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What Does Neuroscience Research Tell Us about Human Consciousness? An Overview of Benjamin Libet's Legacy

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This paper presents an overview of the key neuroscience studies investigating the neural mechanisms of self-initiated movements that form the basis of our human consciousness. These studies, which commenced with the seminal works of Benjamin Libet and colleagues, showed that an ensemble of brain areas — localized to the frontal and medial regions of the brain — are involved in engendering the conscious decision to commit a motor act. Regardless of differences in neuroimaging techniques, these studies commonly showed that early neuronal activities in the frontal lobules and supplementary motor areas, interpreted by some to be reflective of unconscious processes, occurred before one was conscious of the intention to act as well as of the act itself. I examine and discuss these empirical findings with regard to the need to analyze the contents and stages of awareness, and devise paradigm-specific models or theories that could account for inconsistent findings garnered from different experimental paradigms. This paper concludes by emphasizing a need to reconcile the principles of determinism with the notions of free will in future development of consciousness research and theories.

Keywords: consciousness, awareness, prefrontal cortex, supplementary motor area

"Consciousness" is a term that is hard to define. In the simplest sense, it pertains to the subjective state of sentience or awareness that accompanies us throughout the day whenever we are awake and performing our daily tasks (Searle, 1992, 1993). At a higher or more intricate level, it is an essential mental phenomenon

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that applies to both humans and the vast majority of living creatures, creating a platform for the emergence of higher mental faculties like attention, perception, cognition, and memory. Every day we experience multitudes of perceptual sensations, subjective feelings, and streams of thoughts such as hearing the ringing of our alarm clocks, realizing the urgency to get up to go to work, deliberating about the tasks that await us, etc. How the brain makes sense of all these different experiences and bind them into a unified conscious state based on physical/neural processes has been designated as the "hard problem" of consciousness (Chalmers, 1995). Complementing this "hard problem" are the "easy problems" of consciousness, which aim at explaining the dynamics of consciousness by investigating the physical, functional, and/or computational properties of the brain (Baars, 1988; see Chalmers, 1995, for a list of mental phenomena [e.g., responding to stimuli, attention, verbal report, motor control] that are subsumed under such easy problems).

In the domain of neuroscience, many researchers have sought to study consciousness in relation to neural and brain-related processes. The primary focus has been on the easy problems of consciousness, as represented by a search for the neural correlates of consciousness (Crick and Koch, 1998) and establishing a biological framework for visual consciousness (Crick and Koch, 2003). Partly due to the dearth of scientific techniques that could unambiguously reveal the phenomenal aspect of consciousness (i.e., what it subjectively feels like to have an organized or integrated experience of reality [Chalmers, 1995; Nagel, 1974; Searle, 1992]), extant neuroscientific studies showed that the relationship between our conscious decisions and neurophysiological activities is tenuous and susceptible to different interpretations.[1] Keeping these issues in mind, this paper highlights the neuroimaging studies that commenced with the experiments of Benjamin Libet and his colleagues in the 1980s, the criticisms directed against Libet's methods, and the ensuing Libet-type experiments that were done after certain modifications to the original paradigm. By detailing the seminal neuroimaging studies that documented the neural precursors of motor acts, this paper aims to present a historical overview of the Libet-type experiments, and the implications of their findings for understanding conscious decisions and acts. It is vital to note that the study of consciousness via the Libet-type experiments adhered to the philosophical notion of *access consciousness* (Block, 1995), which considers any organism to be conscious as long as it can convert sensory or perceptual information into use for guiding decisions and behaviors. Consequently, there has been a lack of insight into what these experiments mean with respect to the phenomenal aspect of consciousness, and hence this paper proposes some ideas for how the neural

[1]Note that the currently available neuroscientific methodologies and tools are designed for examining brain anatomy and brain-related processes, but not for explaining phenomenal consciousness, which primarily pertains to subjective experience and the feeling of agency ("what is it like?") from an organism's perspective (Nagel, 1974).

precursors of motor acts can be interpreted with regard to some representative constructs of awareness.[2]

The neuroscience techniques used in the studies reviewed pertain to the non-invasive techniques of electroencephalography (EEG) and functional magnetic neuroimaging (fMRI), as well as to the invasive technique of microelectrode recording. In combination, these techniques greatly facilitated the discovery of pre-movement neuronal activity and engendered new questions about how this type of activity should be interpreted with regard to the plausible contents and stages of awareness.

Libet et al.'s Experiments

The seminal studies that investigated the cortical mechanisms of motor acts in humans were performed by Benjamin Libet and his colleagues in the early 1980s at the medical school of the University of California, San Francisco (UCSF) [Libet, Gleason, Wright, and Pearl, 1983; Libet, Wright, and Gleason, 1982]. In the first study in 1982, Libet and colleagues, using electroencephalography (EEG) and electromyography (EMG), examined the event-related potentials (ERP) of six participants performing a simple perceptual–motor task that warranted phasic movements of their wrists or fingers, which were linked to an EMG machine. This task required the participants to fix their gaze at the center of a cathode ray oscilloscope (CRO) clock placed 1.95 m away. A light spot revolved clockwise at the perimeter of the clock at a rapid pace of 2.56 seconds per revolution, and participants were instructed to flex their fingers or wrists after the first revolution whenever they felt a spontaneous urge. They were also asked to note down the spatial location of the light spot on the clock face at the same time they performed the flexing motions. The time that was observed by participants on the clock face corresponded to their consciously self-reported time, while the time that was recorded by the electromyogram pertained to the actual time when participants performed their spontaneous motor acts.

Libet et al. (1982) matched those timings with the ERP of their respective participants and made several discoveries that were startling for their time: they found three types of "readiness potential" (RP) [originally called *Bereitschaftspotentials*, as first discovered by Kornhuber and Deecke, 1965] emanating from the supplementary motor area (SMA) [Brodmann's area (BA) 6] *before* participants' self-initiated motor acts. A Type I RP emerged between 1500 and 1000 milliseconds (ms) before movement, and was generally present among participants who

[2]In line with Libet's (1993) postulate that the neuronal activity before and after movement onset marks the physical correlate of consciousness, this paper identifies awareness as the emergent property of this neuronal activity — that is, as the condition in which there is direct availability of information (perceptual and/or cognitive) for global control (i.e., control of behavior and verbal report) [Chalmers, 1995].

reported some pre-planning of the motor act. A Type II RP emerged at about 550 ms before movement, when the participants were consistently informed to let the urge to move come naturally on its own (i.e., no motor pre-planning). Finally, a late-occurring Type III RP emerged at about 200 ms before the motor act. The Type III RP was further shown to occur earlier than the subjectively reported sensation of a skin stimulus that was randomly delivered after one revolution of the spot of light on the CRO clock (see also Libet, 1989, 1999). This additional finding showed that *W* should not be conceived as being functionally equivalent to the subjective report of being aware of a simple sensory stimulus. Taken together, these three different types of RP showed that cerebral activity emanating from the supplementary motor area could portend the commission of a spontaneous or voluntary motor act rather than simply occuring at the same time as the act itself.[3]

To verify their findings, Libet and colleagues reapplied their experimental design in 1983 using more precise measures of time and ERP onsets, and managed to replicate their findings. This successful replication led to Libet's (1985) proposal that the onset times of the three different types of RP were representative of different cerebral processes. Namely, the Type I RP was regarded as representing pre-intentionality or a general preparedness that was not essentially automatic; the Type II RP was regarded as the harbinger of the cerebral processes that initiated the act before any subjective awareness of it; and the Type III RP was regarded as representing the conscious wish or will (*W*) to make the act. In an attempt to relate consciousness to the emergence of these different types of RPs, Libet (1985) further proposed that our conscious will could function as a *conscious veto* that blocks the consummation of any spontaneous act originating from preparatory cerebral processes at about 150 ms before the act (after removing the time taken for efferent commands to reach the hand muscles). He supported this proposal based on findings of veto RPs from previous experimental sessions in which participants suppressed their intention to act about 100 to 200 ms before the prearranged times at which they were otherwise supposed to act (see Libet et al., 1983). The main negative potential of these veto RPs tended to flatten or reverse at about 150 to 250 ms before the preset time. This implicated that preparatory cerebral processes could be interfered with or vetoed within the same time period that a conscious decision would emerge before a spontaneous act. By describing the conscious will as functioning in the form of a veto, one can imagine a person with conscious will as having the capacity to act intentionally toward the control of a decision.[4]

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[3]Libet's conception of a "voluntary" motor act refers to a physical act performed out of one's volition or intention. Having an intention connotates a commitment to perform a physical act directed toward or in response to objects, stimuli, and/or events (see, e.g., Davidson, 1963, for a discussion of "intention"). In Libet's experiments, the presence of the Type III RP can be conceived as an internal event that engendered the intention or conscious will (*W*) to act (see main text for details).

[4]Even though it can be argued that the suppression of a motor act — as entailed by exercising one's "conscious veto" — cannot directly represent the presence of intentionality or agency, the operational definition of veto still lies upon a desire or act to reject a decision. More importantly,

Repercussions

Despite replicating significant findings and conducting control experiments that demonstrated the preponderance of neuronal activity before spontaneous motor acts, Libet's experiments generated great debate among scientists and philosophers, and many expressed harsh criticisms of his methods concerning the timing of conscious awareness (see, e.g., Breitmeyer, 1985, Glynn, 1990; Gomes, 1998, 2002). Notably, with respect to the CRO clock, Gomes (1998, 2002) called into question Libet's assertion that the self-reported time associated with perceiving the light spot's location can be directly coupled with the onset of conscious motor decision. He argued that some latency should be expected for the conscious perception of the light spot on the clock face, and that this latency may vary in an unspecified manner across trials depending on the light spot's position. However, he did not recommend any way to record this unknown latency.

Other than Gomes' criticisms, further concerns of imprecision in the timing of awareness pertained to the observation that not all participants in Libet-type experiments were able to unambiguously differentiate between the temporal onsets of conscious decision and motor act (Pockett and Purdy, 2010) and that a "smearing artifact" might account for Libet et al.'s (1983) findings (Travena and Miller, 2002). This smearing artifact pertained to the averaging of EEG components that would make the main negativity vertex of the average waveform appear earlier than the average decision time despite the presence of EEG components from some trials that occurred after decision-making (for details see Travena and Miller, 2002, p. 164).

Technical considerations aside, at the conceptual level, there is a pre-existing opinion of the conscious will or veto as nothing more than an epiphenomenon or illusion, in contrast to perceiving the conscious veto as a representation of the conscious will in action (Wegner, 2002). In an analysis of Libet's experiments, Wegner (2002) suggested that the experience of will might be nothing more than a "loose end — one of those things, like the action, that is caused by prior brain and mental events" (p. 55). Central to Wegner's notion of the illusory conscious will is that "the experience of consciously willing an action is not a direct indication that the conscious thought has caused the action" (p. 2). This statement highlights his principle of *exclusivity* — that is, a thought (or its ensuing action) cannot be proven to be conscious unless it is associated exclusively with a conscious cause (or causes). Despite arguing that the conscious will may just be an

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the notion of conscious will as being tied to the exercise of one's intention is what researchers in other Libet-type experiments endorsed (see discussions of these experiments in the main text). Henceforth, subsequent mentions of "conscious will" in this paper refer to a conscious intention to perform a decision or motor act.

illusory perception of control over one's actions, Wegner concurred with Libet on the notion that unconscious neural processes could cause intentions and actions (see Wegner and Wheatley, 1999).[5]

On the other hand, Mele (2009) disagreed with both Wegner and Libet with regard to the causal role of unconscious neural processes. Principally, he characterized Libet's Type II RP as a potential precursor or antecedent to a decision to act rather than the actual cause of that decision, and suggested that the Type II RP might be better understood with regard to "urges to (prepare to) flex soon, brain events suitable for being proximal causal contributors to such urges, motor preparation, and motor imagery" (p. 56).[6] Based on such accounts, Mele eschewed giving a concrete answer as to whether or not all our decisions are conscious, and instead emphasized the causal role of intentions in generating actions regardless of whether or not we consciously experience the process of intention formation that incorporates decisions.[7]

In addition, there were similar views endorsed by Levy (2005), who agreed with Mele with respect to the pertinence of intentions for generating actions, but disagreed with Libet over the implication of the "conscious veto." Levy viewed the control of actions or behaviors strictly in the form of conscious volitions or intentions (brought about by exercising the "conscious veto") as "Libet's impossible demand," saying that the presupposition of a conscious control system would warrant an additional control system at a higher level (ostensibly conscious as well) to control it, and that this process might repeat itself perpetually, causing "an infinite regress of controllings" (Levy, 2005, p. 67). Therefore, Levy argued that our free will — as naturally characterized by the freedom to pursue our actions irrespective of external events — does not need to depend on decisions, volitions, or intentions that are irrevocably conscious (cf. Rosenthal, 2002, presented below). Principally, he stressed that the course of controlling our decisions and actions should not be regarded as inherently conscious, and that non-conscious mechanisms should be assigned functional roles in the emergence of a conscious state. Even though Levy's (2005) advocacy of non-conscious mechanisms was not at odds with Libet's (1985) interpretations of the Type I and Type II RPs as being

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[5]To associate an outcome closely with its cause, Wegner proposed two other principles in addition to *exclusivity*: (i) *priority*: the thought must occur before the action; and (ii) *consistency*: the thought must be congruent with the ensuing action (Wegner and Wheatley, 1999).

[6]Note that a *decision*, according to Mele (2009), is defined as the mental act of forming an intention that is settled on executing a plan of action. Ensuing use of the word in the main text shall adhere to this definition.

[7]Mele (2009) emphasized the role of intentions in generating actions through an interesting example of turning on a switch: "A subject's wanting to flex soon and his experience of wanting to flex soon are not the same thing.… My flipping a light switch — not my *experience* of flipping it — is a cause of the light going on. Analogously, a subject's wanting to flex soon may be a cause of his flexing even if his experience of wanting to flex soon is not" (pp. 32–33).

closed to subjective awareness, he failed to relate his proposed non-conscious mechanisms to any specific readiness potential or neural signal that preceded the emergence of a conscious decision or act. This was perhaps due to his critical view of the empirical evidence produced by Libet and colleagues, which he dismissed as offering any serious challenge to the necessity of free will — a necessity that he thought could be proven on conceptual grounds.

All of the above criticisms, however, did not negate the validity of Libet et al.'s (1982, 1983) original findings, which had been accepted and praised by many of the world's leading neuroscientists (see Libet, 2002). Libet, on many occasions, was also able to offer sound counterarguments against his critics to justify his methodology and interpretations (see, e.g., Libet, 2000, 2002). In the philosophical domain, his works were notably supported by Rosenthal (2002), who argued that the neural signals preceding conscious volition or intention (namely, Type I and Type II RPs) could be identified as the direct indicators of unconscious states/events or their approximate physical correlates (i.e., neural signals that did not represent unconscious events per se but occurred simultaneously with unconscious events). Unlike Mele (2009), who did not openly acknowledge the role of unconscious decisions or events, Rosenthal (2002) argued that we must abandon an essentialist or commonsensical view of consciousness entailed by the belief that "no mental state counts as being conscious unless the individual who is in that state is conscious of the state" (p. 218). Crucially, he asserted that we need to conceptualize a mental state in dynamic terms — that is, a mental state can be conscious at one time and non-conscious at another time. By this account, the train of readiness potentials culminating in a motor act can be seen as a transformation whereby a prior non-conscious state is turned into a conscious state.

More importantly, with respect to empirical research, the implications of Libet's experiments remained relevant because other researchers were able to replicate his basic finding of early emergence of RPs prior to motor decisions based on different instruments and/or stimuli (see, e.g., Keller and Heckhausen, 1990; Pockett and Purdy, 2010; Travena and Miller, 2002). In general, the other Libet-type experiments showed the same pattern of results as that of Libet et al. (1982, 1983) regardless of differences in stimuli and the type of motor response (e.g., pressing keys): the emergence of the RP representing decision onset was found to be either close to or more than 250 ms before the time of action execution. Particularly noteworthy was Haggard and Eimer's (1999) discovery of the lateralized readiness potential (LRP), a special form of the readiness potential that occurred about 800 ms before movement initiation. Haggard and Eimer (1999) showed that the LRP occurred significantly earlier in trials with early awareness of movement initiation than in trials with late awareness of movement initiation, implicating that the processes underlying the LRP may have causal roles to play in initiating our awareness of movements.

Furthermore, a modified Libet-type experiment conducted with functional magnetic resonance imaging (fMRI) by Lau, Rogers, Haggard, and Passingham (2004) pinpointed the pre-supplementary area (pre-SMA) [the rostral portion of BA 6] as the site that is tightly associated with the generation of spontaneous acts. In the experimental condition, the participants gazed at a red dot revolving around a clock face at a rate of 2560 ms per cycle and encoded its location while performing a button press on each trial. Under this condition, the blood-oxygen-level-dependent (BOLD) activation in the pre-SMA was found to be significantly higher than that from the control condition in which the participants made their button presses without attending to the dot's location. Specifically, significant differences in BOLD signals between the two conditions were observed in the first six seconds after the onset of the spontaneous button press. Critically, activation in the dorsal prefrontal cortex (dPFC) [BA 9/46], commonly associated with motor planning, was found to be closely associated with activation in the pre-SMA during the intention phase when participants attended to the dot's location. The authors thereby concluded that activity in the pre-SMA is tightly coupled to an intention to move that involves attending to a moving stimulus. Importantly, this conclusion supported Libet's interpretation of the Type III RP as reflective of conscious intention.

Is Conscious Intention a Veto?

As for Libet's principal proposal of conscious intention functioning as a veto, another Libet-type fMRI study (Brass and Haggard, 2007) gave support to his claim by implicating the dorsal fronto-median cortex (dFMC) [BA 9)] to be involved in action inhibition. In that study, the participants gazed at a Libet clock with a clock hand moving at a rate of 3000 ms per cycle. After one full revolution of the clock hand, participants under the "action" condition had to spontaneously initiate a key press while participants under the "inhibition" condition had to refrain from the act. Both parties had to judge the temporal onset of their decisions after these two phases. Contrasts between the inhibition and action conditions yielded strong activation in the dFMC while the reverse contrast between these two conditions did not yield any significant activation in the pre-SMA and SMA, which suggested that participants prepared their intentional acts equally well under both conditions. Moreover, participants who displayed higher frequencies of inhibition were found to have stronger inhibition-related dFMC activation, and a significant negative correlation was found between activation in both the dFMC and the primary motor cortex (BA 4). The authors concluded that the dFMC could be a specific brain area involved in the inhibition of intentional actions through a top–down signal gating of the neural pathways linking intention to action.

Even though Brass and Haggard's (2007) study seemed to have offered substantial evidence to vindicate the existence of the conscious veto, it did not offer support for Libet's other proposal of the veto operating within a time span of about 150 ms before movement. This time span for vetoing action did not seem to apply to some patients with parietal lobe lesions who reported the onset of intention to be as late as 50 ms prior to action execution (Sirigu et al., 2004).[8] If exercising the conscious veto is as crucial as what Libet purported it to be, those patients would have an almost negligible amount of time to evaluate their spontaneous intentions and inhibit unwanted ones. Yet there were no reports of patients being unable to make and change their motor decisions.

Consequently, this absence of converging evidence for the temporal range in which the conscious veto occurred led other researchers to propose that the motor decision-making time in the Libet experiments could be influenced or modulated by the "attention to the intention to move" (see Lau, 2009; Lau, Rogers, and Passingham, 2006; Pockett and Purdy, 2010). By interpreting Libet's results with referral to the doctrine of *prior entry*, which stipulated that attended stimuli must be perceived prior to unattended stimuli (Shore, Spence, and Klein, 2001), Lau (2009) suggested that in the Libet experiments attention to the intention to move might have acted as an endogenous cuing process, biasing participants' self-reports of response times to be earlier than what were recorded based on their motor movements. This suggestion was backed up by findings from an fMRI study by Lau et al. (2006) that involved the same Libet-type clock as the one utilized previously by Lau et al. (2004). This follow-up study involved a 2 x 2 factorial design with timing and modality as the independent variables. The timing variable involved "timing" and "nontiming" conditions while the modality variable involved "action" (i.e., pressing keys) and "auditory" (i.e., hearing tones) conditions. In all four conditions, the participants gazed at an unnumbered Libet-type clock that had a red dot revolving around its clock face at 2560 ms per cycle and gauged the location or time of the final appearance of the dot. On each trial of the *action timing* condition, the participants observed one revolution of the dot and made a spontaneous button press while noting the location of the revolving dot, which disappeared shortly after the button press. When the red dot reappeared at the clock's center after a variable delay, the participants operated a game pad and moved the dot to where it was located before they pressed the button. The spatial difference between this manually shifted location and the dot's precise location during the onset of the button press was translated into a temporal difference based on the rule of 1° = 7.1 ms. In the *action nontiming* condition, the dot disappeared after just one revolution; it only reappeared at a random location on the clock face after the participant pressed a button. The participants had to remember this location and subsequently relocate the dot from the clock's center after a delay based on

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[8]This relatively late onset of the intention to move was also biased by the fact that the patients with parietal lobe damage were much better at judging the time of actual movement than the time in which the intention to move first arose.

the same (aforementioned) procedure. The *auditory timing* and *auditory nontiming* conditions followed the events from the action timing and action nontiming conditions, respectively, except that no spontaneous button presses and relocation of the dot were involved. A tone sounded before the disappearance of the dot at the end of each trial, and the participants reported their estimated time of the tone's onset.

Based on a whole-brain analysis that yielded Fourier series (i.e., general sinusoidal waveforms) of BOLD signal changes over a period of 16 seconds after the onset of time estimates, Lau et al. (2006) found a significant interaction between timing and modality from activation in the cingulate motor area (CMA), an area that falls below the supplementary motor area (SMA) [i.e., the posterior part of the anterior cingulate cortex (ACC)]. Specifically, significantly greater activation in the CMA was derived from contrasting the action timing condition against the action non-timing condition but not from contrasting the auditory timing condition against the auditory nontiming condition. Lau and colleagues also computed a BOLD modulation measure for the CMA and showed that it was negatively and significantly correlated with the perceived time of onset. This implicated that greater CMA activation was associated with greater negative time estimates showing a perception of button presses that occurred earlier than their actual onsets (i.e., the exact time of pressing the buttons). Critically, Lau et al. (2006) did a reanalysis of their previous data on the pre-SMA (collected by Lau et al. [2004]) and found the same negative correlation to exist between the BOLD modulation measure for the pre-SMA and the perceived onset of intention. Based on these findings, Lau and colleagues suggested that the change in CMA activity could be best understood as attentional modulation brought about by the need for in-depth processing of the information required for action execution. The participants were suggested to make use of this increased activity in the CMA to time their movements. As for activity in the pre-SMA, the authors suggested that it was modulated by the amount of attention devoted to the intention to execute a motor act, and that their earlier finding of 228 ms being the average perceived onset before a button press might have been due to early and full attention to the intention to act on the part of their participants. Therefore, neuromodulation in both the CMA and the pre-SMA leading to individual variability in the temporal perception of action onsets could explain why the onset of intention does not always have to emerge within Libet's proposed period of 250 ms prior to action.

In addition, the relevance of attention for motor decision is also supported by findings from a Libet-type experiment by Pockett and Purdy (2010). During "decision" trials in which the participants were instructed to decide on the correct key to press after summing up a pair of numbers displayed at the center of the Libet clock, some participants either did not exhibit any RP or exhibited RPs that tended to start at the same time as their self-reported decision time. Pockett and Purdy (2010) explained these peculiar findings by suggesting that the attention of participants in the time period before action execution was completely taken up by performing the additions. Thus, their attentional focus on the arrival of any spontaneous urge was undermined, leading to the absence of RPs. Importantly, the authors proposed that the RPs found by Libet and colleagues might be more reflective of general readiness or expectancy rather than specific preparation for movement. They argued that Libet-type experiments could demonstrate the ERPs that engendered urge-related movements but could not relate these ERPs to conscious or unconscious decision-making.

Recent Developments

Pockett and Purdy's (2010) argument that antecedent brain signals could not be related to specific motor preparation or the intention to act was countered by findings from a study by Fried, Mukamel, and Kreiman (2011) that applied microelectrode recordings of neuronal activities in the human medial frontal cortex. Fried et al. (2011) adopted Libet et al.'s (1983) paradigm; aside from two changes entailed by: (i) using an analog clock that had a revolving hand instead of one with a light spot moving along the circumference, and (ii) instructing participants to press keys instead of making wrist movements, the main procedures were kept the same. The researchers planted depth electrodes into the frontal and temporal lobes of 12 epileptic patients and recorded extracellular activity from 760 units (264 single units and 496 multiunits) in the medial frontal lobe, comprising the anterior cingulate cortex (ACC) [BA 24/32], the pre-SMA, and the SMA proper, as well as from 259 units in the temporal lobe. Similar to what Libet et al. (1983) found, Fried et al. showed that the onset of conscious awareness — the will or wish (*W*) to elicit a spontaneous motor act — occurred at an average of 193 ms prior to the key press. Notably, during the 400 ms interval prior to *W*, 17% of all the recorded units in the medial prefrontal cortex exhibited changes in firing rate from the baseline firing rate (recorded from 2500 to 1500 ms before *W*), and this proportion was larger than the 13% of recorded units that exhibited changes in firing rate after *W*. In particular, neurons that increased and decreased their firing rates prior to *W* were found. The former was dubbed "increasing" neurons, and the latter "decreasing" neurons. When comparing the response profile of the increasing neurons between the frontal and temporal lobes, the proportion of responsive neurons demonstrating steady increases in firing rate prior to *W* was markedly higher in the medial frontal lobe (comprising the anterior cingulate cortex, the pre-SMA, and the SMA proper) than in the medial temporal lobe. To determine whether the neuronal activity in the medial frontal lobe had any causal relationship with the onset of *W*, Fried and colleagues applied a support vector machine (SVM) classifier (see Hung, Kreiman, Poggio, and DiCarlo, 2005) to discriminate between neuronal activity before *W* and baseline activity in single trials. In machine learning, support vector machines are supervised learning models associated with learning algorithms that are used for categorization and regression analysis. Given a reference or training data set, which in Fried et al.'s study pertained to the recorded activity of a population of neurons chosen at a certain time before the onset of *W*, the support vector machine training algorithm built a model that enabled the categorization of other ensembles of neurons based on whether they were activated before or after *W*. Overall, this linear algorithm predicted the neuronal onset of *W* (i.e., the readiness potential) to occur at an average of 152 ms prior to the self-reported onset of *W*. Fried and colleagues interpreted these findings as suggestive of an "integrate-and-fire" mechanism that integrates the firing of ensembles of medial frontal neurons until a threshold is reached for the emergence of the intention to act. Despite showing that changes in the firing rates of medial frontal neurons could predict the early onset of *W*, the authors remained circumspect and refrained from passing judgment about whether the neuronal changes detected by them in the medial frontal lobe *caused* the emergence of volition. More recent evidence by Schultze–Kraft et al. (2016) showed that the conscious veto could be exerted after the onset of the RP, but it must be exerted within a short period that occurred less than 200 ms before movement onset in order to enable movement cancellation. In other words, this means that conscious control over a spontaneous act cannot be exercised after passing the mark of 200 ms before movement onset — a so-called "point of no return" (Schultze–Kraft et al., 2016). This suggests that the conscious veto is very transient in nature and must be exercised immediately after RP onset in order to abolish any movement of interest.

Critically, Fried et al.'s (2011) findings resonated with a series of fMRI studies conducted by Soon and colleagues (Bode et al., 2011; Soon, Brass, Heinze, and Haynes, 2008; Soon, He, Bode, and Haynes, 2013; for a commentary, see Soon, Allefeld, Bogler, Heinzle, and Haynes, 2014). All of these studies utilized multi-voxel pattern analysis (MVPA) on spatiotemporal patterns of brain activity acquired from Libet-type experiments. Multivoxel pattern analysis focuses on multiple volumetric brain pixels ("multivoxels") instead of single volumetric brain pixels ("voxels") and applies relevant pattern classification algorithms to decode the multivoxel patterns of activity occurring at certain timepoints; as such, these patterns were regarded as spatiotemporal in nature (for details about the benefits and technical nuances of MVPA, see Norman, Polyn, Detre, and Haxby, 2006). In the first of these studies, Soon et al. (2008) showed the participants slides of single consonants separated by intervals of 500 milliseconds and instructed the participants to make spontaneous button presses with either their left or right hand whenever they felt the urge to do so. A screen with four consonants appeared after each spontaneous button press, and participants had to select the consonant that corresponded to the moment in which they made their motor decision. By using the same type of SVM classifier that Fried et al. (2011) used to predict the type of spatiotemporal pattern of brain activity associated with either a left or right button press, Soon et al. (2008) showed that neuronal activity in the frontopolar cortex (BA 10) and precuneus/posterior cingulate region (BA 7) preceded the onset of motor decision by as long as seven seconds (!). The duration of seven seconds was particularly surprising and groundbreaking at the time of its discovery because it far exceeded Libet's (1985) 300 ms interval that separated the onset of the RP and the first conscious decision to move. In order to clarify the roles of the frontopolar cortex and the precuneus, Soon et al. (2008) also conducted a control fMRI experiment that instructed participants to decide on making a left or right button press when shown a verbal cue of "select," and to respond after a variable interval when shown another verbal cue of "respond." The classification algorithm predicted neuronal activity in the frontopolar cortex with higher classification accuracy than in the precuneus during the selection phase and showed the reverse trend during the response phase, culminating in a double dissociation. These findings led the authors to suggest the frontopolar cortex as the initiator of unconscious processing of motor decisions and the precuneus as the temporary storage site of the motor decision before it reached consciousness:

> The temporal ordering of information suggests a tentative *causal* model of information flow, where the earliest unconscious precursors of the motors decision originated in frontopolar cortex, from where they influenced the buildup of the decision-related information in the precuneus and later in SMA, where it remained unconscious for up to a few seconds. (Soon et al., 2008, p. 545, italics added)

Regardless of the promising findings, there was a noticeable pitfall in the study, as pointed out by Haynes (2010). This pertained to the ostensibly low level of an average classification accuracy of 60% predicting decisions in the respective cortical sites; even though the 60% accuracy rate was reliable, it was far from perfect. The spatiotemporal resolution provided by a conventional 3T fMRI scanner can only offer a limited amount of the broader information that could be gained based on a more direct measurement of the activity of frontal lobe neurons based on microelectrode recordings, as Fried et al. (2011) subsequently demonstrated. Undeterred by this technical limitation, Soon and Haynes, together with a new team of researchers (Bode et al., 2011), re-conducted their study using ultra-high field fMRI (7T scanner) on the frontopolar cortex and replicated their original findings. Based on improved spatial and temporal resolution, the authors showed that the earliest time at which successful decoding (i.e., classification of neuronal ensembles based on whether or not they cohere with the spatiotemporal patterns associated with an upcoming motor decision) was possible was about 7.5 seconds before a decision was reported to be consciously made, which was slightly earlier than the seven seconds found by Soon et al. (2008). Like the previous study, the classification accuracy for upcoming motor decisions from the frontopolar cortex was not remarkably high during this interval of 7.5 seconds, ranging from 52% to

57%. Nonetheless, the fMRI results were supported by post-experimental surveys collected from the participants, who generally reported that they had been very relaxed and spontaneous in their actions, harboring no specific thoughts during the experiment. The successful replication of the earliest onset of neuronal activity in the frontopolar cortex led the authors to propose this region as a core area for free decisions, one that lies at the top of a hierarchically organized prefrontal functional network.

To test the notion that the frontopolar cortex was indeed involved in the early processing of free decisions that were varied in nature and not limited by motor decisions, a follow-up fMRI study was performed to investigate how the frontopolar polar cortex and the precuneus were involved in the early processing of voluntary arithmetic decisions that incorporated additions and subtractions (Soon et al., 2013). The decision to add or subtract numbers was seen by the authors as a higher-level and more abstract type of decision compared to the decision to make a spontaneous key press. The participants viewed a series of slides with four digits placed at the corners and a digit at the center with a consonant placed below it. Whenever the participant felt ready to carry out an arithmetic decision, he attended to the digit at the center of the screen and either added or subtracted the centered digit appearing on the next slide. On the third slide, the participant pressed one of the four buttons that corresponded to the spatial locations of the digits at the corners of the slide. Two of those digits conveyed the right answers to the addition and subtraction, respectively; their positions randomly changed from corner to corner on each slide. After making the button press that indicated whether an addition or a subtraction was performed, a slide with four consonants appeared, and the participant selected the consonant that matched the consonant seen on the earliest slide during which he initially made his voluntary decision to perform the arithmetic task. SVM classifiers were used once more, and were trained to distinguish between the spatiotemporal patterns of brain activity related to addition and subtraction. The results showed that a medial frontopolar region (within (BA 10) and a region straddling the precuneus (BA 7) and the posterior cingulate cortex (BA 23/31) encoded the outcome of the impending decision about four seconds prior to its realization. Once more, like in the previous two studies, the classification accuracies were around 60%. Notably, the time-course of classification accuracies partially overlapped with the time-course of activation in the “default mode” network, an interconnected brain system (spanning the fronto-parietal axis) that is usually activated when the individual is generating spontaneous thoughts without focusing on signals from the outside world (e.g., thoughts generated during mind-wandering; see Buckner, Andrews–Hanna, and Schacter, 2008). Critically, the default mode activity and the level of classification accuracy in the frontopolar and precuneus/ posterior cingulate regions were found to peak at around the same time of four seconds prior to conscious decision. This overlap was seen by Soon et al. (2013)

as supportive evidence for the notion that preparatory neuronal activities in the frontal and parietal regions were reflective of unconscious processes. Importantly, the authors suggested that the relatively shorter period of neuronal activity generated for the upcoming arithmetic decision might showcase the limitations of unconscious processes in developing and stabilizing more complex representations stemming from abstract intentions. These intentions pertain to arithmetics and other higher-level mental operations.

Discussion

Taken together, we get to see that an assembly of areas in the frontal lobe of the brain — namely the pre-SMA, the SMA (both part of BA 6), the anterior cingulate cortex (BA 24), the medial prefrontal cortex (BA 9), and the frontopolar cortex (BA 10) [in a caudal to rostral direction] — are implicated to be involved in engendering the intention or volition to commit a motor act prior to an individual becoming fully conscious of the intention and then performing the act. The works by Lau and colleagues supported the pioneering works of Libet and colleagues by putting emphasis on the "attention to the intention to act" as the driving "force" that brought about activation in the pre-SMA and anterior cingulate cortex. Fried et al. (2011) applied the fine-grained approach of microelectrode recordings and demonstrated that neurons in these brain regions were indeed active before the time at which one became conscious of the wish to act (*W*). However, they are much more restrained in the interpretations of their findings compared to Soon and colleagues, who appeared to be advocating for a causal trajectory of neural events that stemmed from early neuronal activity in the frontopolar cortex (Bode et al., 2011; Soon et al., 2008). It is crucial to note that Soon and colleagues did not implement the Libet-type CRO clock paradigm, nor did they analyze their data based on conventional indicators of neural activity (i.e., BOLD signals, neuronal firing patterns). Principally, they applied a computationally demanding technique of MVPA to see how the spatiotemporal activity patterns of an ensemble or population of neurons (i.e., clusters of 3D volumetric pixels) captured at a time before the onset of a motor decision could predict the likelihood of the decision's impending occurrence. Surprisingly, they found that such a prediction could occur beyond a 50% chance in as long as seven seconds before a simple act of pressing buttons (Bode et al., 2011; Soon et al., 2008), and in about four seconds before deciding to perform an arithmetic problem by pressing a button (Soon et al., 2013). Despite arguing for unconscious processes as the harbinger of the will to act, with respect to higher-level thinking and reasoning (of which doing mental arithmetic is a part), Soon et al. (2013) were not able to ascertain whether unconscious and conscious representations could be subserved by the same substrates within the frontal and parietal regions or whether such representations could be separated at a finer scale. Therefore, future studies, as Soon et al. (2013) proposed, should consider using tasks that elicit conscious and non-conscious/automatic decisions, along with the training of classification algorithms to predict these two types of decisions based on spatiotemporal patterns of pre-movement neuronal activity. This proposal was consistent with that of Fried et al. (2011), who recommended future investigations of the firing profiles of neurons in the parietal cortex *before* and *after* the emergence of conscious intention, so as to better understand the mechanisms of conscious and unconscious processes.

Unresolved Issues and Future Directions

The aforementioned proposals showed that we are merely at the tip of the iceberg in our modern endeavors to understand the nature of consciousness. Despite the technological benefits offered by modern neuroimaging techniques, we are still unclear about how to differentiate between conscious and unconscious processes and their underlying neural substrates. Critically, the proposals for future research by Soon, Fried, and their colleagues show that it is still too early to interpret what an early onset of neuronal activity prior to the onset of a motor decision truly means. And supposing that unconscious (or subconscious) motor pre-planning indeed occurred seven seconds before the act, when and how would Libet's notion of the conscious veto apply — considering these words of Libet (1999)?

> Some have proposed that even an unconscious initiation of a veto choice would nevertheless be a genuine choice made by the individual and could still be viewed as a free will process (e.g., Velmans, 1991). I find such a proposed view of free will to be *unacceptable*. In such a view, the individual would not consciously control his actions; he would only become aware of an unconsciously initiated choice. He would have no direct conscious control over the nature of any preceding unconscious processes. But, *a free will process implies one could be held consciously responsible for one's choice to act or not to act*.[9] (p. 52, emphases added)

Based on this account, it is possible that Libet would have disagreed with Soon et al.'s, (2008) interpretation of tracing the origin of voluntary acts — a representation of free will in action — to unconscious origins. Consequently, this beckons us to question what being unconscious truly means. Does it refer to a superficial form of unawareness (i.e., a state in which information for global control is either not fully available or fully processed [Chalmers, 1995]) that is divorced from underpinning neurophysiological activity — or does it refer to a full-fledged abandonment of attention or intentionality that eschews any reflection on its phenomenological

[9]Ensuing discussions of "free will" shall follow Libet's conception. Specifically, "free will" shall be defined as "the power of an individual to make free choices, not determined by divine predestination, the laws of physical causality, fate, etc." ["free will, n." (2017, March 25). *Oxford English Dictionary Online*. Retrieved from http://www.oed.com/view/Entry/74438?redirectedFrom=free+will]

contents (i.e., an abandonment of the state/event consciousness, with the subject having no access to her internal mental state [Lycan, 1987, 1996])? There is certainly a yearning for a clearer conception of what the "contents" of a conscious (or unconscious) mental state may be, as shown by the caveat raised by Libet (1999) on the distinction between awareness and its contents:

> Our own previous studies have indicated that *awareness* is a unique phenomenon in itself, distinguished from the *contents of which one may become aware*. For example, awareness of a sensory stimulus can require similar durations of stimulus trains for somatosensory cortex and for medial lemniscus. But the *content* of those awarenesses in these two cases is different, in the subjective timings of sensations (Libet *et al.*, 1979). The content of an unconscious mental process (e.g. correct detection of a signal in the brain *without any awareness* of the signal) may be the same as the content *with awareness* of the signal. But to become aware of that same content required that stimulus duration be increased by about 400 msec (see Libet *et al.*, 1991). (Libet, 1999, p. 53, emphases added)

By this account, Libet implied brain-related activity was an instance of the "content of which one may become aware." With regard to the studies of Soon and colleagues, this content could refer to the classification accuracies of the neuronal ensembles. The classification accuracies shown immediately before and after the motor decision matched each other at approximately the same level (Soon et al., 2008), and buttressed Libet's idea of invariant content irrespective of the state of awareness.[10] Hence, the possibility remains for future research to endorse MVPA classification accuracies as potential *observable* representations of the contents of awareness that is distinct from the condition of "being aware." Furthermore, from a conceptual standpoint, Libet's contents of conscious awareness may be conceived as analogous to the contents of higher-order perception engendered by the evaluation of our perceptual experiences (cf. Armstrong, 1968; Lycan, 1996).[11] Since the attainment of any "higher-order" status implies a hierarchy of levels or events, this analogy begs the question of whether being aware could be understood as a subtle progression of mental events leading to the emergence of conscious awareness.

In order to examine what "being aware" connotes, it may be pertinent for future researchers to consider the process of voluntary movement as arising out of several stages of awareness, flowing from (i) a state of total non-awareness of impending movement, to (ii) a state of intentionality contingent on the availability of probes/

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[10] For a graphical illustration of the matching of the classification accuracies, the reader is advised to refer to Figure 2 in Soon et al.'s (2008) article.

[11] This notion ascribes to the theory of higher-order perception that was first proposed by Locke (1690). This theory is also called the "inner sense theory," stipulating that a higher-order, non-conceptual, and intentional state can engender a phenomenally conscious state via a faculty of "inner sense." This "inner sense" refers to our innate capacity to construct mental representations based on first-order perceptual awareness (i.e., the availability of information from the sensory modalities).

cues, to (iii) a state of meta-awareness (akin to the onset of the conscious will [*W*] based on Libet's paradigm, emerging around 250 ms before movement, which is slightly beyond a full-fledged state of awareness following movement onset), and to (iv) a final point of no return after which the motor act cannot be vetoed (i.e., 200 ms before movement, according to Schultze–Kraft et al., 2016; see also Matsuhashi and Hallett, 2008; Smallwood and Schooler, 2006). However, owing to the fact that this proposal of awareness progression (Matsuhashi and Hallett, 2008) stemmed from a veto paradigm (i.e., vetoing finger extensions after hearing tones that coincided with the conscious intention to move) that deviated substantially from Libet's CRO clock paradigm and engendered a much earlier time at which the thought to move arose (1.42 seconds before movement, more than a second earlier than Libet's *W*), it cannot be applied unequivocally to explain the findings of Libet et al. (1982, 1983). Even though the onset of Type I RP (about 1000 ms before movement) recorded in Libet et al.'s studies would have conformed to Matsuhashi and Hallett's (2008) proposed stage of intentionality, the ensuing onset of Type II RP, interpreted as a marker of an absence of pre-plans, would not have fit well with the same stage. This is due to the absence of any auditory signals in the CRO clock paradigm that would have served as potential probes or cues for awareness. Nonetheless, the vetoing of pre-plans to act based on hearing tones does have an advantage over Libet's paradigm in that it relies on real-time decisions rather than on post-event subjective recall and potential latency lapses in reading the dot's position on the CRO clock. Therefore, it would be best to approach Matsuhashi and Hallett's (2008) stages of awareness progression as a paradigm-specific model that addresses the timing of the intention to move in terms of the conscious veto.[12]

Interestingly, an operation of the veto paradigm in reversed mode (i.e., making immediate responses instead of abolishing them) can be seen from a *Libetus Interruptus* paradigm that was designed to test the validity of an accumulator stochastic decision model of the neural decision to move (Schurger, Sitt, and Dehaene, 2012). This paradigm was derived from the CRO clock paradigm and was similar in all aspects except that it further required participants to respond spontaneously (i.e., pressing a button immediately) whenever they heard a clicking sound. The findings based on this paradigm showed that the neural decision to move came at a time closer to the actual movement (about 150 ms before movement) compared to Libet's *W* (about 250 ms before movement) and was preceded by a gradual negative-going voltage deflection that reflected the buildup of the mounting urge to move. When comparing neural decision times of movement obtained from the *Interruptus* and veto paradigms to Libet's *W*, the former paradigm yielded a noticeably smaller temporal difference (around 100 ms) than the latter paradigm (around 1.2 seconds). The same pattern of temporal differences could be seen

[12]This type of theoretical model ought to account for analogous patterns of findings replicable under similar experimental conditions, in which the task stimuli and instructions are kept largely invariant.

when the neural decision times obtained by Bode et al. (2011), Soon et al. (2008, 2013), Lau et al. (2004, 2006), and Fried et al. (2011) were compared to Libet's *W*. The first set of comparisons (involving studies by Bode, Soon, and colleagues) yielded differences on the scale of several seconds (for as large as 6.75 seconds when considering Soon et al.'s [2008] MVPA findings) whereas the latter set of comparisons (involving studies by Lau, Fried, and colleagues) yielded differences on the scale of tenths of milliseconds. In conjunction, these pieces of evidence showed that close variants of Libet's CRO clock paradigm (Fried et al., 2011; Lau et al., 2004, 2006; Schurger et al., 2012) generated less discrepancy in terms of pre-movement neural decision times than other voluntary decision paradigms that did not implement the same testing interface (Bode et al., 2011; Matsuhashi and Hallett, 2008; Soon et al., 2008, 2013). This suggests that the qualitative aspects of an experimental paradigm should be considered when constructing any model or theory that attempts to explain the neural precursors of any conscious decisions or acts. Such aspects centrally pertain to the cues/probes (if any) for conscious decision-making and movement, the modality of stimuli presentation, task-related instructions, demand characteristics, and their relevant control procedures.[13]

More importantly, based on the premise that analogous experimental paradigms/tasks are more likely to yield results that can be framed under a common theory compared to dissimilar or distinct paradigms, it may be worthwhile for future investigators of pre-movement neuronal activity to construct models or theories that are paradigm-specific.[14] Each of these models/theories, being centered on a distinctive paradigm, is likely to contribute to a more nuanced elucidation of the relationship between pre-movement neuronal signals and the contents or stages of awareness. Principally, they should serve the purpose of explaining the inconsistent occurrences of *W* that were found based on different experimental paradigms. Over time, an accumulation of such theories offers the potential to generate a standard or integrated framework that could explain the same neurophysiological phenomenon across different experimental contexts or modes of testing.

Conclusion

We have come a long way since Libet's first experiments demonstrating the presence of cortical activity prior to voluntary acts, and have obtained greater insights into the underlying neural activities, localized to the frontal and medial regions of the brain, through modern neuroscience techniques. However, a complete picture

[13] As defined by Orne and Whitehouse (2000, pp. 469–470), demand characteristics refer to "the totality of cues and mutual expectations which inhere in a social context…which serve to influence the behaviour and/or self-reported experience of the research receiver."

[14] This is contingent on the similar paradigms/tasks being comparable in terms of operation, tools/equipment for task presentation, and modes of data analysis.

of the relationship between a motor act and its neural precursors remains elusive, and more work can be conducted to relate different stages of awareness (or non-awareness) to the different patterns of neuronal activity preceding a movement, preferably with regard to different types of paradigms devised for investigating such pre-movement activity. Ultimately, much more work needs to be done to uncover the hidden mysteries of our consciousness before we launch a thorough intellectual discussion of what being conscious truly means. Until we do so, it is important that we abstain from adopting a bipolar stance regarding the origin of our conscious thoughts and behavior — that is, to characterize these origins as either totally deterministic (i.e., aligned with universal physical laws) or totally non-deterministic (i.e., conforming to imperceptible phenomena that violate physical laws) [Libet, 2004]. As Nahmias (2011) rightly points out, determinism is typified by prior events causing present events founded upon universal physical laws, and should *not* be taken to mean that a person's beliefs, desires, and decisions have no purpose for what one tries to do. Through the survey studies by Nahmias, Morris, Nadelhoffer, and Turner (2005, 2006), the "problem" in linking determinism and free will together has been ascribed to individual differences in the comprehension of whether or not our beliefs, desires, and decisions can be eschewed (or "bypassed," as Nahmias et al. [2005, 2006] termed it) when generating actions. Determinism does not have to be regarded as incompatible with free will so long as we do not endorse a fatalistic view of the world (i.e., a whatever-happen-will-happen mentality) [Nahmias, 2011; Nahmias et al., 2005, 2006; Nahmias and Murray, 2010].[15] If future consciousness researchers and theorists are willing to consider the multifarious differences in belief systems that different organisms endorse with respect to their perceptions of reality, it is very likely that we shall gradually learn to reconcile deterministic events with our deliberations and decisions that mark the cornerstones of free will.[16]

Regardless of the direction chosen for further research, it would be prudent to heed the following advice:

> My conclusion about free will, one genuinely free in the nondetermined sense, is that its existence is at least as good, if not a better, scientific option than is its denial by natural law determinist theory. Given the speculative nature of both determinist and nondeterminist theories, why not adopt the view that we do have free will (until some real contradictory evidence appears, if it ever does)? Such a view would at least allow us to proceed in a way that accepts and accommodates our own deep feeling that we do have free will. (Libet, 2004, p. 156)

[15]Conversely, people could be induced to think that determinism and free will are incompatible when they are instructed to believe that they live in a totally deterministic universe, in which each decision they make must happen in a predetermined way (Nahmias et al., 2005, 2006; Nahmias and Murray, 2010).

[16]In the real world, the need for reconciliation between the laws of determinism and the notions of free will is of invaluable import with regard to law and justice. Legal responsibility is inadvertently tied to free will, and a denial of free will in favor of deterministic elements or events could cause unfavorable impediments or difficulties in the evaluation of eyewitness testimonies and the sentencing of criminals (see Rychlak and Rychlak, 1997).

Perhaps this sums up Libet's legacy — that we must neither conform to a dogmatic view of consciousness nor lose faith in our quest to discover the origin and mechanisms of consciousness. Many untrodden paths in consciousness research awaits us, and we must journey on with courage and open hearts.

References

Armstrong, D. (1968). *A materialist theory of the mind*. London: Routledge.

Baars, B. (1988). *A cognitive theory of consciousness.* Cambridge: Cambridge University Press.

Block, N. (1995). On a confusion about the function of consciousness. *Behavioral and Brain Sciences*, 18, 227–247.

Bode, S., He. A. H., Soon, C. S., Trampel, R., Turner, R., and Haynes, J. D. (2011). Tracking the unconscious generation of free decisions using ultrahigh field fMRI. *PLoS ONE*, *6* (6): e21612. doi: 10.1371/journal.pone.0021612

Brass, M., and Haggard, P. (2007). To do or not to do: The neural signature of self-control. *Journal of Neuroscience, 27*, 9141–9145.

Breitmeyer, B. G. (1985). Problems with the psychophysics of intention. *Behavioral and Brain Sciences, 8*, 539–540.

Buckner, R. L., Andrews–Hanna, J. R., and Schacter, D. L. (2008). The brain's default network: Anatomy, function, and relevance to disease. *Annals of the New York Academy of Sciences*, *1124*, 1–38.

Chalmers, D. J. (1995). Facing up to the problem of consciousness. *Journal of Consciousness Studies*, *2*, 200–219.

Crick, F., and Koch, C. (1998). Consciousness and neuroscience. *Cerebral Cortex*, *8*, 97–107.

Crick, F., and Koch, C. (2003). A framework for consciousness. *Nature Neuroscience*, *6*, 119–126.

Davidson, D. (1963). Actions, reasons, and causes. *The Journal of Philosophy*, *60*, 685–700.

Fried, I., Mukamel, R., and Kreiman, G. (2011). Internally generated preactivation of single neurons in human medial frontal cortex predicts volition. *Neuron*, *69*, 548–562.

Glynn, I. M. (1990). Consciousness and time. *Nature, 348*, 477–479.

Gomes, G. (1998). The timing of conscious experience: A critical review and reinterpretation of Libet's research. *Consciousness and Cognition, 7*, 559–595.

Gomes, G. (2002). The interpretation of Libet's results on the timing of conscious events: A commentary. *Consciousness and Cognition, 11*, 221–230 [Discussion, 308–325].

Haggard, P., and Eimer, M. (1999). On the relation between brain potentials and the awareness of voluntary movements. *Experimental Brain Research*, *126*, 128–133.

Haynes, J. D. (2010). Beyond Libet: Long-term prediction of free choices from neuroimaging signals. In W. Sinnott–Armstrong and L. Nadel (Eds.), *Conscious will and responsibility: A tribute to Benjamin Libet* (pp. 85–96). New York: Oxford University Press. doi: 10.1093/acprof:oso/9780195381641.003.0009

Hung, C. P., Kreiman, G., Poggio, T., and DiCarlo, J. J. (2005). Fast readout of object identity from macaque inferior temporal cortex, *Science*, *310*, 863–866.

Keller, I., and Heckhausen, H. (1990). Readiness potentials preceding spontaneous motor acts: Voluntary vs. involuntary control. *Electroencephalography and Clinical Neurophysiology*, *76*, 351–361.

Kornhuber, H. H., and Deecke, L. (1965). Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale. *Pfliigers Archiv für die Gesamte Physiologie des Menschen und der Tiere*, *284*, 1–17.

Lau, H. (2009). Volition and the function of consciousness. In N. Murphy, G. Ellis, and T. O'Connor (Eds.), *Downward causation and the neurobiology of free will* (pp. 153–169). Chennai: Springer Verlag.

Lau, H. C., Rogers, R. D., Haggard, P., and Passingham, R. E. (2004). Attention to intention. *Science*, *303*, 1208–1210.

Lau, H. C., Rogers, R. D., and Passingham, R. E. (2006). On measuring the perceived onsets of spontaneous actions. *Journal of Neuroscience*, *26*, 7265–7271.

Levy, N. (2005). Libet's impossible demand. *Journal of Consciousness Studies*, *12*, 67–76.

Libet, B. (1985). Unconscious cerebral initiative and the role of conscious will in voluntary action. *Behavioral and Brain Sciences*, *8*, 529–566.

Libet, B. (1989). Conscious subjective experience vs. unconscious mental functions: A theory of the cerebral processes involved. In R. M. J. Cotterill (Ed.), *Models of brain function* (pp. 35–50). New York: Cambridge University Press.

Libet, B. (1993). The neural time factor in conscious and unconscious events. In G. R. Block and J. Marsh (Eds.), *Experimental and theoretical studies of consciousness* (pp. 156–179). Chichester: John Wiley and Sons.

Libet, B. (1999). Do we have free will? *Journal of Consciousness Studies*, *6*, 47–57.

Libet, B. (2000). Time factors in conscious processes: Reply to Gilberto Gomes. *Consciousness and Cognition*, *9*, 1–12.

Libet, B. (2002). The timing of mental events: Libet's experimental findings and their implications. *Consciousness and Cognition*, *11*, 291–299.

Libet, B. (2004). *Mind time: The temporal factor in consciousness*. Cambridge, Massachusetts: Harvard University Press.

Libet, B., Gleason, C. A., Wright, E. W., Jr., and Pearl, D. K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). *Brain*, *106*, 623–642.

Libet, B., Wright, E. W., Jr., and Gleason, C. A. (1982). Readiness-potentials preceding unrestricted 'spontaneous' vs. pre-planned voluntary acts. *Electroencephalography and Clinical Neurophysiology*, *54*, 322–335.

Locke, J. (1690). *An essay concerning human understanding* (first edition). London: Thomas Bassett.

Lycan, W. (1987). *Consciousness*. Cambridge, Massachusetts: MIT Press.

Lycan, W. (1996). *Consciousness and experience*. Cambridge, Massachusetts: MIT Press.

Matsuhashi, M., and Hallett, M. (2008). The timing of the conscious intention to move. *European Journal of Neuroscience*, *28*, 2344–2351.

Mele, A. R. (2009). *Effective intentions: The power of conscious will*. New York: Oxford University Press.

Nagel, T. (1974). What is it like to be a bat? *Philosophical Review*, 83, 435–456.

Nahmias, E. (2011). Intuitions about free will, determinism, and bypassing. In R. Kane (Ed.), *The Oxford handbook of free will* (second edition, pp. 555–576). New York: Oxford University Press.

Nahmias, E., Morris, S., Nadelhoffer, T., and Turner 1, J. (2005). Surveying freedom: Folk intuitions about free will and moral responsibility. *Philosophical Psychology*, *18*, 561–584.

Nahmias, E., Morris, S. G., Nadelhoffer, T., and Turner, J. (2006). Is incompatibilism intuitive? *Philosophy and Phenomenological Research*, *73*, 28–53.

Nahmias, E., and Murray, D. (2010). Experimental philosophy on free will: An error theory for incompatibilist intuitions. In J. Aguilar, A. Buckareff, and K. Frankish (Eds.), *New waves in philosophy of action* (pp. 189–216). Basingstoke: Palgrave-Macmillan.

Norman, K.A., Polyn, S.M., Detre, G.J., and Haxby, J.V., (2006). Beyond mind-reading: Multi-voxel pattern analysis of fMRI data. *Trends in Cognitive Sciences*, *10*, 424–430.

Orne, M. T., and Whitehouse, W. G. (2000). Demand characteristics. In A. E. Kazdin (Ed.), *Encyclopedia of psychology* (pp. 469–470). Washington, D.C.: American Psychological Association.

Pockett, S., and Purdy, S. C. (2010). Are voluntary movements initiated preconsciously? The relationships between readiness potentials, urges, and decisions. In W. Sinnott–Armstrong and L. Nadel (Eds.), *Conscious will and responsibility: A tribute to Benjamin Libet* (pp. 34–46). New York: Oxford University Press. doi: 10.1093/acprof:oso/9780195381641.001.0001

Rosenthal, D. M. (2002). The timing of conscious states. *Consciousness and Cognition*, *11*, 215–220.

Rychlak, R. J., and Rychlak, J. F. (1997). Mental health experts on trial: Free will and determinism in the courtroom. *West Virginia Law Review*, *100*, 1–38.

Schultze–Kraft, M., Birman, D., Rusconi, M., Allefeld, C., Görgen, K., Dähne, S., Blankertz, B., and Haynes, J. D. (2016). The point of no return in vetoing self-initiated movements. *Proceedings of the National Academy of Sciences, U.S.A.*, *113*, 1080–1085.

Schurger, A., Sitt, J. D., and Dehaene, S. (2012). An accumulator model for spontaneous neural activity prior to self-initiated movement. *Proceedings of the National Academy of Sciences, U.S.A.*, *109*, E2904–E2913.

Searle, J. (1992). *The rediscovery of the mind.* Cambridge, Massachusetts: MIT Press.

Searle, J. R. (1993). The problem of consciousness. *Consciousness and Cognition*, *2*, 310–319.

Shore, D. I., Spence, C., and Klein, R. M. (2001). Visual prior entry. *Psychological Science*, *12*, 205–212.

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

Smallwood, J., and Schooler, J. W. (2006). The restless mind. *Psychological Bulletin*, *132*, 946–958.
Soon, C. S., Allefeld, C., Bogler, C., Heinzle, J., and Haynes, J. D. (2014). Predictive brain signals best predict upcoming and not previous choices. *Frontiers in Psychology*, *5*, 1–3. doi: 10.3389/fpsyg.2014.00406
Soon, C. S., Brass, M., Heinze, H. J., and Haynes, J. D. (2008). Unconscious determinants of free decisions in the human brain. *Nature Neuroscience*, *11*, 543–545.
Soon, C. S., He, A. H., Bode, S., and Haynes, J. D. (2013). Predicting free choices for abstract intentions. *Proceedings of the National Academy of Sciences, U.S.A.*, *110*, 6217–6222.
Trevena, J. A., and Miller, J. (2002). Cortical movement preparation before and after a conscious decision to move. *Consciousness and Cognition*, *11*, 162–190.
Wegner, D. (2002). *The illusion of conscious will*. Cambridge, Massachusetts: MIT Press.
Wegner, D. M., and Wheatley, T. (1999). Apparent mental causation: Sources of the experience of will. *American Psychologist*, *54*, 480–492.