VOLUNTARY ACTION, CONSCIOUS WILL, AND READINESS POTENTIAL[1]

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ABSTRACT: Libet and colleagues, and later many others investigated brain activity during voluntary action. They found that electrophysiological "readiness potentials" (RPs) precede awareness of intention to act (W). They also found that awareness of actually moving i.e., initiation of motor command (M) follows W, and action follows M; after W, the decision to act can be consciously vetoed until the action actually starts. Libet proposed that one's brain initiates voluntary acts but not one's conscious will, and that conscious will can still control the outcome by vetoing the action. In this article, we explain why the above experimental observations (RP start, W, M, conscious veto) occur in the order they do, using the two-time interpretation of quantum mechanics. We take into account the general and objective observation that a voluntary action needs to use information pertaining to the desired future state (to go to New York, I take a train to New York not to Philadelphia). This observation is confirmed by cognitive scientists as they state that the mental image of the future must become the content of the present memory as a prerequisite to such action and that our brains are endowed with the ability to create 'memories of the future', i.e., neural models of something that, as of yet does not exist but which we want to bring into existence.

KEYWORDS: Voluntary action; Conscious will; Quantum brain; Wavefunction collapse

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INTRODUCTION

Libet and colleagues (1983) performed various experiments investigating brain activity in voluntary action and found that voluntary acts are preceded by electrophysiological "readiness potentials" (RPs). They found that the RP shift began at about 550 msec before movement actually took place, for spontaneous acts involving no preplanning. The time of conscious intention to act was obtained from the subject's recall of the spatial clock position of a revolving spot at the time of his initial awareness of intending or wanting to move (W). W occurred at about 200 msec before the action (Libet *et al.*, 1983). Subjects distinguished awareness of wanting to move from awareness of actually moving (M). Libet associated M to the awareness of initiation of motor command and initiation of efferent cerebral output for the movement. In Libet et al.'s experiments, W times were consistently and substantially in advance of mean times reported for M. Not only did Libet et al. found that a spontaneous voluntary act is initiated unconsciously by the brain but they also found that the decision to act could be consciously controlled during the remaining 150 msec or so after the awareness of intention to act appears. Subjects could in fact "veto" motor performance during a 100-200 msec period before a prearranged time to act. Hence Libet proposed that conscious control can be exerted to select or control volitional outcome before the final motor outflow. The preparatory cerebral processes associated with an RP can and do develop even when an already intended motor action is vetoed at approximately at the time that W normally occurs. The important events in the experiments of Libet *et al.* (1983) investigating brain activity in voluntary action are shown in Figure 1.

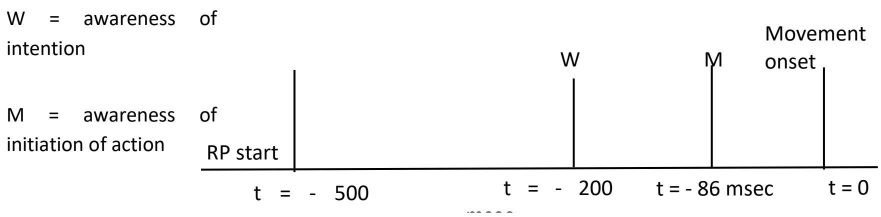

Figure 1. Milestones in a Libet et. al.'s self-initiated voluntary act experiment

Below, we explain why the above experimental observations (RP start, W, M, conscious veto) occur in the order they do, using the two-time interpretation of quantum mechanics while noting the scientific observation by cognitive scientists that the mental image of the future must become the content of the present memory as a prerequisite to any intentional/purposeful action.

NEURAL CORRELATES OF CONSCIOUSNESS

Since we will use the concept of neural correlates of consciousness in our analysis of Libet's experiments, let us recall how neuroscientists describe neural correlates of consciousness. Mormann and Koch (2007) for example, say that "every phenomenal, subjective state will have associated Neural Correlates of Consciousness: one for seeing a red patch, another one for seeing grandmother, yet a third one for hearing a siren, etc. Perturbing or inactivating the Neural Correlates of Consciousness for any one specific conscious experience will affect the percept or cause it to disappear. If the Neural Correlates of Consciousness could be induced artificially, for instance by cortical micro-stimulation in a prosthetic device or during neurosurgery, the subject would experience the associated percept." Thus, a complete and healthy neural correlate is necessary and sufficient for the corresponding conscious experience to occur.

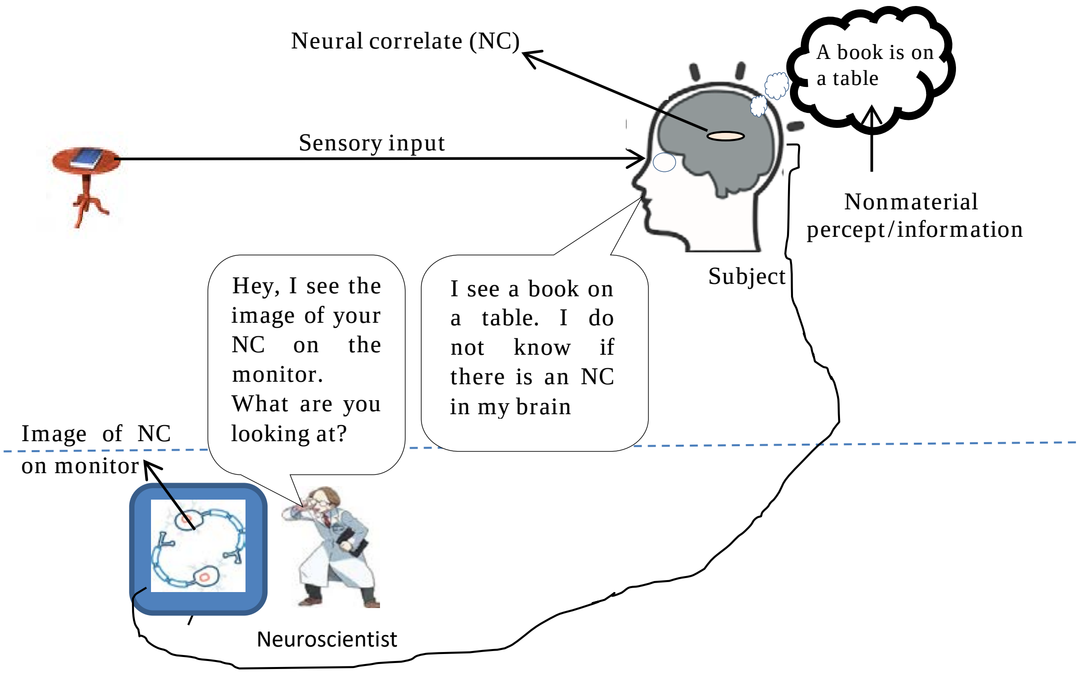

Figure 2. Sensory experience and its neural correlate

Since the examples given above all happen to be sensory experiences, a typical sensory experience is shown in Figure 2 to illustrate that

- The NC is **not** identical with its 'meaning', which is what the first person is aware of. The NC is physical whereas the 'meaning' is nonmaterial. The first person is aware of the 'meaning' but not aware of the NC whereas any third person can see only the NC's picture but does not know the 'meaning' unless the former reports it to the latter using some material means of communication. Briefly put, the first person's experience is subjective.

- The NC is a map, a neural representation of the sensory input[2]; without the input, the NC of the input does not exist.

A digression: In the example of Figure 1, if we have a computer equipped with a camera instead of a human subject, then the computer would create a mapping/record of the book on the table in its memory similarly to the brain's creating the NC, which is a neural map/record of the observed object. The computer can send a picture of the object onto the monitor screen; it can announce that it saw a book on a table if it is equipped with a suitable program in advance. Once the computer has a record of an object (and required instructions), it can simulate almost any observable action that a human being can perform involving the object but it does not have any conscious experience; it is not aware of seeing (or hearing, etc.) the object, or doing anything at all with the object. The computer is not aware of the 'meaning' of the record which it creates because it never creates the 'meanings' of its records, i.e., pieces of 'real information' which exist in our brains (in living beings in general). All records (both data and programs) in a classical or quantum computer's memory are material/physical; 'meanings' are assigned to them by the programmer. Unlike the computer, when the brain receives sensory inputs, both a neural map of the inputs and the 'meaning' of the map are created. We propose that the 'meaning' and awareness of it by the brain's owner are results of the brain's interaction with the so called mind when it pays attention to the brain. The attention involved in creating the awareness component of a sensory experience may be called Process 1 of the von Neumann interpretation of quantum mechanics as explained by Stapp (2011) because to pay attention is to probe for new information. Most probably, such a mind is not present in a classical or quantum computer.

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[2] In the book, "programs of the brain", JZ Young (1978) recognizes that information is carried by physical entities, such as books or sound waves or brains, but it is not itself material. Using the analogy of encoding information in a computer, he says that life is guided by the brain's programs written in neural scripts that are implemented in human action. He says that the detailed characteristics of the cells in the brain provide the code for features of the world, such as a particular line or sound, or the color red. What goes on in the brain provides a faithful representation of events outside, and the arrangement of the cells in it provides a detailed model of the world.

MEMORIES OF THE FUTURE

Not only sensory experiences have neural correlates but our goals, plans, and intentions have neural correlates as well. Baars and Gage (2010) point out that "human cognition is forward-looking, proactive rather than reactive and that transition from mostly reactive to mostly proactive behavior is among the central themes of the evolution of the nervous system. We have visions of the future and formulate goals, plans, hopes, and ambitions, all of which pertain to the future and not to the past. Then we act according to our goals but to do so, these mental images of the future must become the content of our memory; thus the 'memories of the future' are formed. The frontal lobes endow the organism with the ability to create neural models as a prerequisite for making things happen, models of something that, as of yet does not exist but which you want to bring into existence."

We can make two general, logical and objective observations about voluntary actions which are confirmed by the findings of cognitive scientists as stated above:

1. an intentional action with a purpose or goal whether significant or trivial, begins in the present while the goal is in the future;
2. the action needs to use information pertaining to the desired future state; if I want to go to NY, I will take a train to NY but not to Philadelphia.

ACTION OF THE MIND ON THE BRAIN

If building the goal record (a neural model of something that as of yet does not exist) is a prerequisite for the required action to take place, where does the brain get the information about a future state of itself? The answer to this question cannot be that all the information comes from the environment and past memory although for example, when the goal is to reach a visual object, the brain uses inputs from the environment to create a neural correlate (NC) of the goal. The scientist infers from the organism's behavior and location of the NC, whether it is a goal or something the organism has only seen but has no desire to reach. So, whatever scientists observe is not what tells the brain to build a model of the future state. The point is that there is no time information in any sensory input received from the environment. Hence the questions: who assigns the label "future" as opposed to "past" or "present" to the neural model? "Who initiates the goal record creation?" deserve to be thought through. It would be reasonable to assume that the physical brain cannot initiate a new process all by itself (because it would be against the law of causal closure). Even if one argues that the physical brain is a quantum system, and that spontaneous quantum processes such as spontaneous emission happen, such processes happen because of the system being in an unstable state as far as is known. Moreover, the decay phenomenon is irreversible whereas in the case of voluntary actions, one can always have a change of mind until the action has started and even afterwards if the duration of action is long enough. In addition, it seems reasonable to assume that will/volition is not a result of instability. Even the notion called "downward causation" used to explain emergence and self-organization phenomena of some physical, chemical, and biological systems does not answer the above questions because downward causation is irreversible also.

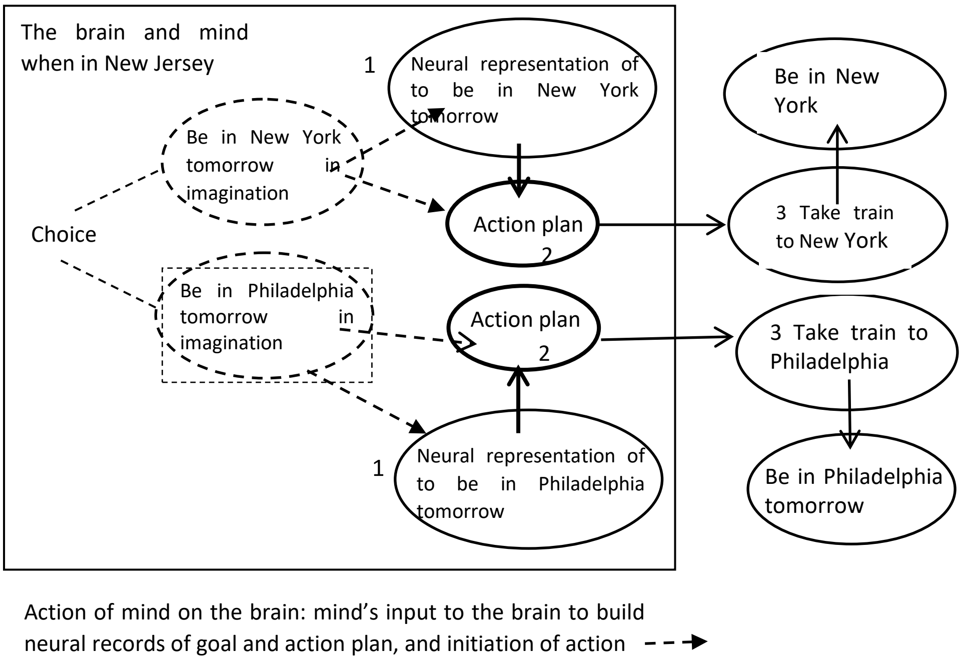


Figure 3. Sequence of Milestones in a Voluntary Action

Thus the questions: "how does the brain acquire in its present memory, information regarding a possible future physical state of itself, "who initiates the goal record creation, and "who initiates action?" arise. We ASSUME that a mental aspect, which we usually call intention or volition initiates creation of goal and action plan records and initiates action as well.

The two general observations in the previous section and the scientific observations of cognitive scientists that the brain creates neural models of the purpose/goal and a plan of action as a prerequisite for action (Baars and Gage 2010) imply the milestones in the performance of a voluntary action shown in Figure 3. Intention/volition and other endogenous inputs from past experiences stored in the brain's memory are used by it to build the neural models of the goal and action plan.

QUANTUM COLLAPSE IN THE BRAIN AND AWARENESS OCCURRENCE

In general, quantum theorists of consciousness assume that awareness of an external event or a thought, intention, etc., is accompanied by a collapse of the quantum brain's wavefunction. The assumption is consistent with the dynamic core hypothesis of Edelman (2000), who says that occurrence of a conscious state rules out or discriminates among billions of other states, each of which may lead to a different potential consequence and that this discrimination happens so fast that it is not achievable at present by a man-made artifact (Edelman, 2000; p.147). He calls this ability of the brain to actualize one state among several possible ones as differentiation.

Accepting von Neumann's suggestion that Heisenberg quantum jumps occur precisely at the high level of brain activity that corresponds to conscious events, Stapp (1995) also explains that there is an actual 'happening' in a particular 'register' of the brain that corresponds to the occurrence of having an awareness of a particular belief, thought, etc. This happening is the quantum jump that shifts the value of amplitude associated with this register from some value less than unity to the value unity. This jump constitutes the Heisenberg 'actualization' of the particular brain state that corresponds to this belief/thought. Assuming that awareness of an event occurs along with a collapse of the quantum brain's wavefunction, Wolf (1998) offered a quantum-physical explanation in support of Libet's delay-and- antedating hypothesis (Libet *et al.*, 1979) regarding the timing of the conscious sensation of a sensory stimulus. Wolf's assumption is therefore justified by the results of Libet's experiments.

Thus collapse of the brain's wavefunction is assumed to be a necessary condition for occurrence of a conscious experience.

Using the two-time interpretation of quantum mechanics (TTIQM) we will show that completion by the quantum brain (QB), of an observable neural model (neural map, model, record, or representation are all the same as neural correlate) of sensory or endogenous input implies a corresponding collapse of the QB's wavefunction. This will allow us to justify the order of occurrence of the events W and M, and conscious veto as reported by Libet et al.

SEQUENCE OF QUANTUM BRAIN'S WAVEFUNCTON COLLAPSES IN LIBET'S FINGER RAISING EXPERIMENTS

The preceding discussion suggests the following sequence of events in Libet's "finger lifting" experiments.

1. Intention initiates RP to build a neural model of the goal state (a future position of the finger different from the present one), as prerequisite to action. Completion of an observable neural record requires the QB's wavefunction to

collapse giving rise to awareness of the intention (W). Thus, awareness of intention occurs after RP progresses enough. The collapse will be seen to be onto the eigenspace of a degenerate eigenvalue of the future-finger-position observable of the brain.

2. The RP activity continues to build potential action plans, which include the above neural model. Another quantum collapse of the brain indicates completion, choice, activation of the plan, and awareness of readiness to act (M).
3. After figuring out what to do, one may or may not act upon it. So, either intention initiates action, or veto (change of mind) stops activity already in progress. Using TTIQM, we explain why veto is felt as being conscious.

W OCCURRENCE – THIRD PERSON VIEW

The neural correlate (NC) of the raised position of the finger (RPF) is an observable of the quantum brain (QB) with eigenvalues 1) YES, if the NC is complete and different from the present position, 2) NO, if otherwise.

The neural model of the future position of the finger is similar to a 'data record' in a computer and always passive. Action plan is similar to a 'program record'; it has to be activated (by intention) after it is completed (the quantum zeno effect of Process 1 described by Stapp (2011) may come into play here). Hence the activation status (AS) of the action plan is an observable of QB with eigenvalues: 1) ACTIVE, and 2) INACTIVE. QB may receive the trigger value any time while it receives cortical inputs.

The Hilbert space H of the states of QB is three dimensional with an orthonormal basis consisting of the state vectors: |(YES, ACTIVE)>, |(YES, INACTIVE)>, and |(NO, INACTIVE)>, where the first label shows the eigenvalue of the observable RPF and the second label shows the eigenvalue of the observable AS. RPF and AS provide a complete set of commutating operators on H.

We assume that the brain has mechanisms R and R' to measure and report the eigenvalues of RPF and AS respectively. Let R' be the finger moving mechanism. From an observation of the finger position a third person would infer that the finger moved from its initial position and therefore that the action plan was activated. If the finger does not move, the observer does not know whether QB is in the state

|(YES, INACTIVE)>, or in |(NO, INACTIVE)>, but assume it to be in a superposition of the two. The observer has to question the first person to find this information. Hence let R be the mechanism that can measure RPF eigenvalues and make them reportable (causing the wavefunction to collapse into one of the eigenstates

of RPF) so that the first person can report it to others. On the other hand, if R' shows a finger position different from its initial position, then the third person can infer that the finger moved and also that the RPF value is YES, in other words, that QB collapsed into |YES, ACTIVE>.

We also assume that the measurement is ideal, that is, when R or R' communicate an observable state of QB to the outside world, it does so with minimal disturbance to the QB state.

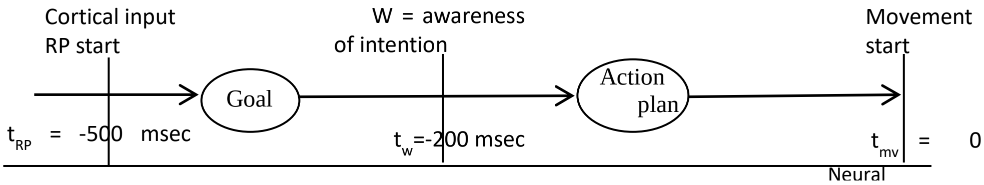


Figure 4. W Occurrence

Initially at $t=t_{RP}$, the finger is observed in the initial position. So the state of QB is a superposition such as

$$|QB(t_{RP})> = a|YES, INACTIVE > + b|NO, INACTIVE>.$$

After receiving cortical input and progress of RP, at $t= t_o< t_{mv}$, let the state of QB evolve to

$$|QB(t_0)> = \alpha\ |(YES, INACTIVE) > + \beta|(NO, INACTIVE)> + \chi|(YES, ACTIVE)>. \quad (1)$$

Since the action plan cannot be completed before the neural model of the finger's future position is completed, let us first consider a measurement of the QB state by means of R. At $t=t_o$, the state of QB, R, and environment E is

$$|\psi(t_0)> = \{\alpha\ |(YES, INACTIVE) > + \beta|(NO, INACTIVE)> + \chi|(YES, ACTIVE)>\} \otimes |R(t_0)> \otimes|E(R(t_0), R'(t_0))>,$$

where $|R(t_o)>$ is the state of R ready to read QB state, and $|E(R(t_o), R'(t_o))>$ denotes the environment state corresponding to the states of R and R' at $t=t_o$. After interaction and entanglement of QB with R, at $t_o < t_1 < t_{mv}$, the combined system of QB, R, and E evolves to

$$|\psi(t_1)\rangle = \{\alpha|(YES, INACTIVE)\rangle \otimes |R(YES)\rangle + \chi|(YES, ACTIVE)\rangle \otimes |R(YES)\rangle + \beta|(NO, INACTIVE)\rangle \otimes |R(NO)\rangle\} \otimes |E(t_0, R'(t_0))\rangle$$

because R tries to read the value of the observable RPF only and does not care about AS the state of R', which does not change at this time. After decoherence in the environment in a short time ϵ, the state of the combined QB, R and E is

$$|\psi(t_1+\epsilon)\rangle = \alpha|(YES, INACTIVE)\rangle \otimes |R(YES)\rangle \otimes |E(YES, R'(t_0))\rangle + \chi|(YES, ACTIVE)\rangle \otimes |R(YES)\rangle \otimes |E(YES, R'(t_0))\rangle$$

$$+\beta|(NO, INACTIVE)\rangle \otimes |R(NO)\rangle \otimes |E(NO, R'(t_0))\rangle$$

Since the finger is seen in a position different from the initial position after t_{mv}, at any time $t > t_{mv}$, it is reasonable to assume that the first person, if asked to do so, can and would report that he/she is intentionally raising the finger during this time. Therefore the post boundary condition for the combined system of R and E is that

for $t \geq t_{mv}$, the state of R and E is $\langle R(YES)| \otimes \langle E(YES, R'(t))|$,

where bra notation indicates a backward evolving state. The backward evolving state of the combined system for $t_2 \geq t_{mv}$ is

$$\langle\Phi(t_2)| = \langle\varphi| \otimes \langle R(YES)| \otimes \langle E(YES, R'(t_2))|,$$

where ϕ is the state of QB after possible further inputs (a superposition different from that in equation (1).

In the interval $t_1+\epsilon < t < t_2$, the combined system is described by the two-state density matrix:

$$\rho(t) = |\psi(t_1+\epsilon)\rangle\langle\Phi(t_2)|$$

Because environment states $|E(YES, R'(t))\rangle$ and $|E(NO, R'(t))\rangle$ are approximately orthogonal, tracing out environmental degrees of freedom removes all terms containing $|E(NO, R'(t))\rangle$. Ignoring normalization, the reduced density matrix, for $t_1+\epsilon < t < t_2$

$$\text{Trace-env}\ (\rho(t)) = \{\alpha|(YES, INACTIVE)\rangle\langle\varphi| + \chi|(YES, ACTIVE)\rangle\langle\varphi|\} \otimes |R(YES)\rangle\langle R(YES)| \qquad (2)$$

This means that QB state partially collapses to H(YES), the state spanned by |(YES, ACTIVE)> and

(YES, INACTIVE)>, and remains in H(YES) in the time interval ($t_1+\epsilon$, t_2). The partial collapse which keeps QB state in the subspace that corresponds to the eigenvalue YES means that the neural model of the future finger position is already completed. This suggests that W, the awareness of the intention, that is, awareness of where the finger should be in the future, occurs in this time interval along with the partial collapse. Since the collapse occurs only after receiving cortical input and building the neural model of the future state, awareness of intention occurs only after RP progresses enough.

M Occurrence – Third Person View

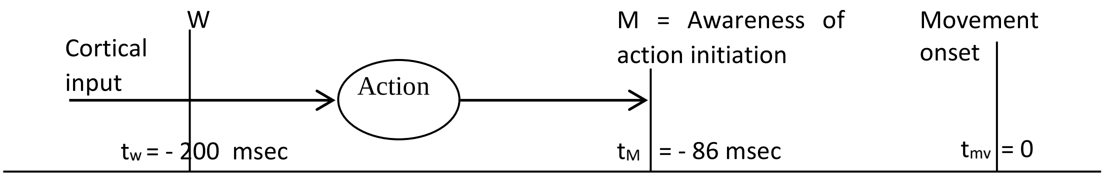


Figure 5. M Occurrence

As said before, the action plan is completed only after the neural model of the future state is completed and therefore not before t_w, the time of occurrence of W. After receiving further inputs, QB interacts with the measuring/reporting mechanism R' at $t= t_3$ where $t_w < t_3 < t_{mv}$; afterwards, in a short time δ, entanglement with the environment E and decoherence happen. The forward evolving state of the combined system of QB, R', and E at $t= t_3+\delta$ is

$$|\psi(t_3+\delta)> = c|(YES, ACTIVE)> \otimes|R'(ACTIVE)>\otimes|E(YES, ACTIVE)> \\ + d|(YES, INACTIVE) > \otimes|R'(INACTIVE)> \otimes |E(YES, INACTIVE)>,$$

where the first argument of the environment state is YES because the QB state is already in the subspace H(YES) due to partial collapse. The post-boundary condition is that for $t \geq t_{mv}$, the state of the combined system R' and E is

$$<R'(ACTIVE)|\otimes <E(YES, ACTIVE)| \qquad (3)$$

and the backward evolving state of the combined system of QB, R', and E, for $t \geq t_{mv}$ is

$$<\Psi(t)| = <\varphi| \otimes <R'(ACTIVE)| \otimes <E(YES, ACTIVE)|.$$

Again, ϕ indicates possible further interactions of QB with other micro or macro systems. In the interval $t_3+\delta< t\leq t_{mv}$, the combined system of QB, R', and E is described by the two-state density matrix:

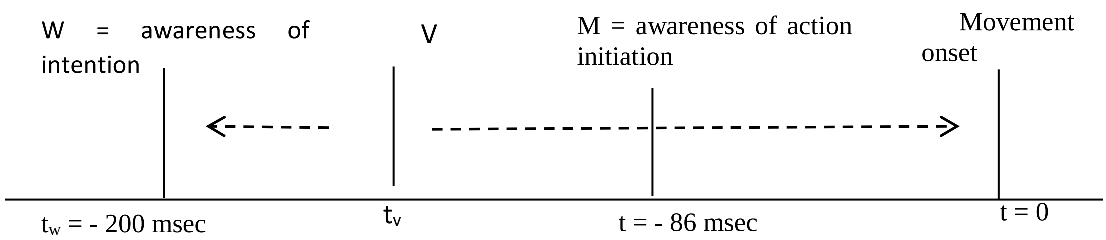
$$\rho(t) = |\psi(t_3+\delta)> <\Psi(t)|$$

Tracing out environmental degrees of freedom and ignoring normalization, the reduced density matrix, for $t_3+\delta< t\leq t_{mv}$,

$$\text{Trace-env}\ (\rho(t)) = |(YES, ACTIVE)><\varphi| \otimes |R(YES)> <R(YES)|$$

QB state reduction occurs in the time interval $(t_3+\delta, t_{mv})$ and the awareness M of activation of action plan occurs along with state reduction. M does not occur if veto occurs before action initiation because then the post boundary condition for R' and E is not (3) as will be seen below.

Conscious Veto



The veto may come any time after W and before movement occurs. It means that the QB is instructed by an intention to set the value of the activation trigger to INACTIVE instead of ACTIVE as was the case in the M-occurrence scenario. Since the instruction is to stop all activity immediately and no movement of the finger is seen experimentally, the post boundary condition in this case is that

for $t \geq t_w$, the state of R', and E is $<R'(INACTIVE)| \otimes <E(YES, INACTIVE)|$. (4)

If t_v is the time when the brain receives veto, it can be seen as in the case of M-occurrence, that collapse to the state $|(YES, INACTIVE)>$ occurs in the interval t_v and $t_v+\varepsilon$ for an; and that awareness of veto happens along with the collapse in the interval $(t_v\ t_v+\varepsilon)$. Since ε is infinitesimally small, the awareness of the veto occurs almost immediately. There is debate in the neuroscientist community, whether the veto intention is also preceded by its own RP. This debate has no bearing on the present analysis; even if veto requires a preceding RP, it would be included in the cortical input mentioned above and the post boundary condition associated with the veto does not change from (4). That the finger should never move implies that the wavefunction should collapse within an infinitesimally short time after receiving veto endogenously, and therefore the awareness of veto occurs at the same time as well.

ENDNOTE

Experiments first performed by Libet et.al (1983; 1985) and later by many others seem to show that the brain but not our conscious will is what initiates voluntary acts. But our perception is otherwise; we think that the conscious intention to achieve a desired future state causes us to take the required action. This feeling occurs probably because no required action would be taken if there is no conscious intention to achieve the goal, or if there is a conscious change of mind; moreover, the conscious decision to act does precede the action as verified by the same experiments. Hence the finding that pursuit of our goals is prepared unconsciously, at least in the earlier moments before we act on them appears to challenge our traditional belief in free will. However, once we recognize that the human brain is a quantum system, according to the analysis above, the sequence of awareness events found in such experiments should not be surprising. Actually, research to find neural basis for unconscious thought is on-going (for example, see Dijksterhuis (2013)). Neural and psychological data found from experiments conducted by cognitive scientists show that unconscious will plays a role in goal setting and activation (Custers and Aarts, 2010).

On the other hand, Libet's proposals were considered controversial by many cognitive scientists and ignited vigorous debates when he first announced them. The controversy continues even today probably because we know volition or will intuitively but we do not have rigorous definitions for subjective notions such as volition, will, goal-oriented-ness, planning, intentionality etc. Although they all involve making decision with regard to a future state, they are all different from a strictly psychological point of view. For example, psychologist Breitmeyer (1985) thought that of finger/wrist flexion used in Libet's experiments does not have any meaningful purpose and therefore cannot be taken as a typical voluntary action. Recently, Maoz et.al. (2017) expressed similar views as their experiments showed RPs associated with arbitrary decisions as expected but the RPs were strikingly absent for deliberate decisions (a deliberate decision has a more significant consequence than an arbitrary decision, for example, which clothes to wear to what route to take to work versus decisions about life partners and career choices).

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