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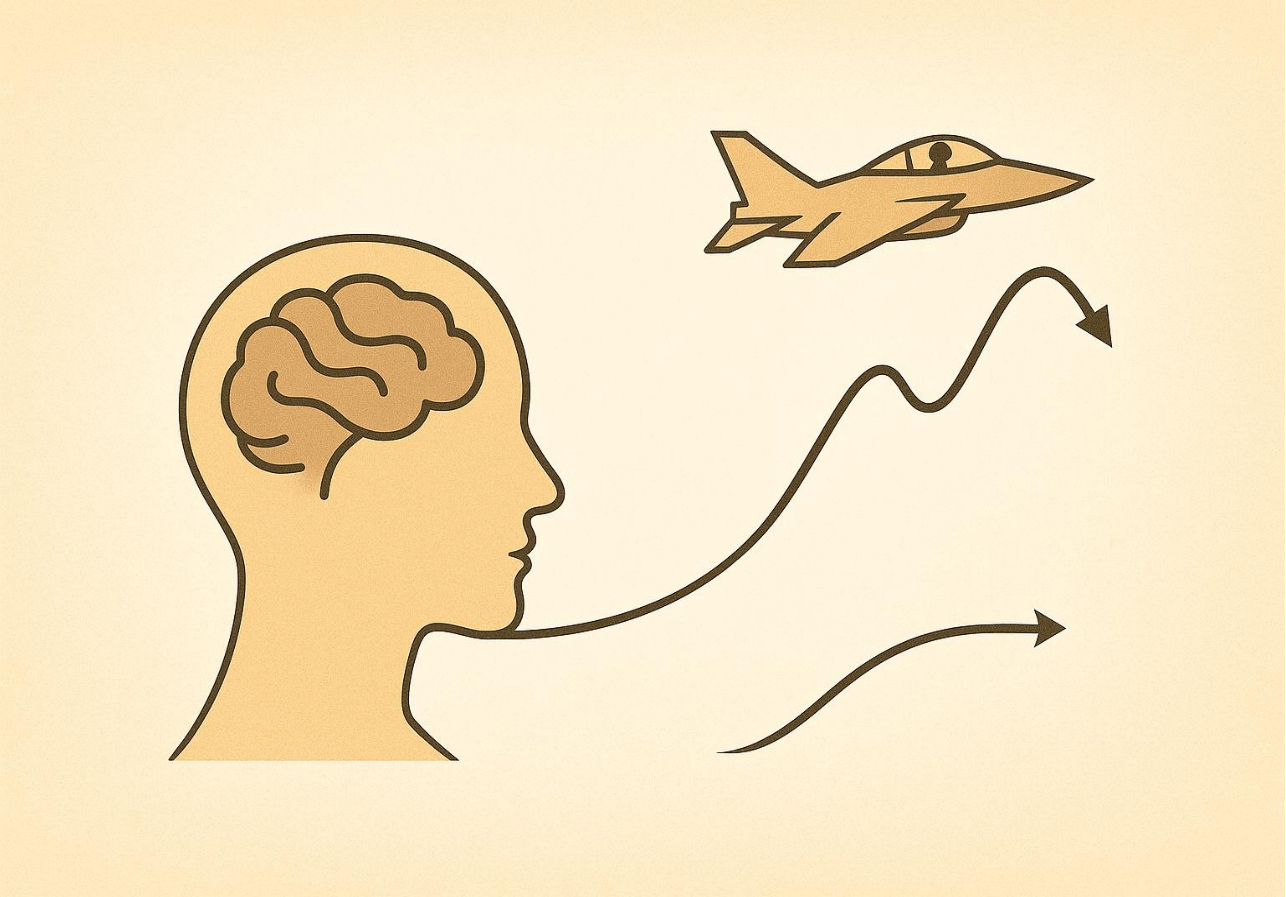

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Libet and the OODA Loop

From Readiness Potential to Situational Awareness

From Readiness Potential to Situational Awareness: The Libet Paradigm as a Neurophysiological Demonstration of the OODA Loop.

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Abstract

This paper reinterprets Benjamin Libet's classic experiments on voluntary action as evidence consistent with a real-time Observe–Orient–Decide–Act (OODA)–style control cycle in the human brain. Libet's original data—readiness potential (RP) preceding reported intention (W) by several hundred milliseconds—have often been taken to challenge free will. Re-examined through predictive-coding and active-inference accounts, these latencies suggest a temporally extended hierarchy of control rather than unconscious determinism. We argue that the RP aligns with an Orient→Decide transition in sensorimotor networks, W marks prefrontal monitoring of an impending commitment, and the late veto reflects rapid inhibitory re-entry via right inferior frontal gyrus–subthalamic pathways. Mapping these dynamics to the OODA framework as a structural homology indicates that volition emerges from recursive perception–action inference that minimises prediction error while retaining capacity for conscious override. Libet's measurements thus illuminate the temporal anatomy of adaptive agency—the milliseconds by which biological control balances speed with evaluative flexibility. This synthesis reframes debates on free will in mechanistic terms, treating freedom as a property of adaptive, self-modifying control loops rather than a metaphysical postulate.

Keywords: *Libet experiment; readiness potential (RP); conscious intention; OODA loop (structural homology); predictive coding; active inference; decision neuroscience; volition; adaptive control; inhibitory control; temporal dynamics of agency.*

Introduction & Background

In the early 1980s Benjamin Libet and colleagues crystallised a deceptively simple question into a laboratory paradigm: *when, in time, does a voluntary act begin?* Using scalp EEG over the vertex (Cz) and a rotating "clock" on an oscilloscope, they asked participants to make a spontaneous wrist/finger flexion at any moment of their choosing, then report the instant they first *felt the urge or intention* to move (the famous "W-time"). Averaging many trials time-locked to muscle activation (EMG), Libet observed a slow negative potential—the Bereitschaftspotential or readiness potential (RP)—that, on average, began roughly 500–600 ms before movement, whereas the conscious urge ("W") was reported only ~200 ms before movement. The headline inference was startling: neural activity associated with initiating an action seemed to precede the conscious intention to act. Libet's follow-up work sharpened the claim but also softened its existential edge: even if initiation is unconscious, consciousness may still exert a late *veto*—"free won't"—in the final 100–200 ms before execution.

Those traces—RP, W, EMG—reframed a centuries-old debate in philosophy within the temporal coordinates of neurophysiology. The initial impact was twofold. First, Libet supplied an empirical anchor for discussions of agency that had been largely conceptual: he gave the field numbers and latencies. Second, the paradigm was transparent and replicable enough to travel; in the decades since, versions of the task have been ported to intracranial recordings, fMRI multivariate decoding, and clever behavioural probes. Each iteration returned to the same tension: does early neural build-up *cause* the act, or does it reflect a preparatory landscape within which multiple outcomes remain possible?

Unsurprisingly, the paradigm ignited controversy on several fronts. **Methodologically**, critics questioned the accuracy of introspective timing. The "Libet clock" requires subjects to read out a fleeting internal event against a fast visual sweep; postdictive reconstruction, attention shifts, and stimulus-response calibration biases all complicate the story. **Physiologically**, others argued that the RP is a population-level average that can hide the real single-trial dynamics. This line culminated in stochastic accumulator accounts, which show that aligning many threshold-crossing events at movement onset naturally produces an apparent ramp—so the RP need not be a dedicated "decision command." **Ecologically**, the task's simplicity (a trivial twitch without stakes) raised worries about generalising to deliberative choices, moral decisions, or extended action sequences. And **conceptually**, the inference from "precedence" to "priority" (or from correlation to causation) was pressed hard: even if unconscious processes start earlier, it doesn't follow that consciousness is epiphenomenal—especially if late inhibitory control can reshape, delay, or cancel the outcome.

Yet the paradigm evolved rather than collapsed under critique. Intracranial studies in medial frontal regions found neurons whose activity rose hundreds to more than a thousand milliseconds before movement; fMRI decoding studies showed that weak biases predictive of left/right choices can be detected seconds before reported awareness; behavioural interrupt paradigms suggested that subjects often lack access to the earliest phases of motor build-up and only become aware once the system is already trending toward threshold. Meanwhile, converging work on stopping and inhibitory control (right inferior frontal gyrus, basal ganglia loops) gave the "veto" a plausible neural substrate. Reviews synthesised these strands into a more nuanced position: volition is extended in time, distributed across interacting networks, and shaped by both spontaneous neural fluctuations and goal-directed constraints. Within this view, consciousness is not a punctual spark that *starts* action, but a supervisory process that samples, endorses, reshapes, or withholds action as internal and external conditions evolve.

This is the context in which we propose to reinterpret Libet's data through the lens of the **OODA loop**—Observe, Orient, Decide, Act. On this view, the readiness potential marks the *Orient–Decide* transition in a continuously running perception–action cycle; the emergence of W reflects conscious alignment with a motor hypothesis approaching commitment; and the veto window instantiates rapid re-entry for mismatch correction before execution. Rather than a challenge to agency, Libet's latencies become measurements of the temporal cost of adaptive control: the brain's ongoing observation and orientation set the stage; deciding and acting unfold under uncertainty; and conscious oversight intervenes when prediction and context require it. In what follows, we develop this thesis, specify testable predictions, and show how the Libet paradigm—augmented with modern single-trial analyses—can serve as a concrete, neurophysiological case consistent with an OODA-style control cycle, testable with modern single-trial analyses.

2 Theoretical Framework

2.1 The OODA Loop as a Universal Control Architecture

The **OODA loop**—Observe, Orient, Decide, Act—was introduced by the US Air Force strategist **John Boyd (1987)** to explain how adaptive systems prevail under rapidly changing conditions. Its genius lies in describing decision-making not as a discrete event but as a *recursive control cycle*: sensory input is continually gathered, contextualised by prior knowledge, integrated into a choice, and translated into action, which in turn reshapes the environment that the next cycle must observe. The loop's speed and accuracy determine the system's survival; its *fluidity* rather than any single decision guarantees success.

When imported into cognitive science, the OODA sequence became a natural metaphor for perception–action coupling, adaptive expertise, and sense-making in dynamic contexts such as combat, sport, and clinical judgment. It also anticipates modern **control-theoretic** and **predictive-processing** models of the brain: the mind is not a serial decision engine but a continuous feedback controller that maintains coherence between internal models and sensory reality. Each loop compresses thousands of neuronal micro-cycles operating at different latencies—from autonomic arousal through limbic evaluation to cortical planning.

In this light, the OODA loop is more than a metaphor: a **useful systems-level descriptor** for neurobiological control dynamics; in what follows we use it **heuristically**, not as an asserted identity.

2.2 Predictive Coding and Active Inference: The Brain as an OODA Engine

Contemporary neuroscience converges on the idea that the brain operates as a **predictive control system**. According to **Friston's Free Energy Principle (2010)**, neural hierarchies minimise prediction error by continuously updating internal generative models. Sensory data constitute the *Observe* phase; cortical and subcortical model comparison forms *Orient*; policy selection within motor and premotor networks corresponds to *Decide*; and motor execution through descending pathways is *Act*.

At every level, feedback from the periphery returns to the sensory cortices, closing the loop. The rate of this cycle varies with domain: fast (tens of milliseconds) for reflexive stabilisation, slower (hundreds of milliseconds) for conscious, goal-directed behaviour. The predictive-coding formalism thus provides a mathematically explicit version of Boyd's intuition: **adaptive intelligence is continuous inference through action**.

2.3 Volition and Temporal Dynamics in the Libet Paradigm

The **Libet experiments** offer an unparalleled window into the temporal unfolding of such inference loops. By synchronising EEG-derived readiness potentials, subjective intention reports, and muscular output, Libet effectively captured one complete perception–action cycle at millisecond precision.

- **Readiness potential (RP)**: slow cortical build-up beginning ~550 ms before movement, localised to the supplementary and pre-supplementary motor areas (SMA, pre-SMA).

- **W-time**: conscious awareness of intention, reported ~200 ms before movement, likely arising from prefrontal–parietal monitoring networks.
- **EMG onset**: overt execution (0 ms), when corticospinal neurons fire the final motor command.

These intervals delineate a natural mapping onto the OODA sequence: *Observe* and *Orient* unfold during the sub-second integration of sensory, limbic, and motor readiness; *Decide* corresponds to the threshold crossing indexed by late RP and the subjective W; *Act* is the motor discharge itself.

2.4 Bridging Decision Theory and Neurodynamics

Recent accumulator and drift-diffusion models (Schurger et al., 2012; Maoz & Schurger, 2022) describe motor initiation as a **stochastic accumulation to threshold**, modulated by attention and motivation. This framework harmonises with OODA's *Decide* phase: evidence builds until a criterion of confidence or urgency is reached. Conscious awareness may emerge when the internal state approaches that threshold—precisely the moment Libet's participants report their intention. The "veto" capability aligns with the inhibitory control circuits of the **right inferior frontal gyrus** and **basal ganglia**, providing a neurophysiological mechanism for rapid re-entry into the loop when contextual mismatch is detected.

Thus, the OODA loop provides the *macro-structure* of adaptive behaviour, while the Libet-style evidence-accumulation models describe its *micro-physics*. The two are not competitors but complementary scales of the same recursive process. providing a neurophysiological mechanism for rapid re-entry when contextual mismatch is detected **(see also real-time cancellation dynamics in Schultze-Kraft et al., 2016)**."

2.5 From Determinism to Dynamics

The enduring philosophical contention around Libet's work—whether early neural activity negates free will—rests on a static, linear notion of causation. An OODA-based interpretation replaces this with a **dynamic systems perspective**: agency emerges from the continual coupling of internal predictions and environmental affordances. Conscious intention does not initiate movement ex nihilo; it modulates an already-running loop. Temporal precedence of neural activity is therefore expected, not paradoxical—it reflects the cost of maintaining predictive alignment.

By situating Libet's data within this control-theoretic framework, we move the debate from metaphysics to mechanism: the question becomes not *"Is free will real?"* but *"How does the brain achieve flexible, self-modifying control in real time?"*

3 Neural Dynamics as OODA Stages

3.1 Observe — Continuous Sensory Sampling and Arousal

The **Observe** phase corresponds to the brain's perpetual intake and pre-processing of sensory and interoceptive information. Subcortical and cortical mechanisms maintain an online map of the organism's state and surroundings long before any explicit decision arises.

- **Primary loci:** brainstem reticular activating system, thalamic relay nuclei, hypothalamus, locus coeruleus (noradrenergic tone), and primary sensory cortices.

- **Function:** sustain vigilance, regulate baseline cortical excitability, and transmit prediction-error signals upward.
- **Temporal span:** effectively continuous, but Libet's RP slope suggests that relevant sensorimotor sampling already biases the SMA **≈ 1 s** before movement onset.
- **Empirical signatures:** alpha/beta desynchronisation in posterior cortices and low-amplitude pre-movement potentials detectable even when no action follows.

Here, the nervous system is not idle but maintaining an *anticipatory readiness state*. This persistent low-level activity sets the baseline for the Orient phase to integrate context and value.

3.2 Orient — Contextual Integration and Expectancy Formation

The **Orient** stage fuses sensory inflow with memory, emotion, and learned expectation. It defines *what the situation means* and *which responses are plausible*.

- **Structures:** amygdala, hippocampus, posterior parietal cortex, insula, and limbic–striatal loops feeding the pre-SMA.
- **Dynamics:** pattern-matching and affective tagging of stimuli; reactivation of associative networks; modulation of autonomic tone.
- **Neurochemical mediators:** dopaminergic prediction-error coding (ventral tegmental area → striatum), cholinergic attentional enhancement.
- **Timing:** early RP component (Type I/II; −800 to −500 ms) indexes this orientational build-up.

This phase constitutes the "sense-making" half of the Libet trace: neural populations in SMA and parietal areas gradually converge on a motor hypothesis that embodies the current situational model. The resulting cortical field potentials manifest as the **onset of the readiness potential**.

3.3 Decide — Threshold Crossing and Prefrontal Oversight

Decision is not a singular command but an emergent property of **accumulating neural evidence** reaching a trigger level.

- **Core network:** supplementary and pre-supplementary motor areas (SMA/pre-SMA), dorsal anterior cingulate cortex (dACC), dorsolateral prefrontal cortex (dlPFC), and basal ganglia (BG) direct pathway.
- **Mechanism:** stochastic accumulation of competing action representations until one crosses a gating threshold in the BG–SMA loop.
- **Empirical marker:** late RP / "BP2" component (~ −400 to −200 ms), immediately preceding the reported W-time.
- **Conscious correlate:** once prefrontal monitoring detects that an action plan nears threshold, the subject *becomes aware* of intending to move.

In this interval, **conscious awareness (W)** is a meta-representational signal that the decision variable has matured. The **veto** capability resides in reciprocal inhibitory projections (rIFG →

subthalamic nucleus → GPi) that can arrest the motor cascade within the final ~100–200 ms—Libet's 'free-won't'—**with a 'point-of-no-return' window empirically constrained by EEG-triggered stop paradigms** (Schultze-Kraft et al., 2016).

3.4 Act — Motor Execution and Efference Feedback

When the threshold is reached and inhibition is lifted, **primary motor cortex (M1)** discharges corticospinal volleys initiating contraction.

- **Timing:** EMG = 0 ms; cortical output peaks ~50 ms before muscle activity.
- **Peripheral feedback:** proprioceptive and visual signals loop back through the cerebellum and sensory cortices within ~80–120 ms, updating the Observe stage.
- **Parallel processes:** cerebellar forward models predict sensory consequences; mismatch signals refine subsequent cycles.

This closure of the loop—the re-entry of consequences into perception—is what sustains continuous agency rather than isolated acts.

3.5 Cross-Layer Coupling and Temporal Architecture

OODA Stage	Dominant Networks	Neurochemical Bias	Approx. Latency (before EMG)	Observable Marker
Observe	Thalamus, sensory cortices, RAS	Noradrenaline, ACh	Ongoing	baseline arousal
Orient	Amygdala–hippocampus–parietal	Dopamine, ACh	−1000 → −500 ms	early RP
Decide	SMA, pre-SMA, ACC, BG, PFC	Dopamine, GABA	−550 → −200 ms	late RP, W-time
Act	M1, cerebellum, spinal tracts	Glutamate	0 ms → +100 ms	EMG onset
Re-Observe	Sensory feedback loops	Mixed	+100 → +500 ms	post-movement potentials

This table translates the Libet waveform into a control-system timing diagram: each OODA stage overlaps, producing the apparent continuous slope of the RP rather than discrete steps.

3.6 Functional Implications

1. **Temporal Overlap:** Multiple OODA cycles operate concurrently; while one action executes, earlier layers already update perception for the next.
2. **Hierarchical Coupling:** Fast subcortical loops (tens ms) provide reflexive stability; slower cortical loops (hundreds ms) enable deliberation and learning.
3. **Adaptive Latency:** The 500-ms lead time observed by Libet is the nervous system's *prediction horizon*—the window needed to prepare movement under uncertainty.

4. **Conscious Oversight:** Prefrontal engagement acts as an executive checkpoint, invoked when automatic prediction fails or context demands reevaluation.

Thus the readiness potential represents the electrophysiological footprint of **OODA recursion in neural time**—a multi-layered cascade rather than a linear cause chain. Conscious intention is not late; it is *higher-order supervision* entering the loop when variability requires explicit control.

4 Experimental Reinterpretation: The Libet Paradigm as an OODA Timeline

4.1 From Potentials to Processes

Viewed through a control-systems lens, Libet's traces record a *temporal unfolding of adaptive regulation* rather than a one-way causal chain.
Each of the classic signals—RP, W, and EMG—marks a boundary between successive OODA sub-phases:

Libet Measure	Mean Onset (ms before movement)	OODA Stage	Functional Meaning
Early RP	≈ –1000 → –600	**Observe → Orient**	Continuous sensory sampling begins biasing SMA networks; situational context and memory converge.
Late RP (BP2)	≈ –550 → –250	**Orient → Decide**	Integration of perceptual, emotional, and motivational signals; drift toward threshold in SMA–BG loop.
W (Time of intention)	≈ –200	**Decide → Act**	Conscious awareness of commitment; prefrontal monitor detects approach to threshold.
Veto window	≈ –150 → 0	**Re-Orient / Re-Decide**	Possible inhibitory re-entry via rIFG–STN pathways.
EMG onset	0	**Act**	Corticospinal execution; motor command issued.
Post-movement potentials	+100 → +500	**Re-Observe**	Feedback and error correction; loop closes.

In this reconstruction, Libet's data depict a *nested cascade of orientation and decision cycles*, with consciousness sampling the system state as it nears a commitment boundary.

4.2 The Readiness Potential as Orient–Decide Transition

The **Bereitschaftspotential**—a slow, central negativity over SMA—represents not a discrete "start signal" but the *integrative layer* of the OODA process.

Single-unit recordings (Fried et al., 2011) show SMA neurons ramping stochastically long before overt awareness, consistent with a **drift-diffusion accumulator**:

$$\frac{dx}{dt} = \eta(t) + k\,[E_{\text{context}} - E_{\text{goal}}]$$

where x is motor readiness and $\eta(t)$ the endogenous noise term.

The RP slope therefore indexes the gradual convergence of sensory observation and contextual orientation into a decision variable—Boyd's *Orient → Decide* hand-off in neuroelectric form.

4.3 Conscious Intention (W) as Supervisory Sampling

Libet's "W-time" aligns temporally with the point at which prefrontal-parietal monitoring networks detect the nearing of an action threshold.
Rather than initiating movement, the conscious intention signal marks the **meta-cognitive recognition** that the system is already oriented and committed.
In OODA terms, this is the cortex's *inspection of the Decide → Act transition*.

EEG–fMRI studies (Haggard & Eimer 1999; Soon et al. 2008) show that awareness coincides with a transient synchronisation between pre-SMA and dorsolateral prefrontal cortex—consistent with the cortex "reading out" the imminent crossing of a motor accumulator. Consciousness thus functions as an *observer of the loop*, not an exogenous trigger.

4.4 The Veto and Rapid Re-Entry

Libet's postulate of a **veto window (~100–200 ms)** finds anatomical grounding in the **right inferior frontal gyrus (rIFG)** and **subthalamic nucleus (STN)**—key components of the inhibitory control network identified in stop-signal paradigms.
When new sensory or contextual information invalidates the current motor plan, these circuits transiently suppress basal-ganglia output, effectively reopening the loop for re-orientation.

This is the brain's *"fast OODA recycle"*: rapid Observe → Orient → Decide iterations within the final pre-movement milliseconds, demonstrating that agency remains dynamically modifiable even after unconscious preparation has begun.

4.5 Consolidating Evidence Across Replications

Later replications reinforce this control-loop interpretation:

Study	**Technique**	**Key Finding**	**OODA Implication**
Haggard & Eimer (1999)	EEG LRP analysis	Conscious intention aligns with lateralised motor preparation	Prefrontal "Decide → Act" synchrony
Fried et al. (2011)	Intracranial (SMA neurons)	Neurons ramp 800–1500 ms before move	Orient → Decide accumulation
Schurger et al. (2012)	Computational model	RP = random accumulation to threshold	Noise-driven evidence integration

Study	Technique	Key Finding	OODA Implication
Maoz & Schurger (2022)	Review and refinement	Shift from “free will” to “control dynamics”	Explicit OODA-like reframing

The common theme is not unconscious determinism but *layered feedback control*: actions arise from continuous observation and orientation processes modulated by conscious supervision.

4.6 Summary of the Re-Interpretation

1. **Libet’s experiment inadvertently recorded neural dynamics homologous to a short OODA cycle**.
2. **The RP** corresponds to *Orient* + *Decide*—the internal alignment of sensory, emotional, and motor states.
3. **The W-signal** marks the *conscious audit* of a decision approaching execution.
4. **The veto window** demonstrates *rapid re-orientation*, not absence of will.
5. **The EMG event** is simply the *Act*—the physical emission that closes one cycle and opens the next.

In this frame, the Libet data no longer threaten the concept of free will; they quantify the temporal scaffolding of **adaptive autonomy**. (Figure 1). Consciousness appears not as a belated passenger but as the system’s reflective layer, sampling and, when necessary, retuning its own control loop in real time.

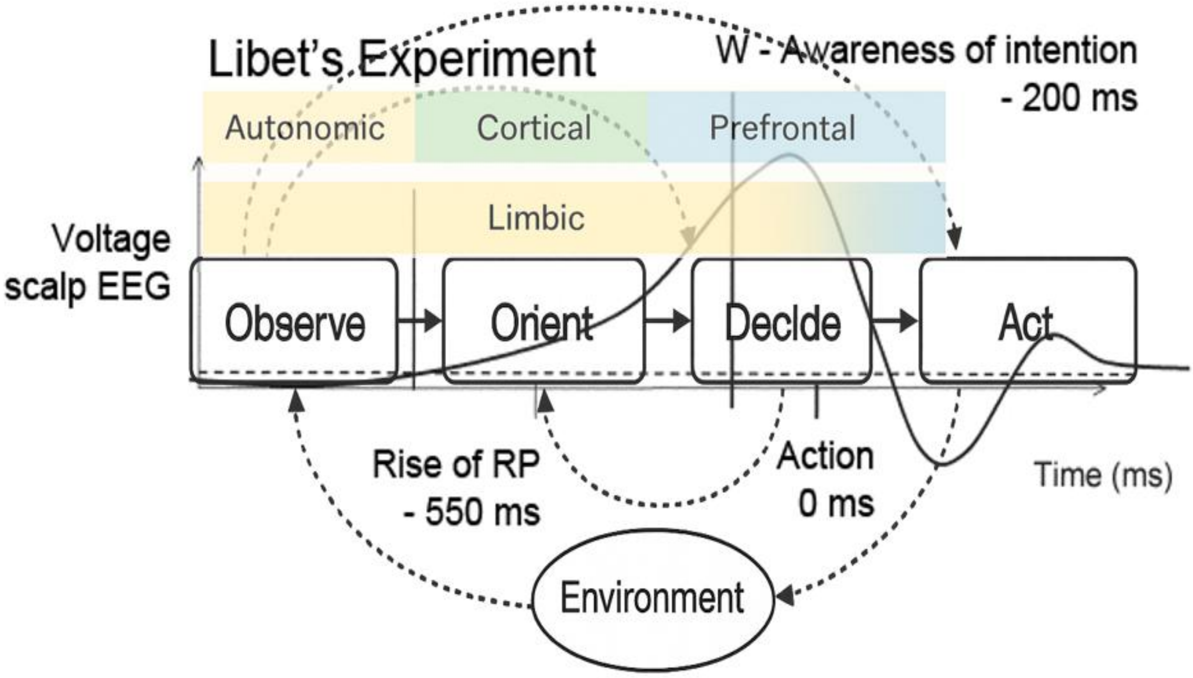

Figure 1 – The coherence and consistency of the Boyd and Libet decision processes

5 Discussion

5.1 From Free Will to Functional Control

The most enduring misunderstanding of the Libet findings is the claim that the readiness potential demonstrates the *illusory nature of free will*. That interpretation rests on a linear causality model in which conscious intention must temporally precede neural activity to be genuine. Yet biological control systems are not linear command chains—they are recursive networks that continuously anticipate, compare, and adjust. When reframed through the OODA architecture, the several-hundred-millisecond lead of neural activity over conscious awareness no longer negates agency; it *defines the temporal bandwidth of adaptive control*. The brain's motor system must begin integrating sensory evidence and contextual information before consciousness can evaluate the emerging act. Conscious will is thus best modelled as **executive sampling and modulation**—entering the loop as uncertainty or conflict rises.

5.2 Predictive Coding and Temporal Efficiency

Under the **predictive-coding** and **active-inference** formalisms, perception and action minimise a shared quantity: prediction error or free energy. Continuous "Observe–Orient" loops attempt to reduce surprise by updating internal models, while "Decide–Act" loops adjust behaviour to align sensations with those models. Libet's measured latencies quantify this hierarchy. The ~550 ms RP interval corresponds to the period of evidence accumulation and precision weighting in midline motor areas; the ~200 ms conscious-intention window marks when prefrontal monitoring crosses a confidence threshold sufficient to endorse or inhibit the plan. In control-theoretic terms, the nervous system operates near the edge of **just-in-time optimality**: neural preparation runs slightly ahead of awareness so that motor output can remain smooth and timely even when deliberation intervenes. The brain therefore behaves as a **Bayesian OODA engine**, constantly trading speed for certainty.

5.3 The Neural Economics of the Loop

Boyd emphasised that advantage arises from *shortening the decision cycle relative to the environment's rate of change*. Libet's data, and later intracranial recordings, reveal the physiological limits of that speed. Approximately half a second is required for multimodal convergence in SMA and prefrontal cortices—the minimal time needed to integrate perception, context, and affect into a coherent action schema. The conscious veto window shows that the loop can still re-enter and update in the final 150 ms if new evidence appears. These figures place human volitional control within a well-defined dynamical bandwidth: rapid enough for adaptive behaviour, slow enough for evaluative correction. The *illusion* of instantaneous free will dissolves into the *reality* of finite-time computation in biological tissue.

5.4 Multi-Scale OODA Cascades

The Libet cycle captures a single sub-second loop, but the same architecture repeats across scales. Fast sensorimotor loops (tens of milliseconds) stabilise posture; mid-range cognitive loops (hundreds of milliseconds) select actions; slower reflective loops (seconds to minutes) govern strategy and learning. Consciousness stitches these nested recursions into a coherent narrative of "self in control." What Libet recorded was one layer—the motor-intentional OODA—embedded within deeper autonomic observation and higher deliberative oversight. This multiscale nesting reconciles apparently contradictory observations: automatic readiness potentials coexist with reflective freedom because they belong to different tiers of the same hierarchy.

5.5 Experimental and Computational Tests

The OODA interpretation makes specific, falsifiable predictions:

1. **Entropy–latency coupling:** RP duration should lengthen with contextual uncertainty (more time spent in Orient–Decide).
2. **Predictive modulation:** Manipulating prior expectation should shift RP onset earlier or later, tracking the Observe–Orient cycle.
3. **Veto as inhibitory burst:** In trials where subjects cancel at the last moment, rIFG–STN coherence should transiently spike, demonstrating fast re-entry.
4. **Information-theoretic efficiency:** The ratio of RP slope to EMG variability could quantify an individual's adaptive bandwidth—an empirical measure of OODA efficiency.

Implementing such paradigms with high-density EEG, MEG, or intracranial arrays, coupled to stochastic accumulator models, would transform the philosophical "free-will experiment" into a **quantitative systems-neuroscience assay** of decision-loop dynamics.

5.6 Implications for Human Performance and Artificial Control

If volition is an emergent property of recursive OODA processing, then both training and technology can target loop optimisation. Expertise—from pilots to surgeons—appears as a progressive migration of control from conscious to automatic layers, shortening the loop while retaining prefrontal veto capacity. Conversely, stress, fatigue, or pathology may desynchronise the layers, producing delayed awareness or impulsive actions. Understanding these temporal mechanics offers a path to neuroadaptive interfaces and AI systems that emulate *human-like control loops*: continual sensing, contextual orientation, probabilistic decision, and reversible action.

5.7 Reframing the Legacy

Libet's experiment, once seen as undermining autonomy, now reads as its **empirical anatomy**. The observed latencies do not describe the failure of will but its architecture: perception, emotion, cognition, and action coupled through iterative inference. Consciousness occupies the high-latency end of a multi-layer control hierarchy, entering the loop when novelty or conflict demands explicit coordination. In the physics of adaptation, this delay is not a defect—it is the temporal cost of maintaining flexibility in an uncertain world.

6 Conclusion: Libet, OODA, and the Temporal Architecture of Agency

Benjamin Libet's deceptively simple timing experiment has endured for over forty years because it touches the deepest question in cognitive science: how mind and matter combine to yield agency. Its original framing—neural activity preceding conscious intention—was interpreted as a challenge to free will, yet that interpretation relied on a linear, single-stage notion of causation. When recast within a **recursive control architecture**, the very same data reveal something different: the temporal scaffolding by which an adaptive organism **updates predictions and regulates action** in a changing world.

The OODA loop provides the conceptual geometry for this reinterpretation. Its four stages—**Observe, Orient, Decide, Act**—describe not a discrete sequence but a continuously cycling feedback process in which perception and action are reciprocally entangled. Libet's electrophysiological traces correspond precisely to one such cycle operating at sub-second scale:

- the **readiness potential** indexes the transition from observation and orientation to decision;
- the **W-time** records the moment at which conscious monitoring detects that a commitment is imminent;
- the **veto window** demonstrates the system's capacity for rapid re-entry and correction;
- and the **EMG discharge** closes the loop, producing feedback that seeds the next iteration.

Far from discrediting will, these latencies delineate the **temporal bandwidth of control**—the finite but flexible interval within which prediction, evaluation, and execution must align.

Re-examined through the principles of **predictive coding** and **active inference**, he Libet paradigm provides **quantitative constraints on a putative OODA-style cycle** in the human brain. The neural system operates as a Bayesian controller that minimises prediction error across nested time-scales: autonomic loops stabilise physiology, limbic loops integrate emotion and memory, cortical loops construct context, and prefrontal circuits oversee and, when necessary, inhibit action. Consciousness enters not to start behaviour but to regulate it, sampling the ongoing process when uncertainty or conflict exceeds a threshold. The apparent delay of awareness is therefore the price of flexibility—the time required to keep options open until evidence, context, and value converge.

This synthesis shifts the philosophical terrain. "Free will" is no longer a metaphysical assertion but a **quantifiable property of adaptive regulation**: the ability of a control loop to monitor its own state and alter course before commitment. Libet's RP–W–EMG sequence thus becomes a dynamic measure of *responsivity*—how quickly and accurately a biological agent can re-enter its decision cycle in light of new information. In this sense, Libet experimentally captured the microphysics of autonomy: not freedom from causation, but freedom *within* causation.

The implications reach beyond philosophy. By treating volition as a measurable control phenomenon, we can begin to model, train, and augment human decision loops. Expertise and intuition emerge as optimised OODA synchrony; indecision, impulsivity, or pathological compulsion reflect breakdowns in inter-loop timing. The same principles can guide the design of **neuroadaptive machines** and **AI agents** that emulate human-like agency—systems that, like the brain, perpetually observe, orient, decide, and act while retaining the capacity for self-interruption.

In summary, the Libet experiments no longer stand as a reductive claim about unconscious determinism but as **an early experimental glimpse of the OODA dynamics of the human mind**. They chart the rhythm by which living systems transform sensation into action and awareness into adaptation. What Libet measured was not the absence of will, but its temporal anatomy.

Postscript: From Fighter Cockpits to Cortical Loops

When Colonel **John Boyd** first described the OODA loop, his concern was tactical, not neural. He sought to explain why some fighter pilots could survive engagements that others lost despite equal machinery. Success, Boyd realised, depended not on faster reflexes but on a *faster and more adaptive decision cycle*: the capacity to extract relevant cues, reframe the situation, choose, and act before an opponent could complete their own loop. The principle proved universal — from air combat to business strategy — because it captured the essence of adaptation under uncertainty. What Boyd inferred in the cockpit, Libet inadvertently demonstrated in the cortex.

By translating intention into milliseconds, Libet revealed timing regularities **compatible with an OODA-like control architecture**. The same recursive logic that guides pilots through chaotic skies governs the internal economy of perception and action. The neural readiness potential is the electrophysiological counterpart of a pilot's orientation phase; the conscious "W" marks the commitment point where prediction hardens into choice; the veto is the last instant of manoeuvre when the trajectory can still be altered. The battlefield, in this sense, lies within: every voluntary act is a micro-combat between evolving predictions and the constraints of reality.

As neuroscience matured, the parallels deepened. Predictive-coding models described the brain as a **hierarchical inference engine**, perpetually reducing uncertainty by aligning expectations with sensory evidence — precisely the function of an OODA loop in formal control terms. Cognitive psychologists reframed *attention* as the process of orienting within this inference space, while decision neuroscientists measured accumulation-to-threshold dynamics that mirror the Decide–Act juncture. Libet's laboratory, once accused of disproving free will, thus emerges in retrospect as an empirical observatory of *adaptive decision control*.

Today, this lineage converges again in the design of **artificial cognitive systems**. Machine-learning architectures increasingly rely on active perception, continual feedback, and policy updating — algorithmic OODA loops. In robotics and autonomous vehicles, temporal hierarchies echo the nested loops of human control: rapid sensorimotor reflexes under slower deliberative oversight. The neurophysiological constants measured by Libet — a half-second of orientation, a fifth of a second of conscious validation — now serve as benchmarks for synthetic agents striving for human-like responsiveness and restraint.

Seen through this wider lens, the Libet experiments occupy a pivotal place in the history of ideas. They mark the moment when metaphysical debate about will crossed into *quantitative physiology*, and, with the OODA reinterpretation, into *control theory*. Boyd's strategic insight and Libet's temporal data describe the same phenomenon at different scales: how living systems stay ahead of the world they inhabit by continually sensing, predicting, deciding, and revising. The physics of adaptation and the phenomenology of choice are thus one and the same process, viewed from opposite ends of the loop.

What began as a challenge to human freedom ends as its most precise description:
freedom is the capacity to re-enter one's own control cycle before the world closes it for you.

Annotated References

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