LRP rather than RP may be at least partially causal in generating awareness of the intention to move. However, Schlegel et al. (2013) were not able to replicate the correlation of LRP and *W* time with a larger group of participants using several variations of the analysis techniques used by Haggard and Eimer (1999). And Trevena and Miller (2002) showed that LRP may in fact follow rather than precede *W* time. Moreover, in later work, Trevena and Miller (2010) showed that RPs and LRPs occurring before decisions to move were not significantly different from these signals preceding decisions not to move. Thus, one possibility is that the RP and LRP are related to general readiness to act rather than to the specific decision to act now (Pockett & Purdy, 2011). And there appears to be no clear-cut evidence that either RP or LRP are neural markers of intention onset, or that they are part of the causal chain leading to intention.

In another study that used the Libet task, Sirigu et al. (2004) showed that patients who suffered from parietal lesions due to stroke could correctly report the onset of their movement time, but were not able to report *W* time. This is in contrast to cerebellar patients who could report both movement and *W* times like healthy subjects. Lafargue and Duffau (2008) further specified these results, reporting that they could not be replicated in patients with surgical resection of the inferior parietal lobule (that was performed due to slowly evolving brain tumors). They suggest that this specific part of the parietal cortex is of interest because it was demonstrated to be involved in various aspects of awareness of voluntary action and in the sense of agency. They further speculate that, taken together, the two studies indicate that the conscious experience of intending to act could be at least partially compensated following brain damage.

In sum, Libet's claim that the onset of RP (a slow-wave brain negativity preceding voluntary action, on average over many trials aligned to movement onset) precedes the *W* time (the reported timing of the first urge to move) appears valid given the independent corroborating studies. Yet, these follow-up studies also specify more clearly the conditions under which RP could be a neural precursor of voluntary action and seem to show that RP is not a neural marker of intention.

### 3. Further Criticism of the Libet Experiment and the Readiness Potential

In addition to follow-up work extending the original findings, the Libet experiment also garnered a lot of criticism. Much of that criticism focused

on the seemingly implicit assumptions behind the experiment. The early critique of Lato (1985) focused on the choice to operationalize voluntary action using monotonous and random actions. He accepted Libet's (1985) claim that such movements, at least some of the time, are initiated unconsciously. However, he contended that these unconsciously initiated movements might not be completely voluntary. Rather, they appear as such because of the non-ecological conditions created by Libet's instructions to his subjects to carry out voluntary actions, together with the requirement to report the timing of their so-called intention to move. This combination, he claims, may have retrospectively converted subjects' movements into voluntary actions in their minds.<sup>6</sup> For our purposes, Lato's criticism emphasizes the artificial conditions imposed on the participants of the Libet experiments, when instructed to report, and thus attend, to the onset of their intention.

Lato's criticism therefore stresses the possible attentional confound in the Libet experiments: to what degree do the results depend on subjects having had to attend to their intention to act, because of the instruction to time its onset? The answer, claim Miller, Shepherdson, and Trevena (2011), is "to a considerable extent"; these researchers showed that the amplitude of the RP was significantly smaller when subjects were instructed to only spontaneously press a key when compared to being instructed to also monitor the clock. More support for attention's role in the formation of the RP was found in the study of Baker, Piriyaapunyaorn, and Cunnington (2012). There, tones that randomly lasted either 3.5 or 4.5 s were played to subjects. After each tone, subjects were instructed to reproduce the duration of the tone as accurately as possible by the duration between two presses of a button. They were asked to wait a bit before the first button press and were given feedback on how accurately they replicated the tone's duration after the second button press, in every trial. Therefore, the timing of the first button press was determined by the subjects at will, while the second button press reflected the subjects' best estimate of the tone's length. In line with the hypothesis that RP is tightly related to subjects' attention to timing, RP before the first button press had a significantly smaller amplitude than RP before the second button press.<sup>7</sup> The authors thereby concluded that attention to the timing of movement is key to a strong RP. This compounds the earlier empirical evidence for the role of attention in RP generation, discussed before (Keller & Heckhausen, 1990).<sup>8</sup> Nevertheless, it should be noted that even the studies that were critical of the Libet results all found RPs, though diminished, before unattended and even possibly before unconscious action.

A different criticism of the RP was recently made by Schurger, Sitt, and Dehaene (2012). They used a task reminiscent of Libet's (i.e., a general

instruction to move with no specific movement cue or motivation to move) and constructed a stochastic decision model of neural activity. They then showed that, in this model, the precise moment when the decision threshold was crossed and movement was initiated was mainly determined by sub-threshold neuronal fluctuations that were completely spontaneous. Critically, time-locking this neural activity to movement onset made the fluctuations appear, on average, as a gradual increase in neuronal activity—akin to the traditional RP. The authors therefore claimed that the RP is an artifact of the alignment of the neuronal signal on every trial to movement onset, rather than a genuine event-related potential that indexes action initiation. They further suggested that the role of spontaneous neural fluctuations in crossing the decision threshold is unique to the meaningless and unmotivated movements used in the Libet task.

Thus, critiques of the Libet experiment mainly focus on two issues. First, its reliance on the RP, whose amplitude and sometimes distribution over scalp electrodes correlates with the amount of attention that the subject pays to various facets of the task. Second, while RP reliably precedes unmotivated voluntary action, it may be no more than artifactual to the manner in which it is calculated—averaging over many trials and aligning to movement onset—reflecting the accumulation of noise leading to unmotivated decisions.

#### 4. Follow-up Experiments that Do Not Rely on Readiness Potential

Following this discussion, it seems that the RP does not necessarily reflect neural activity related to the initiation of voluntary action. Accordingly, the relation between the RP and subjects' conscious decision to act may not be so easily interpreted. However, some more recent research no longer relied on RP or EEG to investigate the temporal relation between neural precursors of action and the reported time of the decision or intention to act. Instead, these studies used decoding techniques to decode subjects' upcoming decisions from brain activity that occurred prior to subjects' reported decision time. For instance, Fried, Mukamel, and Kreiman (2011) showed that some single-neuron activity in the supplementary motor-area (SMA) and anterior cingulate-cortex in humans starts to ramp up about a second before *W* time and movement time. This was suggested to potentially underlie RP in scalp EEG (Haggard, 2011).

Soon, Brass, Heinze, and Haynes (2008) and Bode et al. (2011) had subjects press one button with their left hand or another with their right at a time of their choice, while observing a randomized sequence of letters that switched every 0.5 s. Using functional magnetic-resonance imaging (fMRI), the investigators showed that there is some information about which hand the subjects would eventually use up to 10 s (ten seconds) before movement onset from the frontopolar cortex and up to about 8s in advance from the SMA. The decoding accuracy was low, at about 60%, but significantly above chance. They further found information coding when the subjects would move<sup>9</sup> up to 7s or so before movement onset in the pre-SMA; decoding accuracy was at roughly 20%, which was significantly above chance level, at 17%. These decoding times preceded the reported awareness of the decision when and which hand to move by roughly 5s and 6s, respectively.

Two competing interpretations could be proposed for these results, assuming subjects' reports about the timing of their decisions are accurate. The first is that the early decoding signals stem from unconscious decision processes that preceded subjects' conscious intention to move,<sup>10</sup> and so unconscious brain activity initiated the action. This interpretation leaves less room for effective, conscious intentions in the causal chain leading to action—at least in the case of the unreasoned and unmotivated behavior investigated in these experiments.<sup>11</sup> Therefore, it led to a debate about whether the intuitive concept of free will is no more than an illusion (Harris, 2012; Libet, 1985; Mele, 2006, 2009; Roskies, 2010; Sinnott-Armstrong & Nadel, 2011; Wegner, 2002).

However, an alternative interpretation is that these decoded signals relied on bias activity that has some influence on later action selection but does not fully define it. For example, ongoing brain activity may break the symmetry or speed up decisions among similarly valued decisions, creating a bias toward one of the decision alternatives (Haynes, 2011a, 2011b). Such a bias may then be combined with the values the subject associates with the decision alternatives to determine the decision outcome. The influence of the bias would be greater as the values of the decision alternatives become more similar. In this vein, we showed that when monkeys were deciding between smaller, more immediate rewards and larger, delayed ones, their choices could be decoded from single-neuron activity in frontal cortex and the basal ganglia before they were even informed of the delays associated with the decision alternatives, and hence before rational deliberation could begin. As expected, and as the circuit model we devised suggested, the bias activity was more predictive as the values of the two alternatives became more similar (Maoz, Kim, Rutishauser, Lee, & Koch, 2010; Maoz et al., 2013). In all the Libet experiments and follow-ups

discussed above, the values associated with the random left- or right-hand movements were generally similar, if not identical. Thus, our results support the claim that the early decoding signals found in these studies reflect early bias signals rather than early determination of the action. The single-neuron activity we found may therefore underlie neural fluctuations that might considerably influence unmotivated decisions about which action to take, similarly to the neural fluctuations that bring about action onset and RP in the computational model of Schurger et al. (2012).

However, importantly, Libet et al. (1983), Haggard and Eimer (1999), Soon et al. (2008), Fried et al. (2011) and the other experiments discussed earlier focused on random decisions: raising a hand, or one of two hands, for no reason or purpose and with no consequences.<sup>12</sup> But it is not clear to what extent these random decisions generalize to the more interesting deliberate decisions humans make every day. In fact, there is some preliminary evidence that deliberate and random decisions rely on dissociated neural systems.<sup>13</sup>

## 5. Criticism of the Use of W Time

Previously we reviewed some criticism against Libet's experiment, focusing on the validity of the RP and other neural markers as precursors of intention or action as well as on the generalizability of random decisions to deliberate ones. But another aspect common to all the Libet-paradigm studies, from those based on EEG, through fMRI, to single-neuron recordings, is their reliance on Libet's introspective W time to clock the moment subjects had the conscious intention to act. So, how valid is W time as a measure of conscious-intention onset?

Measuring W time in the Libet experiment requires subjects to time the onset of their intention to act with a rotating clock using introspection, commit it to memory, and retrieve it after movement onset. The various stages of this process have come under criticism, generally suggesting reasons for the onset of intention to have occurred earlier than the W time reported by the subjects. But the majority of the criticism focused on the attempt to externally, yet accurately, time the onset of the intention to act.<sup>14</sup>

It was suggested, for instance, that the timing of the intention was biased due to its reliance on an external rotating clock together with the internal introspection of time (Jasper, 1985; Wasserman, 1985). In particular, concerns were raised about the reliability of reports about timing intentions; it was claimed that the timing in such reports depends on the subjective threshold

that each participant sets for the strength of a conscious urge that merits reporting as a full-blown urge, assuming a gradual development of awareness (Latto, 1985; Marks, 1985). Doubts were even raised about whether an urge is an instantaneous event with a clear onset (Ringo, 1985; this claim is elaborated later). And it was commented that W time measures the onset of the ability to report awareness—sometimes termed meta-awareness—rather than the onset of the awareness itself (Rollman, 1985). Other concerns were that the attempt to self-monitor an internal process—urge or intention formation in this case—may interfere with that process, perhaps because it requires switching from introspective to visual attention (Wasserman, 1985).<sup>15</sup> Another type of criticism noted possible temporal discrepancies between the motor (wrist flexion) and sensory (clock-position perception) tasks in the experiment (Wasserman, 1985), suggesting that this stems from Libet's views of mental processes as instantaneous—that is, not allowing time for their development, processing, and propagation (perhaps due to Libet's dualism; Wood, 1985).

Beyond the early criticism directed at the concepts or experimental setup of the Libet paradigm, recent empirical findings further cast doubt on how accurately W time measures the onset of the intention to act. Matsushashi and Hallett (2008) instructed subjects to move their finger at a time of their choice—as soon as they formed an intention to move—while tones were played to them at random times. Importantly, the subjects were required to cancel their movement if and only if the tone was played after they formed the intention to move. This paradigm allowed the authors to calculate the distribution of tones in relation to movement onset. And from that distribution they were able to compute that the intention to move in fact began already 1.4s or so before movement onset. This was about 1.2 s earlier than W time in the Libet experiments, and generally congruent with the onset of the earliest part of the RP. These results could be viewed as supporting the idea that intention formation is gradual and thus takes time (Latto, 1985; Marks, 1985; Wasserman, 1985). The task in Matsushashi and Hallett's (2008) experiment might have thus prompted subjects to report an earlier phase of the intention to move than the one reported using W time.

Further criticism against W time as a measure for intention onset comes from a recent study we conducted with consenting intractable epilepsy patients, implanted with electrodes as part of their presurgical evaluation. The patients played a matching-pennies game. At the beginning of each trial, they pressed a button with each hand, and then decided which hand they would raise at the go signal, which followed a 5 s countdown. If they raised the same hand as their opponent, they won \$0.10 from that opponent.

Otherwise they lost \$0.10 to their opponent. Both players started with \$5.00. If the patient finished the game, which consisted of roughly 50 trials, with more money than her opponent she received that sum in cash from the experimenter. We constructed a system that predicted which hand the patients would raise 0.5 s before the go signal online and in real time. Its prediction accuracy was at 70%, on average, over two patients. We also applied this system on retrospective data, with more offline computational power. We could then increasingly well decode which hand the patient would raise, with the decoding accuracy rising above chance already 4 s or so before movement onset. The decoding accuracy reached over 82% correct, on average, over 7 patients, just before the go signal. If we let the system decode only on the 70% of the trials on which it was most confident, its average correct decoding rate rose to 92% (Maoz et al., 2012). In separate experimental sessions, we asked the patients to report when they finalized their decision regarding the hand they would raise at the go signal by one of two methods. One was by remembering the countdown when they decided (the digits flipped every 0.5 s)—that is, the Libet condition, though with a digital clock. The other was by starting the trial with neither button depressed and then pressing both buttons down at the perceived decision onset (and later, as usual, raising the chosen hand at the go signal). We found that the decision-onset time reported for the button-press condition was about 500 ms earlier than for the Libet condition, a statistically significant difference. Banks and Isham (2011) also showed that, when measured with a rotating clock, a digital clock, and a clock with randomly changing digits, *W* time preceded movement onset by 138 ms, 30 ms, and 380 ms, respectively, on average. So, *W* time appears to depend both on the manner of reporting (recalling the countdown at the decision versus pressing buttons as the decision occurred) and on the type of clock used to time it.

Interestingly, in the original Libet experiment, RT preceded *W* time by about 350 ms. So, assuming the results just discussed would generalize to this experimental condition, the button-press *W* time would have preceded RP by more than 100 ms. Therefore, had Libet opted for his subjects to report *W* time using button presses (possibly on separate trials, like us, to avoid motion artifacts in the EEG recordings), he would have found a result congruent with his intuition. Similarly, had Libet used randomly changing digits to clock *W* time, his *W* time would have preceded RP by about 30 ms. Either way, he may well have then decided not to publish such results, and the history of this field might have been quite different.

The conceptual criticisms, experimental suggestions, and experimental evidence suggest that the onset of intention might actually be somewhat earlier

than measured by *W* time. But even if the onset of intention leads the *W* time measured in the Libet paradigm by about a second, it still does not invalidate results like those of Soon et al. (2008), where the temporal gap between the decoding of action onset or contents and *W* time was 4–6 s.

Nevertheless, other empirical results join these criticisms to cast doubt on the validity of *W* time as any kind of marker for the onset of intention. Lau, Rogers, and Passingham (2007) instructed subjects to carry out the Libet experiment while randomly applying transcranial magnetic-stimulation (TMS) to their pre-SMA on half the trials (and sham TMS on the other half) either immediately or 200 ms after movement onset. They found that TMS shifted the perceived onset of motor intention slightly backward in time and the perceived onset of action execution slightly forward in time, regardless of whether it was applied at movement onset or 200 ms later.<sup>16</sup> It therefore appears that the perceived onset of intention depends, at least partially, on neural activity that took place after the onset of action.

Even more compelling evidence against *W* time as a measure of the awareness of intention comes from a study by Banks and Isham (2009). There, subjects carried out the Libet experiment, pressing a button that gave no tactile feedback, while they could not see their hand. They received either auditory feedback (a beep) or visual feedback (a video of their hand pressing the button). Critically, this feedback was deceptive, with the beeps delayed by 5 to 60 ms, and the video delayed by 120 ms. The results showed that the timing of the false feedback significantly influenced subjects' report of *W* time: irrespective of their actual movement onset, subjects reported *W* time about 130 ms before the beep, and about 90 ms before the video began.<sup>17</sup> These results suggest that rather than being able to accurately time the onset of their intention to move, subjects rely on sensory information about the timing of action execution to infer *W* time.<sup>18</sup>

It is therefore not clear whether *W* time refers to anything at all from the conceptual point of view. After all, concepts like will, decision, urge, or intention need not necessarily correspond to a specific neural event. The computational, neural mechanism of decision making may well not imitate the structure and flow of practical syllogisms<sup>19</sup> or of the folk-psychology conception of intentions or decision making.

What is more, this folk-psychology notion of decision making appears to be a serial account. According to it, information is retrieved from the senses and/or from memory. The alternatives are then weighed and the decision is made. This then leads to a commitment to a plan of action—immediate or deferred. This account includes a clear onset of the decision and with it the intention to act, which *W* time could then potentially measure. But there

is mounting evidence that this serial model of decision making may not be accurate. Instead, sensory information and the subjects' current state (e.g., motivation, goals, and so on) are apparently used to continuously maintain several conflicting and competing potential action plans in parallel, and often by the same brain regions that later control the chosen behavior (Cisek & Kalaska, 2010; Freedman & Assad, 2011; Gold & Shadlen, 2007; Kable & Glimcher, 2009; M. N. Shadlen, Kiani, Hanks, & Churchland, 2008; Wise, Boussaoud, Johnson, & Caminiti, 1997). These parallel action plans appear to be sustained even once the decision has been made and one of those potential actions begins to be carried out. Keeping a representation of the unselected parallel action plans after action onset may facilitate quick changes of mind, if required, especially when the decision alternatives are associated with similar values for the agent (Resulaj, Kiani, Wolpert, & Shadlen, 2009; Selen, Shadlen, & Wolpert, 2012). Hence, a decision might be an ongoing, developing process that continuously updates and remains amenable to changes, rather than a process that converges to a final unalterable outcome at one specific point in time, and is subserved by a definite brain area or neural system. If this is the case, it might not be possible to clearly map decision and intention onsets onto a single neural process or a specific moment in time (Ringo, 1985). In other words, there may be no place in the neural causal chain leading to action that can be identified as the decision or the intention.<sup>20</sup>

In sum, there are various strong conceptual and empirical criticisms of the use that the Libet and follow-up experiments made of *W* time. It may even be that intentions have no clear neural correlates, in which case it might be futile to ask subjects to introspectively time their onset. Or, less radically, even if neural correlates of intentions do exist, these may not be all-or-none processes that have a clear onset time that *W* time could capture. Either way, *W* time may well be a folk concept (Banks & Isham, 2011). But, when so instructed, subjects generally have no problem reporting *W* time. Yet, what are they reporting? Empirical results suggest that *W* time may be backward computed from movement time after movement onset. And this backward-inferred timing may well be the afterthought that the subjects are reporting.

## 6. Conclusions

In the Libet and follow-up experiments, subjects are generally instructed to pinpoint when they decided and formed an intention to act using an external

clock. However, given the conceptual and experimental criticism cited as well as some recent empirical results, this approach appears to rely on a systematically biased measure of intention onset, at best; arguably it is worse, and subjects are in fact instructed to formulate an artificial mental construct, with no ecological validity. Indeed, outside the lab it is not clear that decisions are even accompanied by awareness of the intention to act. Humans do not seem to experience finalizing a decision leading to action onset when steering the wheel of a car to avoid an obstacle on the road, or when deciding what to wear in the morning (to the extent that the results in the Libet experiments generalize to such everyday choices). What is more, it is not clear that for the big decisions in life—like selecting a partner or career—there is, introspectively, a clear point in time when the decision was made, and the plan of action, which was not there a moment ago, emerged.<sup>21</sup> So, perhaps, the Libet experiments, which rely on *W* time, are simply misguided, measuring something that does not independently exist.

What then should neuroscientists do to investigate the relation between awareness of the urge, intention, or decision to act and the neural correlates of this action? They should not ask subjects to report intention onset or *W* time during the same trials where they carry out the action, because these reports apparently confound the neural precursors of action that are measured in the experiment. They also render the experimental task and the action measured therein much less ecological, and by that decrease its validity and generalizability to everyday situations. If one insists that *W* time is a valid measure, previous literature has rather well delineated the distribution of *W* times that subjects report with respect to movement time for Libet-like tasks. So this distribution could be used instead of measuring *W* time during the experiment, at least when subject-specific or trial-by-trial information about *W* time is not needed.

A better approach would be to consider decision making a continuous process rather than a discrete one. Then, one could identify neural markers that track deliberation leading to decisions and reflect the (potentially gradual) buildup of intention, to the extent that it exists and is approachable with our technology. One idea is to construct a decoder of the upcoming action and investigate where its accuracy plateaus in relation to action onset. The moment where the decoder plateaus would then replace *W* time as the proxy for decision onset. Work of this sort appears to have found correlates of deliberation, in the form of evidence gathering leading to decisions in the monkey brain for perceptual judgments (the random dot-motion task), at least for eye movements (Gold & Shadlen, 2001, 2007; Shadlen & Newsome, 2001). And some work on humans demonstrated encoding of what could be intentions



for random decisions (purposeless addition and subtraction of small numbers) using fMRI (Haynes et al., 2007; Soon, He, Bode, & Haynes, 2013). But the most rigorous and convincing demonstration of such neural markers of decisions might be in closed-loop experiments, where these markers are identified and analyzed online and in real time (Maoz et al., 2012) and then potentially used to control a task on the fly (Cerf et al., 2010). Such experiments could, for example, track the neural correlates of decision reversals as they occur, and even attempt to influence them. While some work in this direction has already been done, much more remains ahead. And neuroscientists should perhaps devote more resources to attempts of this kind instead of trying to better understand the relation of neural precursors of action and the potentially nonexistent *W* time.

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## NOTES

1. We distinguish between voluntary action (sometimes just action) and movement. We tend to think that for an action to be voluntary at least one of the following—whether to carry the action out, when to perform the action, or which action to execute—must be up to the agent, in the sense that it depends on the agent's decision or intention (Haggard, 2008). The term movement refers more generally to any kind of displacement of body parts due to any cause—voluntary, reflexive, following the application of external force, and so on.
2. The RP is a more complex neural phenomenon than discussed here, possibly composed of an early and late component, for instance. For details, see Shibasaki and Hallett, 2006.
3. While Libet and much of the follow-up literature do not generally distinguish between the urge, intention, and decision to move, these concepts are not identical, which leads to conceptual confusions that permeate the literature. Briefly, an intention entails at least a temporary plan to go through with an action, while

- an urge is the wish to carry out an action or the conscious experience of an impeding intention. Also, by intentions here we mean proximal intentions. For more details about these distinctions see Mele, 2009. Nevertheless, it is not clear that subjects are able to differentially report the onset of their urges, intentions, and decisions. We generally refer to intentions rather than urges or decisions here.
4. The discovery of the RP enabled neuroscientists to speculate about the neural process leading to action. Similarly, a neural marker for intention may allow neuroscientist to investigate the brain processes leading to intention onset. However, such a neural marker need not be more "genuine" or in any way superior to introspection when it comes to measuring the onset of intention, for instance. And this marker may well be no more than a neural correlate of this introspection.
  5. We attempt to describe some key studies pertaining to the Libet experiment here. But a full account of the follow-up conceptual and empirical work is beyond the scope of this chapter. See Banks and Pockett (2007), for example, for a review.
  6. Although the conclusions of Keller and Heckhausen (1990) are similar to Lattó's (1985), they might have not been aware of his criticism, though they do reference Libet (1985) and another commentary on it from the same issue.
  7. It should be noted that while the three criticisms cited invoke the effect of attention to timing, they all focused on different aspects of such attention: Lattó (1985) discussed attention to the onset of intention. Miller et al. (2011) investigated attention to the *W*-time clock. And Baker et al. (2012) looked at attention to the timing of movements.
  8. Keller and Heckhausen (1990) studied the effect of attention on RP in the main task versus the distractor task.
  9. They divided the 10 s before movement onset into 1.67 s bins, and attempted to identify in which of the 6 time bins movement could begin.
  10. The weak decoding accuracy (60% and 20%) would then be attributed to technological limitations of current brain imaging technologies.
  11. A key concern in case conscious intentions are ineffective for action is what this entails for our notions of moral and legal responsibility. For a discussion of the extent to which these concerns are warranted see Maoz and Yaffe, 2014; Yaffe, 2011.
  12. An exception is Maoz, Ye, Ross, Mamelak, and Koch (2012), which investigated predicting decisions in a competitive matching-pennies game and is described in this chapter.
  13. Mudrik, Maoz, Yaffe, and Koch, The role of consciousness in deliberate and random decisions: an ERP study, in preparation; and Pockett and Purdy, 2011.
  14. Although the use of working memory as an indicator of consciousness was also found suspect (Jasper, 1985).
  15. This might be part of a cognitive analogue of Heisenberg's uncertainty principle (Stamm, 1985).
  16. The effect size in this experiment is small, shifting *W* time by 10–20 ms.

17. The auditory delays were of 5, 20, 40, and 60 ms. And, interestingly, this experimental manipulation had subjects report *W* times that followed EMG onset for all but the 5 ms-delay condition.
18. Following the results of Sirigu et al. (2004), discussed earlier, it seems that the neural system involved in generating *W* time is not the same as that used for generating information about the timing of movement onset.
19. Aristotle suggested representing practical reasoning in syllogistic form, the conclusion of which is an action. Thus, for example, the decision to drink a glass of water might be compounded from the following argument: (1) water can quench thirst; (2) I am thirsty; (3) this is a glass of water; which together entail the action of drinking the water (or forming the intention to drink it). This is similar to the manner by which an ordinary syllogism entails its conclusion. However, even if this model can be used as a standard for evaluating and justifying rational behavior, it is not necessarily an adequate description of the neural mechanisms underlying decisions or actions.
20. While several well-known computational models exist for decision making, it appears that they generally assume the serial account of decisions, at least implicitly (e.g., Gold & Shadlen, 2007; Palmer, Huk, & Shadlen, 2005; Ratcliff & Rouder, 1998; Wong & Wang, 2006). It would be both interesting and important to construct a computational model of decision making with the characteristics described above. Potentially more difficult, though possibly more rewarding, would be to construct a neural-circuit model of decision making, which would be closer to the neural hardware than more abstract models like drift-diffusion or race-to-threshold.
21. Again, such distal, deliberate decisions are conceptually different from the proximal, random ones of the Libet paradigm (Mele, 2009), and may well be empirically different too.

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