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The Timing of Conscious Experience: A Causality-Violating, Two-Valued, Transactional Interpretation of Subjective Antedating and Spatial-Temporal Projection[1]

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Abstract — Quantum systems in the time interval between two events, so-called two-time observables (TTO), are known to behave in a manner quite different from expectations based on initial value quantum mechanics. According to the transactional interpretation (TI) of quantum physics, wave functions can be pictured as offer and echo waves — the offer wave passing from an initial event, *i,* to a future event, *a,* and the echo wave, the complex conjugate of the offer wave, passing from *a* back in time toward *i.* TTO and the TI have been used to explain certain quantum physical temporal anomalies, such as non-locality, contrafactuality, and future-to-present causation as explicitly shown in Wheeler's delayed choice experiment, an experiment wherein the history of the objects under scrutiny are not determined until the final observation. Experimental evidence involving neurological functioning and subjective awareness indicates the presence of the same anomalies. Here I propose a model based on TTO and the TI wherein *two* neural events are ultimately responsible for backwards-through-time wave function collapse in the intervening space-time interval. After providing a simple argument showing how quantum physics applies to neurological functioning and a simple demonstration of how the TI and TTO explain the delayed choice paradox, I propose that such pairs of causality-violating events must occur in the brain in order that a *single* experience in consciousness take place in the observer. Using this proposition I offer a quantum physical resolution — similar to that of the delayed choice experiment — of the "delay-and-antedating" hypothesis/paradox put forward by Libet *et al.* (1979) to explain certain temporal anomalies associated with a delay time, D, required for passive perception experienced by experimental subjects including the blocking of sensory awareness normally experienced at time t by a cortical signal at later time $t + fD$ $(0 < f \leq 1)$ and the reversal in time of the sensory awareness of the events corresponding to cortical and peripheral stimuli. The model may be a first step towards the development of a quantum physical theory of subjective awareness and suggests that biological systems evolve and continue to function in accordance with TTO and consequently a causality-violating, two-valued, TI of quantum mechanics. The model successfully predicts and explains Libet's temporal anomalies and makes a new prediction about the timings of passive bodily sensory experiences and imagined or phantom sensory experiences. The predictions of the model are compared with experimental data indicating agreement.

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Introduction

I offer a quantum physical resolution — similar to that of the Wheeler delayed choice experiment in quantum physics — of the "delay-and-antedating" hypothesis/paradox put forward by Libet *et al.* (1979) to explain certain temporal anomalies associated with passive perception. I propose a model wherein *two* neural events cause backward-through-time and forward-through-time neurological signaling in accordance with wave function collapse in the intervening space-time interval. Pairs of causality-violating events must occur in the brain in order that a *single* experience in consciousness occurs. The model offers a first step towards the development of a quantum physical theory of subjective awareness and suggests that biological systems evolve and continue to function in accordance with a causality-violating, two-valued, transactional model of quantum mechanics. The model makes a new prediction about the timings of passive bodily sensory experiences and imagined or phantom sensory experiences. The predictions of the model are compared with experimental data indicating agreement and new experiments are proposed testing the model.

In his recent book Penrose (1994) poses the paradox of the relationship of awareness and physical events that elicit it as follows, "Is there *really* an 'actual time' at which a conscious experience does take place, where that particular 'time of experience' must precede the time of any effect of a 'free-willed response' to that experience?... If consciousness... cannot be understood... without... quantum theory then it might... be... that... our conclusions about causality, non-locality, and contrafactuality[2] are incorrect." Penrose believes that there are reasons for being suspicious of our physical notions of time in relation to physics whenever quantum non-locality and conterfactuality are involved. I would add that the same thing must be said with regard to consciousness. He suggests that "*if,* in some manifestation of consciousness, classical reasoning about the temporal ordering of events leads us to a contradictory conclusion, then this is strong indication that quantum actions are indeed at work!"

In this paper we examine a quantum theory of the relationship between the awareness of timings of events and their corresponding physical correlates and show that indeed not only are quantum actions at work, they are indispensable in explaining the temporal paradoxes inherent in the phenomena.

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[2] Many people believe that non-locality and contrafactuality are impossible tenets. Non-locality refers to an action wherein two or more correlated events occur that are separated by space-time interval(s) greater than the distance traveled by light. Hence, even though it is not possible for one event to act as a cause for the other(s), the events are in definite "communication" with each other. Contrafactuality implies that a possible history or sequence of events that did not occur nevertheless affects and even changes an observed or inferred history or sequence of events.

What is the problem? In a nutshell there appears to be an innate fuzziness in the relationship between physical time and conscious experience. This fuzziness indicates that a precise timing of physical events marked by the apparent awareness of these events does not match a causal sequence and that at times physical events eliciting awareness take place after one becomes conscious of them. This has been indicated in a remarkable series of experiments performed by Benjamin Libet and his co-workers at the University of California San Francisco Medical School. They showed that events in the brain eliciting consciousness of passive sensory occurrences occur *after* the apparent awareness of these events and not before. They also hypothesize that a specific mechanism within the brain is responsible for or associated with the projection of these passive events both out in space (spatial referral) and back in time (temporal referral). Libet refers to this as the *delay-and-antedating hypothesis/paradox.*

We shall investigate a plausible resolution of this paradox, in terms of a new model of the timings of conscious experience which includes a specific mechanism for time order reversal, temporal projections, and spatial projections. My model (called TTOTIM) is based on Cramer's transactional interpretation (TI) (Cramer, 1986; see also Cramer, 1983) and incorporates both the TI and, to a lesser extent, the work of Aharonov and his co-workers dealing with the properties of a quantum system between two measurements called two-time observables (TTO) (Aharonov & Vaidman, 1990; see also Aharonov *et al.,* 1987, Vaidman *et al.,* 1987 and Aharonov *et al.,* 1988).

After examining Libet's data and *the delay and antedating hypothesis,* I offer a plausible argument showing that *quantum mechanical descriptions are relevant to neural behavior.* Consequently the brain and nervous system can be treated as a quantum system. This shows that mental events do correspond with neural events through the action of the collapse of the probability field of the quantum wave function. Specifically, I show that the uncertainty in velocity of a presynaptic vesicle as predicted by the Heisenberg uncertainty principle compares favorably with the required magnitude for vesicle emission. I also show that vesicle wave packets spread on a time scale associated with neural conduction. This suggests that a sudden change in probability as predicted by the change in the quantum wave function known as the collapse of the wave function is enough to modify vesicle emission and effect timing.

In the *two-time observable transactional model: Wheeler's delayed choice,* I show how the TTOTIM explains this well-known backwards-through-time causality violation paradox and in so doing how these theories work. In *the brain as a delayed choice machine* I show how the link between mental and neural events explains the projection of mental events into space-time and how a conscious experience occurs if and only if *two* events defining a space-time interval occur.

In *the quantum mechanics of the passive mind,* I show how two pairs of events are required for perception: one of the event pairs acts as the causal *setup* and the second, acts as the finalized *projection* regardless of the *projection/setup* time order.

In *the thalamus and space-time projection,* I show how TTOTIM deals with sensory inputs passing through the thalamus or medial lemniscus and indicates the origination of Libet's *time marker* signal and specific space-time projection mechanism.

In *the space-time projection mechanism: evolution and experimental data,* I discuss why evolution would allow such a seemingly bizarre projection mechanism and its early appearance in the lower brain. The answer seems to be connected with perception, evolution, and survival. I then show how the theory predicts a slight change in otherwise simultaneously perceived stimuli from skin and thalamus: the experience of real stimuli slightly earlier than a time marker signal to the actual skin site and phantom stimuli slightly later than a time marker signal elicited by the thalamus at the cortex.

In *causality violation in sensory and cortical stimuli experiences,* I offer a TTOTIM explanation of Libet's hypothesis/paradox temporal reversal relationship between the timings in cortical and skin stimuli.

The paper concludes with a discussion of the TTOTIM prediction that phantom or projected images of sensations must become conscious *after* the arising of the temporal markers elicited at somatosensory cortex while "real" external sensory sensations must reach awareness *before* the time markers arise. The fact that phantom experience is forward projected in time and real experience is backward projected in time provides the resolution of paradoxes associated with timing of conscious events.

Finally I offer some speculation about the implications of TTOTIM. The speculation that a new theory of time, possibly relating subjective time order with the time order appearing in thermodynamics, is offered. A new theory of time will need to take into account the subjective requirement of two time observables as presented here.

1. The Delay and Antedating Paradox

Honderich (1984) criticized the evident "delay-and-antedating" hypothesis first put forward by Libet *et al.* (1979) to explain the illusive paradox in the timing of events associated with bodily peripheral sensation and brain *neuronal adequacy* (discussed further on) required to elicit consciousness of the sensation. In a later paper Libet (1985) defended his hypothesis, pointing out that "this phenomenon, though conceptually strange, must be encompassed by any mind-brain theory."

Following this, Snyder (1988) offered a resolution of the paradox based on relativistic consideration of the time interval between the events. Snyder's idea was to consider the events from two different reference frames. The apparent difference between the relative time intervals as observed in these reference frames was postulated to account for the discrepancy. Namely simultaneous events in one reference frame would appear to occur with a time interval between them in another reference frame. However, the paradox indicated by Libet deals with events that are *timelike* separated. Because of the *timelike* character of the space-time interval between the events, there is no frame of reference where the two events would ever appear as simultaneous. Hence Snyder's proposal failed to resolve the paradox.

I later proposed a resolution of the paradox based on quantum physical arguments that deal with similar temporal anomalies (Wolf, 1989). In this paper I offer a more detailed model indicating how the TI and TTO resolve the paradox.

Penrose, in examining this paradox, came to a similar conclusion that the ordinary form of logic one uses to deal with it tends to go wrong. "We have to bear in mind how quantum systems behave and so it might be that something funny is going on in these timings because of quantum non-locality and quantum contrafactuals" (Penrose, 1997).

The "delay-and-antedating" paradox/hypothesis refers to the lag in time of cerebral production resulting in a conscious sensory experience following a peripheral sensation, combined with subjective antedating of that experience. For reasons to be explained shortly, conscious experience of external or bodily stimuli cannot occur unless the brain has time to process data associated with them. In a series of studies (Libet *et al.,* 1979) several subjects' brains showed that neuronal adequacy was not achieved until a significant delay time D as high as 500 msecs followed a stimulus. Yet the subjects stated that they were aware of the sensation within a few msec (10-50 msec) following the stimulation. Put briefly, how can a subject be aware of a sensation, that is, be conscious of it, if the subject's brain has not registered that "awareness?"

The duration of a typical peripheral stimulus signal detected at the somatosensory cortex (*SI*) is actually quite long (more than 500 msec). We can consider this signal to have two parts, a short onset and a long finish (see Figure 1). Libet calls the $\approx$50 msec pulse width onset signal a "time marker" but, although it appears in *SI,* according to Libet subjects are not aware of it. In this paper I shall refer to these two parts of the signal as time marker and "caboose." Libet points out it is clear from other studies and from the effects of anesthesia that during surgery even though peripheral stimuli plentifully give rise to time-markers at *SI* there is no awareness of them because the approximately D-20 msec caboose is not elicited.[3]

Time markers do not ordinarily occur in the cortex. In fact most of the time cortical processing takes place without them. But, if a stimulus is applied to the body, this includes taste, smell, sound, touch, or vision, or if a stimulus is applied to a certain region of the brain within the thalamus or slightly below it in the *medial lemniscus,* (*L*) a time marker signal is elicited at *SI.* It is known that sensory data, stimuli originating in the body, produce signals that pass through the thalamus on their way to *SI.* It thus appears that time markers

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[3] This means that there is no evidence of this part of the signal registering in the cortex of an anesthetized patient while there is clear evidence of time marker presence.

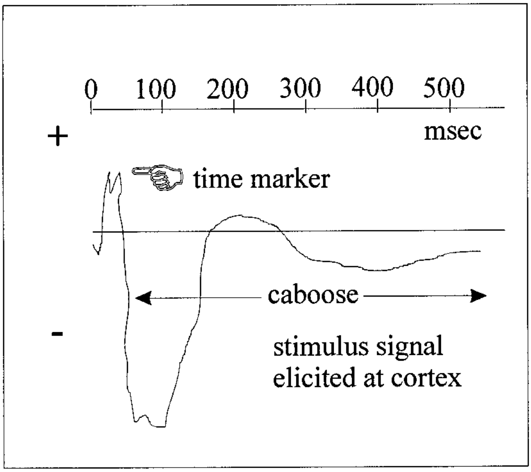

Fig. 1. The two parts of a somatosensory cortical signal elicited by a peripheral stimulus. External (*SS*) and subcortical thalamic (*L*) signals always begin with a relatively sharp pulse (time marker) of approximate pulse width 50 msec occurring ($\approx$15 msec for *SS* and nearly immediately for *L*) after the stimulus is applied. The caboose part of the *SS* signal consists of a large negative pulse followed by a smaller positive train and a slowly falling off negative train lasting about 500 msec.

originate in the thalamus. This suggests that the time markers are associated with some mechanism in the thalamic region and, as I shall indicate, play a significant role in our perceptions of the world.

Further consideration of the timings of sensory stimuli and conscious perception of the stimuli shows that this paradox cannot be resolved by simple causal consideration of the events. In Figure 2 we see a display of these temporal anomalies (based on Libet's data and presented by Penrose, 1989). In (a) we note that the onset of awareness of a skin stimulus occurs $\approx$15-25 milliseconds after the stimulus is applied. The onset of this awareness can be associated with the time-marking fast neural signal (primary evoked potential) reaching the cortex within 15-25 msec of skin stimulus.

Libet explains that what seems to be required for apparent sensory awareness is sufficiency of signal as determined by strength, polarity of signal delivered to the cortex, and length of time the signal is "on." The sufficiency of signal strength, polarity and time determine neuronal adequacy.[4] In what follows I shall assume that the conditions of the stimuli wherever and whenever they are applied require the same sufficiency leading to a time-on period *D* (roughly 0.5 sec).

Cabooses are required to achieve neuronal adequacy as Libet demonstrated

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[4] Neuronal adequacy is not restricted to neurons in the primary *SI* cortex. The caboose part of the signal is widely distributed over the cortex and often more variable in form than shown in Figure 1. However, the primary component – the time marker – is relatively highly localized within the *SI*.

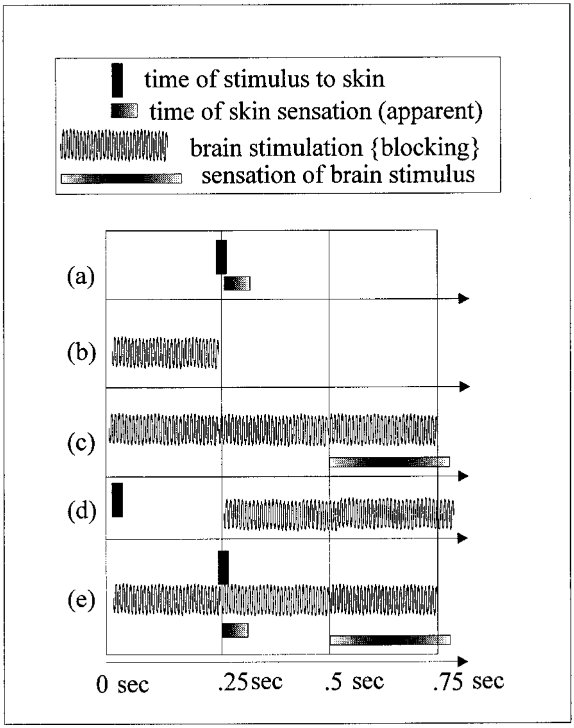

Fig. 2. Data from Libet's experiment. In (a) the skin stimulus is apparently perceived at about the same time as the stimulus is applied. In (b) a cortical stimulus of less than D (0.5 sec) is not perceived. In (c) a cortical stimulus of over D is perceived D after onset. In (d) we have causality violation. The perceived skin stimulus is blocked by a cortical signal applied $0.5D$ later. In (e) we have a time reversal. The skin stimulus is perceived at about the same time as it is applied while the non-blocking cortical stimulus even though applied $0.5D$ before the skin stimulus is not perceived until $0.5D$ after. Libet calls the backward-through-time referral, (e), subjective antedating.

by directly stimulating the cortex. In (b) the cortex itself is stimulated with a train of electrical activity. If that signal is turned off before D, the subject has no awareness that any signal was even applied. But as in (c) if a cortical train duration is over D in length the signal is perceived D after the onset of the cortical stimulus. Cortical signals are different from signals received from the sensory body in that they do not exhibit time markers and they are apparently sensed after a time delay. In (d) we see a seeming paradox arising because of this exception. The skin stimulus was applied and then $0.5D$ (about 0.25 seconds) later a cortical signal train was applied to a region near the cortical area associated with the stimulus. The latter signal train, applied for a time greater than D, acts as a blocking signal. It succeeds in inhibiting any awareness of the skin stimulus even though it is not applied until later. This would indicate that awareness of peripheral stimuli does not occur until a sufficient delay time has passed and neuronal adequacy has been achieved.

One could argue from this data that the blocking signal, in occurring after the skin stimulus, interfered with the reception of the caboose part of the stimulus signal and thus disabled it. One could conclude from this that the awareness of a stimulus experienced by a subject must not occur near the time of the stimulus, but certainly more than $0.5D$ later. Thus the subject must be in error in reporting that the awareness of the skin stimulus occurred near the time of the stimulus.

In (e) we have another apparent paradox. This time the skin stimulus is applied 0.25 seconds *after* the blocking cortical signal which in this case fails to block out the skin stimulus signal. Now the apparent perception of the two signals is in the reverse time order — the subject experiences the skin stimulus a full 0.25 seconds *before* he experiences the cortical signal. This experiment was repeated over 40 times with 3 different subjects and the results were as indicated in the figure. One could conclude from this that again the subject was in error.

Libet posits that in (e) the subject antedates the awareness of the skin stimulus (which only occurs after the caboose has successfully arrived at the cortex) to the time marker which arrives within 15 msec of the stimulus. Assuming that the caboose arrives within 500 msec the subject should actually experience awareness of the skin stimulus 0.75 sec after the onset of the cortical signal. Thus, it would appear, he would then project this experience backward in time, possibly in short-term memory, and then report the skin stimulus as having occurred before the delayed cortical stimulus.

Libet hypothesizes that a peripheral sensory input elicits a time marker signal and when neuronal adequacy is achieved the subject refers this conscious experience backward in time to the time marker rather than consciously experiencing the stimuli at the onset of neuronal adequacy. He further posits that if a stimulus does not elicit a time marker then no such backward through time referral is made. His experiments confirm his hypothesis.

In Figure 3 we see comparisons of four different experiments involving relative timings for stimulus of the medial lemniscus (*L,* ellipse symbol), the somatosensory cortex (*C,* circle symbol), and the skin (*SS,* square symbol). Both *SS* and *L* signals elicit a primary evoked response in the somatosensory cortex and hence each has a time marker signal present. On the other hand *C* stimuli elicit no such evoked response and do not show any time markers. In Figure 4 we see roughly where the thalamus lies with respect to the cortex.

In Figure 3(a), an *SS* was applied about $0.5D$ before *L* and the subject compared his experiences of both stimuli indicating that the SS signal occurred before the *L* stimulus (see arrows on the left side of the time-line) in the correct time order. According to Libet's results a signal train of at least *D* must be applied to *L* to elicit any conscious awareness response.[5] Hence the subject should not be aware of the signal until the time indicated on the right side of

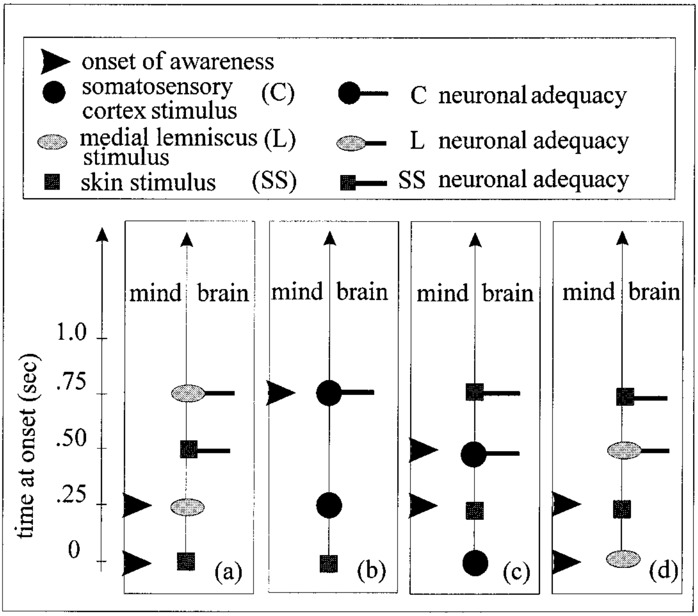

Fig. 3. A comparison of timings in the brain and mind as portrayed by Libet's experiments. The timings of objective experiences — applications of stimuli — are shown on the right side of each time-line while subjective experiences — timings noted by the cortex-exposed conscious observer — are indicated on the left side. The onset of awareness of a particular stimulus shown by a left-side arrowhead indicates when the subject experiences the stimulus pointed to. The absence of an arrowhead to the left of a symbol indicates no awareness at the indicated time. According to these experiments and the ordinary logic of causality the subject should only become aware of the stimulus, whatever it is, at the onset of neuronal adequacy and not before. The results indicate causality violations occurring in both *L* and *SS* stimuli but not for *C* stimuli.

the time-line (shown by a line extending to the right from the ellipse symbol). Although the subject should not indicate awareness of the *L* signal at the time of onset, when it is applied alone, Libet infers that he would "refer" the signal to onset when this signal is compared with another applied stimuli because it gives rise to an earlier time marker. Comparing the *L* result with that given in the case of *SS* suggests the subject is referring both experiences backward in time to their respective time markers. Libet explains since both *L* and *SS* elicit time marker signals, the experience of each signal will be in the correct time

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[5] The actual time needed to achieve neuronal adequacy was often less than 500 msec. Libet indicates a "signal on" time of about 200 msec as typical particularly in reference to *L* signals and whenever the subjects tended to become bored by the experiments. In these cases the strength of the signal was increased and the minimum train duration was found to be 200 msec. I have used the symbol *D* as a base reference for "time on" regardless of whether the brain stimulus was *L* or *C* for clarity and demonstrative purposes. The implications of the relative timings between *SS* and *L* or *C* are therefore correct as indicated, specifically the indicated subjective timings relative to the actual applied onset of stimuli, although the "time-on" in some cases might not be actually 500 msec.

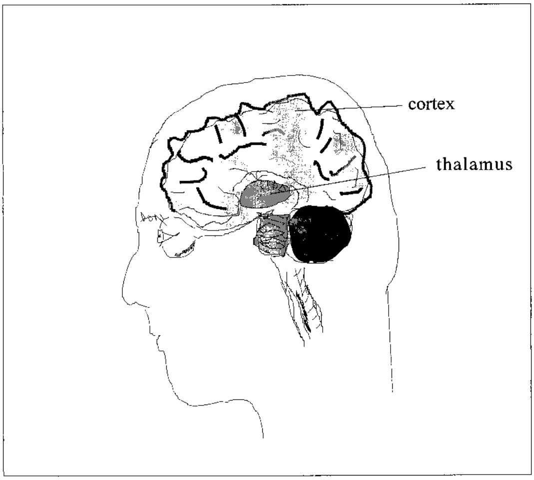

Fig. 4. A schematic of the brain showing the location of the cortex and the thalamus. The latter lies roughly symmetrically within the lower brain near the brain stem.

order,[6] however, each experience of neuronal adequacy is referred back in time by the delay interval.

Case (a) strongly suggests that neuronal adequacy is required for perception, and subjective awareness involving two or more signals may not be experienced as would be inferred by normal causality, but as predicted by Libet's delay-and-antedating hypothesis. Case (b) seems to close the door on any other possible interpretation. Here *SS* is followed by *C*. The train of *C* (see Figure 2) is long and weak enough that neuronal adequacy for it does not occur until *D* later. This signal appears to block out any awareness of *SS* at all. Apparently *C* inhibits the caboose signal from arising in cortex and acts in a manner similar to anesthesia. Hence neuronal adequacy of *SS* is not achieved.

In case (c) the order of *SS* and *C* is reversed with the surprising result that *SS* is experienced well before *C* even though *C* began well before *SS*. Again Libet takes it that since *C* has no time marker no temporal referral can occur. It will be experienced at the "normal" time of neuronal adequacy while the *SS* signal will be backwards-through-time referred.

This is further supported by case (d) where an *L* stimulus replaces *C*. Here both signals are backwards-through-time referred and hence nothing unusual takes place in their normal time order. As in case (a) it is inferred that *both* signals are antedated.

Considering the precise timings of the stimuli, one is tempted to regard Libet's hypothesis as being the only correct interpretation. The question remains: When do people really experience sensory data? One could infer from Libet's hypothesis (he does not make this inference) that the time of occur-

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[6] It will turn out that a slight difference in timings for *L* and *SS* is predicted by the model in reference to the time marker.

rence is not the time reported by the subjects but is somehow rewired in their brains so that they believe they had experienced within the excepted time frame. However, what purpose could evolution have in allowing such a strange and confused temporal ordering of conscious experiences? Consider the possibility that the subjects were not in error and correctly experienced the skin stimulus shortly after it occurred (within 15 msec) and correctly experienced the time delayed cortical stimulus *just when it was perceived D after onset.* What does this tell us about consciousness? It appears to suggest an evolutionary advantage if a subject could in some manner make use of information from his immediate future when dealing with passive sensory awareness.

Others, possibly in disbelief that anything like a future-to-present signal could ever occur, treat this temporal referral as an error or a phantom possibly akin to "normal" spatial referral mechanisms as in the case of vision or to phantom limb phenomenon as in the illusory sensation of touch. As such our brains somehow and as if in illusion project experience out in space and in a similar manner backwards in time.

The projection of the sensation of vision out in space is called spatial referral and appears to us as quite normal procedure. We see things "out there" not "in here" on the backs of our retinas. In the phantom limb phenomenon a person indicates the presence of a sensation in an amputated arm. Even when our brains are electrically stimulated we feel the effects at the associated body organ. Libet in turn believes that our brains are also able to temporally refer sense data backwards in time but rejects the idea that this is illusory or erroneous. For the same reason that it makes sense to project from our brains the feeling of an arm (phantom or not) or the vision of an object in space, it makes sense to project backward through time our perceptions of sense data to a time when the stimuli actually occur as for example indicated by time markers. If there are no time markers present then no such backward-through-time referral takes place.

From this, one could believe that the subject is mistaken about perceived time sequences of external events. If the subject is mistaken about his perceptions, we might ask why natural selection would work in this manner. What could be of possible evolutionary advantage in this case? It would appear to be a disadvantage to ever have our wires crossed, evolutionarily speaking.

If the subject is not mistaken, and is indeed able to receive projections from his future electrically excited brain, we might ask the same question. Here the answer is perhaps obvious. In order to take action in the immediate world of sense data, a great advantage would be bestowed upon the person able to move correctly and intelligently in response to stimuli at the time of the stimulus. Since full awareness requires neuronal adequacy — the brain firing long enough to form cogitative responses to data presented to it — the person could certainly not just sit and wait until all of that brain functioning is accomplished. Thus it may be argued that natural selection would bestow a great advantage enabling us to take full benefit of what our future cogitations were as they bear upon our immediate problems. Perhaps we could argue that seeing into the future a period of D is necessary for intelligent species evolution.

We need next to consider the question of the relevancy of quantum mechanical descriptions to the nervous system. After, I'll show how my model explains the delay-and–antedating paradox and makes a new prediction for the relative timings of sensory and projected experiences.

2. Are Quantum Mechanical Descriptions Relevant to the Nervous System?

While it may have long been suspected, it is only recently that the question of the mind-brain problem having a solution based on quantum physical considerations has taken on a new look (Hameroff *et al.,* 1996). Current interest in macroscopic quantum systems as well as interest in molecular biology suggests that quantum physical principles do operate in the nervous system.

In his 1986 article, Eccles (1986) offered plausible arguments for mental events causing neural events *via* the mechanism of wave function collapse. Conventional operations of the synapses depend on the operation of "ultimate synaptic units" called "boutons." Eccles states that, "these synaptic boutons, when excited by an all-or-nothing nerve impulse, deliver the total content of a single synaptic vesicle, not regularly, but probabilistically." Eccles points out that refined physiological analysis of the synapse shows that the effective structure of each bouton is a paracrystalline presynaptic vesicular grid with about 50 vesicles. The existence of such a crystalline structure is suggestive of quantum physical laws in operation in that the spacing and structure are suggestive of crystalline structure in common substances.

Eccles focused attention on these para-crystalline grids as the targets for non-material events. He showed how the probability field of quantum mechanics which carries neither mass nor energy, can nevertheless be envisioned as exerting effective action at these microsites. In the event of a sudden change in the probability field brought on by the observation of a complementary observable, there would be a change in the probability of emission of one or more of the vesicles.

The action of altering the probability field without changing the energy of the physical system involved can be found in the equation governing the Heisenberg principle of uncertainty,

$$\Delta v \, \Delta x \geq \hbar / m \tag{1}$$

where Δv is the tolerance set for determining the velocity of the object, Δx is the tolerance set for determining the position of the object, and is Planck's constant 1.06×10^{-27} erg-sec.

In my earlier paper (Wolf, 1986), thus unknowing of Eccles's work, I presented similar lines of reasoning showing that protein gate molecules in the neural wall could also be candidates for micro-objects subject to quantum physical probability fields. I also explained how the sudden change in the probability field resulting from an observation, could be the mechanism by which mental events trigger neural events.

A key argument for the plausibility of Eccles's and my argument comes from a simple inquiry based on the mass of a typical synaptic vesicle, m, 40 nm in diameter. It can be calculated to be 3×10^{-17} g. If the uncertainty of the position of the vesicle in the presynaptic grid, Δx, is taken to be 1 nm, it is possible to determine, according to the uncertainty principle, the uncertainty of the velocity, Δv, to be 3.5 nm per msec. This number compares favorably with the fact that the presynaptic membrane is about 5 nm across and the emission time for a vesicle is about 0.1 – 1 milliseconds.

Using the same parameters it is also possible to determine how long it takes for a wave packet for a localized particle or group of particles to spread one standard deviation. The time, τ, is given by

$$\tau = 2m\Delta^2/\hbar \tag{2}$$

where Δ is the initial width of the wave packet. Using a pulse width of $\Delta = 5$ nm and a mass of 3×10^{-17} g yields $\tau = 15$ msec. This means that within the range of neural conduction times (15 msec) quantum effects associated with temporal anomalies could easily be occurring and the uncertainty in velocity as shown by the uncertainty principle is well within the range necessary to modify the vesicle emission through mental intention in the manner known as the "collapse of the wave function."

Eccles concluded that calculations based on the Heisenberg uncertainty principle show that the probabilistic emission of a vesicle from the paracrystalline presynaptic grid could conceivably be modified by mental intention in the same manner that mental intention modifies a quantum wave function. Although my conclusions were based on the operations of protein gating molecules in the neural wall, I came to a similar conclusion: mental events stimulate neural events through sudden changes in the quantum physical probability field and the timing of these events could be governed by quantum mechanical consideration.

For experimental evidence showing how mental events influence neural events, Eccles pointed to that put forward by Roland *et al.*, (1980) who recorded, using radioactive Xenon, the regional blood flow (rCBF) over a cerebral hemisphere while the subject was making a complex pattern of finger-thumb movements. They discovered that any regional increase in rCBF is a reliable indicator of an increased neuronal activity in that area. Other evidence, using the same technique of monitoring rCBF, showing that silent thinking has an action on the cerebral cortex was also offered by Eccles. For example, merely placing one's attention on a finger that was about to be touched, showed that there was an increase in rCBF over the postcentral gyrus of the cerebral cortex as well as the mid-prefontal area.

Eccles concluded from his research that the essential locus of the action of non-material mental events on the brain is at individual microsites, the presynaptic vesicular grids of the boutons. Each bouton operates in a probabilistic manner in the release of a single vesicle in response to a presynaptic impulse. It is this probability field that Eccles believes is influenced by mental action that is governed in the same way that a quantum probability field undergoes sudden change when as a result of observation the quantum wave function collapses.

The question remains, how and when does the probability field change in this manner? The TTOTIM may shed some light and Libet's data may indeed be showing how mental events influence neural events and in fact just what is necessary for a conscious (knowing) event to occur.

3. The Two-Time Observable Transactional Interpretation Model (TTOTIM): Analysis of Wheeler's Delayed-Choice Experiment

According to the TTOTIM, a future event and a present event are involved in a transaction wherein a real (complex-valued retarded wave) quantum state vector, $|O(1)>$, called the "offer" wave, issues from the present event (1) and travels to the future event (2). The future event is then stimulated to send back through time an "echo" state vector (complex-conjugated advanced wave), $<E(2)|$, toward the present event.

According to the rules of quantum mechanics, the probability distribution (probability per unit volume) for an event to occur, is given by $<E(2)|O(1)>$. Following the TTOTIM, the echo wave modulates the offer wave thus producing the required probability pattern. Thus, it is necessary for future events to influence present or past events by sending back into time a corresponding echo wave, following an offer wave, from the present or past that *confirms* the offer. Specifically, the echo wave contains the complex conjugated reflection of the offer wave multiplying the offer wave in much the same manner as a radio wave modulates a carrier signal in radio broadcasting. The probability amplitude $<E(2)|O(1)>$ equals the positive real probability for a transaction — a correlation between the two events — arising as a probability field around the initial event. However, this field depends on values acquired at the echo site (2) as well as values obtained from the initiating site (1).

To see how TTOTIM works, and how a future event could influence by confirmation an earlier one, let us consider a well-known causality violation paradox known as Wheeler's delayed choice experiment (Hellmuth *et al.,* 1986; see also Wheeler, 1978). The delayed choice arises after allowing a single photon to travel either by (a) one path or (b) by both paths in a two-arm Mach-Zehnder interferometer to a detector setup. The choice is made after the photon has already entered the device and has presumably "decided" which way to go. The outcome is determined when a half-silvered mirror is placed or not placed at the detection site. The complete analysis using TTOTIM is shown in Figure 5.

In Figure 5(a) the decision at $t = 0_{++}$ is to not insert an additional half-sil-

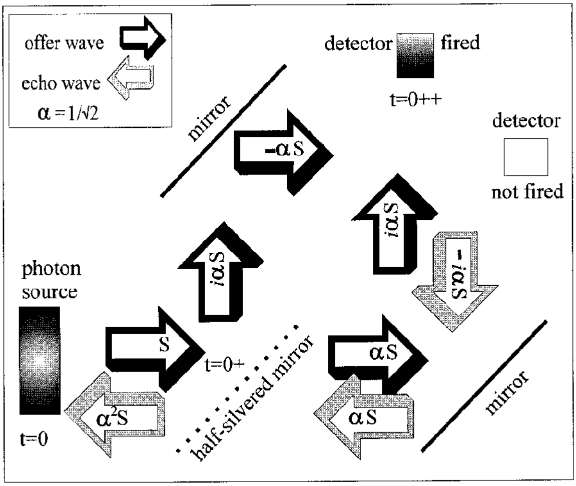

Fig. 5a. Wheeler's delayed choice experiment as depicted using the TTOTIM. The delayed choice is between allowing the photon to travel by a single path or by both paths to reach the detector setup. The choice is made at the later time when a half-silvered mirror is placed or not placed at the detection site.

vered mirror. Consequently, at $t = 0$ a photon source emits a single photon. Accordingly, an *offer* quantum wave vector, $|S>$, travels forward in time to a half-silvered mirror arriving at $t=0_+$ where the state vector, $|S>$, is partially transmitted; $|_\alpha S>$, continuing through the mirror onto the lower path, and partially reflected, $|i_\alpha S>$, onto the upper path ( ).[7] Next at $t = 0_{++}$ the vertical detector fires[8] sending an echo wave vector, $<_{-i\alpha}S|$, backwards in time only onto the lower path where it once again reflects from a mirror leading to the continuation echo wave vector $<_\alpha S|$ which in passing through the half-silvered mirror becomes $<_{\alpha^2}S| = <{}^1/_2 S|$. The probability for the transaction is $<{}^1/_2 S|S> = {}^1/_2$ as indicated by the amplitude of the echo wave arriving at the original source. Since the horizontal detector did not fire, there was no echo from it and consequently the photon did not pass through the upper arm of the device even though its offer wave vector did. Only when a transaction is

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[7] There are some additional assumptions at play here. The half-silvered mirror is in fact a thin piece of transparent material with just the right thickness in relation to the wavelength of the light to produce the quarter wavelength shift when the wave reflects from the surface of the mirror and equal amplitudes of reflected and transmitted waves. Thus, the factor takes into account the splitting of the wave at the "half-silvered" mirror and the *i* factor in $|i_\alpha S>$ accounts for the 90 degrees or quarter wavelength phase shift that arises between the transmitted and reflected wave. The fully silvered mirrors reflect the wave vector with no absorption. The "*i*" factor here is a compromise to agree with the "half-silvered" mirror case. Any phase factor could have been used here as long as it is the same for both mirrors in the setup.

[8] The horizontal detector could just as well have fired. But only one detector can fire since only one photon is present. In this case the echo wave vector would have been $<_{-\alpha}S|$ which would have next reflected at the mirror into the state $<_{-i\alpha}S|$ which would have continued back to the source after another reflection from the original half-silvered mirror leading to a final wave vector $<_{\alpha^2}S| = <{}^1/_2 S|$ just as in the vertical detection scenario.

completed, where both a final conformation and an initial offer are concluded can a history be decided.

If the alternative decision is made after the photon has already entered the device, the delayed choice changes the past and allows the photon to travel by both paths to reach the detector. In Figure 5(b) the decision at $t = 0_{++}$ is to insert an additional half-silvered mirror. At $t = 0$ a photon source emits a single photon. An offer quantum wave vector, |*S*>, travels forward in time to a half-silvered mirror ($t = 0_{+}$) where the state vector, |*S*>, is partially transmitted, |α*S*>, continuing through the mirror onto the lower path, and partially reflected, |*i*α*S*>, onto the upper path as before. Each partial wave is again reflected by a mirror and continues as before. The upper partial wave undergoes, as a result, two 90-degree phase shifts while the lower partial wave undergoes only one phase shift. Next at $t = 0_{++}$ both partial waves encounter the just-inserted half-silvered mirror where again reflection and transmission occur. The reflected upper wave enters the vertical detector where it, because of the phase-shifting, cancels out with the lower transmitted wave. The vertical detector does not fire. The transmitted upper path vector continues to the horizontal detector and adds in phase with the lower path reflected vector resulting in the firing of the horizontal detector. Although each wave is phase-shifted by 180 degrees and reduced in amplitude by a factor of $^1/_2$, they add together to produce the 180-degrees phase-shifted wave vector |_*S*> and the firing of the horizontal detector. Now the horizontal detection event sends backward through

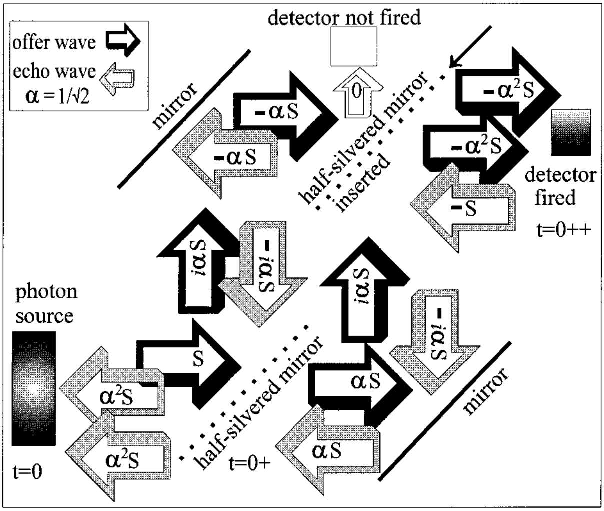

Fig. 5b. Wheeler's delayed choice experiment as depicted using the TTOTIM. This time the delayed choice allows the photon to travel by both paths to reach the detector. Here the decision at the later time is to insert an additional half-silvered mirror. Now the photon follows both paths to complete and confirm a successful transaction.

time the echo wave, $<-S|$, which upon following the same two trajectories back to the source arrives in *toto* phase shifted through another 180 degrees as the echo wave, $<S|$, thus completing the transaction. The probability for the transaction is unity as indicated by the sum of the amplitudes of the echo waves arriving at the original source.

4. The Brain as a Delayed Choice Machine

It is widely believed that no experimental evidence favoring one interpretation of quantum physics over another is possible. However, it has been recognized that the action of observing any quantum system can alter the physical property under scrutiny. While this has been broadly recognized, no one to date has any idea how this happens or when it happens. Up to now, research has been occupied with investigations of temporal paradoxes in physical systems. Wheeler's delayed choice experiment has already been confirmed. What I am proposing here is that the timing of events taking place within the human brain may under certain circumstances exhibit behavior showing a similar delayed choice scenario as above is being played out. Moreover few physicists investigate anything like precise timing of conscious events in human subjects for a variety of reasons. Libet's data may suggest that a biological foundation for quantum physics exists and that the question of which interpretation of quantum physics is correct can only be answered biologically. This step may also provide the beginning of a theoretical basis for a quantum physical model of the mind-brain.

The TTOTIM links mental and neural events and explains the relationship between physical exterior events, mental events, and the projection of mental events into space-time. A conscious experience occurs if and only if *two* events occur. If one assumes that consciousness arises with a single event, paradoxes like the ones indicated by Libet's experiments occur. Neuronal adequacy and subjective experience are not one and the same events. Neither are peripheral stimulation and subjective experience one and the same even though they seem to be. The truth actually lies somewhere in-between. Both the stimulation and neuronal adequacy (two events) are needed for the apparent conscious (one event) experience, even though the time of that experience may be referred back close to the time of the elicitation of a particular signal.

Although one might believe that Libet's data suggest that this may be an illusion, that the real "recognition" of the event only occurred later at the time of neuronal adequacy and that the subject "subjectively" and mistakenly remembered the event as having occurred earlier, this "illusion" is precisely how the brain-mind works in dealing with passive stimuli.

The TTOTIM sheds light on both "subjective referral in time" as well as "subjective referral in space." Libet suggests that, in the same manner that neuronal adequacy following a peripheral sensation is projected "out there" on the peripheral site and not felt to occur at the cortex, visual experience is "projected" onto the external world and not referred to the retinal net. Not only must the achievement of neuronal adequacy following a peripheral stimulus elicit a backwards-through-time signal but the SI upon its receipt must relay it out to the physical location of the stimulus. What happens if the stimulus is not real or if the stimulus is applied to the brain itself? Then this projection must occur forward-in-time!

In my original hypothesis (Wolf, 1989), neither the time nor the location of the experience was precisely determined and no experience of the "out there" sensation takes place unless a projection to the stimulus site occurs. Thus phantom experiences and subjective "filling-in" of neurological "blind spots" or even a whole field of *SI*-induced sensory information will appear as *real* experiences. It would be hard to explain how appropriate behavior based on awareness could occur if this projection did not occur. What I have added here is a specific time difference between projections of real and phantom or brain stimuli. This hypothesis also fits with certain experiments performed by physiologist von Békésey and phantom limb experiences reported to Pribram which I described in my earlier book (Wolf, 1984).

5. The Quantum Mechanics of the Passive Mind

Now that we have looked at the general analysis of the TTOTIM as it applied to Wheeler's delayed choice scenario, let us consider its application to Libet's data.

Figure 6 illustrates offer and echo state vectors involved in a typical peripheral stimulus response action using a pseudo-sequence similar to that shown in Figures 5. At $t = 0$ a skin stimulus is applied (*SS*). Accordingly, a quantum state vector, $|S>$, travels forward in time to the somatosensory cortex arrival area *SI* where it elicits a time marker slightly later (about 15 msec) at $t = 0_+$.

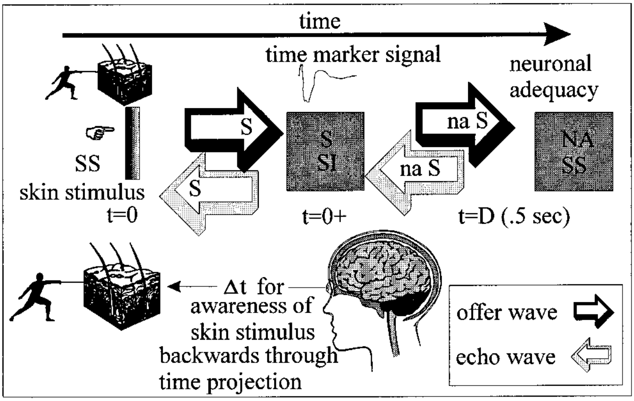

Fig. 6. Here we see, using a simplified pseudo-sequence typical of the TTOTIM, what transpires when at $t=0$ a skin stimulus is applied (*SS*) leading to a time marker signal being elicited on the somatosensory cortex (*S SI*) at $t=0+$ (≈ 15 msec). The perception occurs within 15 msec of the stimulus.

As time continues, the state vector, $|na\ S>$, travels forward in time leading to neuronal adequacy, elicited by the caboose part of the *SS* signal, at *SI,* which occurs after the delay time D (taken to be 0.5 sec). The time-reversed echo state vector, $<naS|$, goes back in time to $t = 0_+$ where it initiates the backwards-through-time state vector, $<S|$, that returns to the site of the skin stimulus. The perceived event — conscious awareness of *SS* — does not occur at a precise time but subjectively, accordingly, somewhere in an interval Δt (15 msec) between time $t = 0$ and $t = 0_+$. The time marker signal acts as a reference for the timing of the awareness event.

Following the use of TTOTIM, there are two pairs of events required for perception. We may consider one of the event pairs to be the causal *setup* and the second to be the finalized *projection.* The projection is (1) $[SS \leftarrow S\ SI]$ and the setup is (2) $[S\ SI \rightarrow NA\ SS]$ where the forward arrow indicates a forward through time projection and the backward arrow the contrary. Even though the two event setup sequence (2) occurs later than the two event projection sequence (1), the setup (2) acts as the "confirmation" cause for the conscious projection (1). The absence of (2) completely eliminates the confirmation and the possibility for (1) to occur. In apparent agreement with the tenet of contrafactuality, what does not happen later affects what consciously happens earlier.

The skin stimulus timing is to be contrasted with a cortical stimulus directly applied at $t = 0$ at *SI* where no time marker signal arises. Figure 7 illustrates how a phantom skin stimulus is not felt until neuronal adequacy is achieved sometime after $t = D$ (taken to be .5 sec). A quantum wave vector, $|na\ C>$, initiated at *SI* without any time marker signal, travels forward in time. As time continues, a train of pulses is elicited, leading to neuronal adequacy at $t = D$. This elicits a state vector, $|pS>$, associated with a phantom sensation that travels forward in time arriving at $t = D_+$ at the area of the skin associated with the

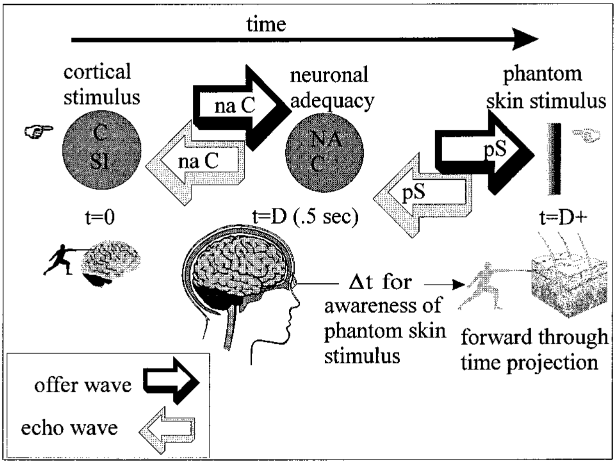

Fig. 7. Here a cortical stimulus (*C SI*) is applied at $t=0$. The phantom skin stimulus is not felt until neuronal adequacy is achieved sometime after $t=D$.

particular site on the somatosensory cortex. Next, the time reversed echo state vector, $\langle pS|$, goes back in time to $t = D$ where it initiates the backwards-through-time state vector, $\langle na\ C|$, that returns to the onset site of the original cortical stimulus and completes the circuit. The apparent event for conscious awareness does not occur at a precise time but accordingly somewhere in the interval Δt between time $t = D$ and $t = D_+$.

In contrast to the skin stimulus, the theory posits that the cortical stimulus will be sensed as a result of a phantom projected "image" associated with the cortical area stimulated and that this projection will occur after the achievement of neuronal adequacy. The key is the absence of a time marker reference. Without it, the location of the event in time and space will correspond to the time of achievement of neuronal adequacy.

The TTOTIM successfully explains the difference between a phantom sensation elicited by the cortical stimulus occurring around $t = D$ and the real sensation elicited by the skin stimulus occurring around $t = 0$. The key difference lies in realizing that the impetus for the sensation is quite different in each case in that one occurs at the skin and the other at the cortex. The skin stimulus elicits a time marker signal and the cortical stimulus does not. Instead it elicits a forward through time phantom signal at the skin site. In this case the setup interval $[C\ SI \rightarrow NA\ C]$ takes place before the projection interval $[NA\ C \rightarrow PS]$.

Figure 8 illustrates the comparison between the two stimuli. A pseudo-sequence with two signals is applied corresponding to Figure 3 (b). At $t = 0$ a skin stimulus (*SS*) is applied. A quantum wave vector, $|S\rangle$, travels forward in time to the somatosensory cortex arrival area *SI* eliciting a time marker signal on the somatosensory cortex (*SI*) at $t = 0_+$. As time continues, the state vector, $|na\ S\rangle$, moves forward in time. At $t = 0.5D$, a cortical stimulus is applied interrupting and interfering with the state vector, $|na\ S\rangle$. The caboose is not elicited at the somatosensory cortical region associated with *SS*. Neuronal adequacy for *SS* at *SI* is not achieved. Instead a quantum wave vector, $|na\ C\rangle$, initiated at the cortical stimulus site *SI* without any time marker signal travels forward in time. As time continues a train of pulses is elicited leading to neuronal adequacy at $t = 1.5D$ (around 0.75 sec). This elicits a state vector, $|pS\rangle$, that travels forward in time arriving at $t = 1.5D_+$ at the area of the skin associated with the particular site *SI*. Next the time reversed echo state vector, $\langle pS|$, goes back in time to $t = 1.5D$ where it initiates the backwards-through-time state vector, $\langle na\ C|$, that returns to the onset site of the original cortical stimulus at $t = 0.5D$ completing the blocking cycle. Consequently there is no echo state vector, $\langle na\ S|$, returning to *SI* and no echo wave vector, $\langle S|$, returning to the skin. There is no awareness of the actual skin stimulus although a phantom skin sensation produced by the cortical train is felt later if the wave train duration is sufficient as indicated in the figure. The phantom event for conscious awareness does not occur at a precise time but subjectively accordingly somewhere in the interval Δt between time $t = 1.5D$ and $t = 1.5D_+$.

The normal setup $[S\ SI \rightarrow NA\ S]$ has been disrupted by the introduction of the

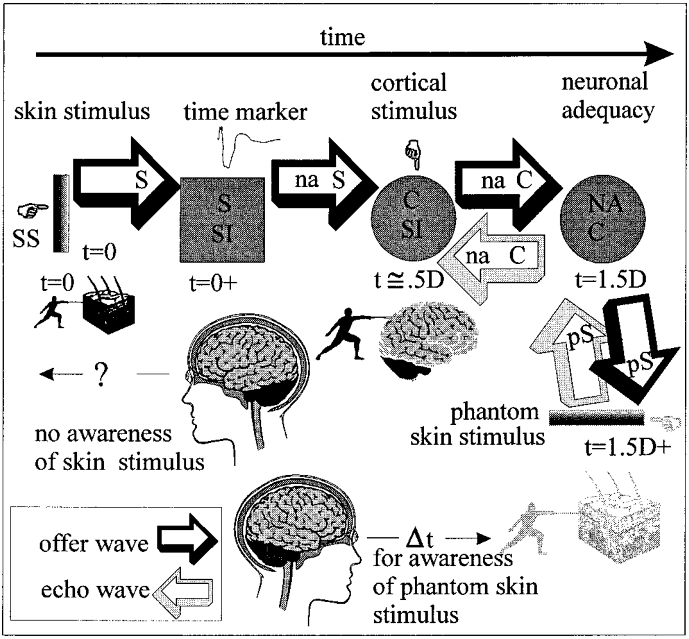

Fig. 8. Here two stimuli are applied corresponding to Figure 3 (b). There is no awareness of actual skin stimulus although a phantom skin sensation produced by the cortical train is felt later. The phantom event for conscious awareness does not occur at a precise time but accordingly sometime after $t = 1.5D$.

later two-valued setup. Consequently there is no projection of the *SS* experience, the projection $[SS_{\leftarrow}S\ SI]$ does not arise. However, the projection $[NA\ C_{\rightarrow}PS]$ occurs with $[C\ SI_{\rightarrow}NA\ C]$ as its cause.

One would think from this that the paradox has been resolved. However, a question arises when we compare these stimuli with direct stimuli to the thalamus or medial lemniscus just below the thalamus. Signals applied there, unlike cortical stimuli, do elicit time marker signals at *SI.* Thus one would expect, according to Libet's hypothesis, a similar antedating for the awareness of such signals when compared with cortical signals. Although this has been confirmed in a number of studies (Libet, 1979) there is a difference in the timings predicted by the TTOTIM.

Figure 9 demonstrates, using the TI pseudo-sequence, what transpires when a thalamus (medial lemniscus) stimulus is applied at $t = 0$. A time marker signal is elicited at *SI* at $t = 0_+$ ($_{\approx}1$ msec) and a phantom skin stimulus is felt slightly later, between $t = 0_+$ and $t = 0_{++}$ (about 15 msec later).

Was this signal felt shortly after the time marker signal? Since all of Libet's experiments were done with comparisons of the relative timings between two signals (*e.g., L&C, L&SS, C&SS*) and in no case ever was the timing of a single signal determined, the question remains unanswered. If a brain signal was applied either to *C* or *L* for a period less than *D,* neuronal adequacy was not

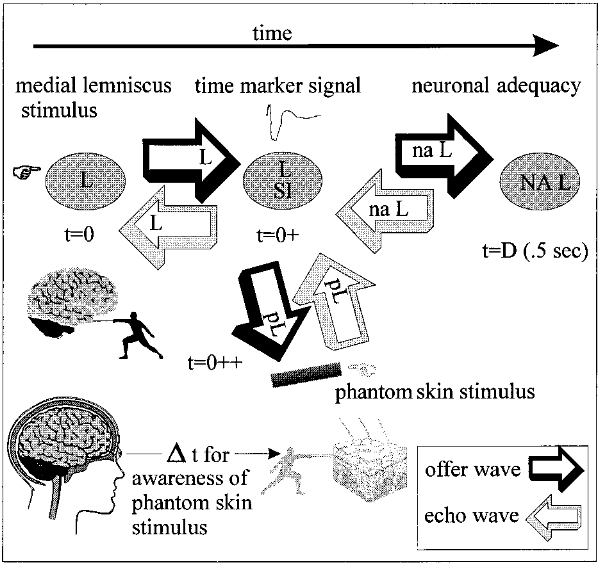

Fig. 9. Here a thalamus stimulus is applied at $t{=}0$. The phantom event for conscious awareness does not occur at a precise time but slightly later similar to what occurs with a real event skin stimulus (Figure 6).

achieved and certainly no awareness took place. When the signal was applied for D or longer, awareness did take place but was always compared with another signal (either another brain signal or a peripheral stimulus). The relative timings experienced support Libet's hypothesis. According to my model, L signals are experienced near the time of onset and not significantly later, provided the L signal train duration is sufficient to achieve adequacy. Paradoxically, but in accord with the TTOTIM, if the train duration is too short, adequacy is not achieved at $t = D$ and no signal is experienced in the earlier interval between $t = 0_+$ and $t = 0_{++}$.

According to the TTOTIM a quantum wave vector, $|L>$, travels forward in time to the somatosensory cortex arrival area SI where it elicits a time marker signal at $t = 0_+$. From here two signals are sent out: the state vector, $|na\ L>$, representing the cortical wave train signal leading to neuronal adequacy at $t = D$ and a forward-through-time phantom offer wave, $|PL>$, that arrives at $t{=}\,0_{++}$ (slightly after the L signal reaches SI) touching the skin site associated with the SI site where neuronal adequacy was achieved. The time reversed echo state vectors, $<na\ L|$ and $<PL|$, then go back in time to SI which initiates the time reversed echo, $<L|$, to return to L at $t = 0$, completing the whole cycle. The phantom event for conscious awareness does not occur at a precise time but accordingly subjectively somewhere in the interval Δt between time $t = 0_+$ and $t = 0_{++}$, or similar to what occurs with a skin stimulus, but, and this is essential for the theory, slightly later. The setup $[L\ SI \rightarrow NA\ L]$ causes the earlier projection $[L\ SI \rightarrow PL]$ due to the presence of the time marker. There is no

space-time projection associated with the $|L\rangle$ wave vector since this vector originates in the thalamus.

Thus both *S* and *L* signals elicit time marker signals at *SI* while *C* signals do not. Libet explains that all signals regardless of where the onset site exists require adequacy — a time delay to become conscious. My theory explains the time order of the awareness of passive stimuli events and predicts that phantom or projected experiences whose origins are brain-based will appear later than their associated time marker events (if they occur) while peripheral stimuli will become conscious earlier than their time markers. It answers the question, "How are we to explain the fact that even though *L* elicits a time marker signal, there is no awareness of this signal unless neuronal adequacy is achieved?" The answer becomes apparent when we realize that space-time projection and therefore sensation does not occur unless neuronal adequacy does and then it occurs in reference to the time marker.

6. The Thalamus and Space-time Projection

Libet's experiments suggest that sensory inputs in passing through the thalamus or medial lemniscus, elicit time marker signals. This may indicate that the thalamus is responsible for the origination of the time marker signal and that the specific space-time projection mechanism arises there. In Figure 10, in comparison with Figure 6, we have added a relay through the thalamus showing how a skin stimulus passes through the thalamus in order to elicit a time marker at *SI*. At $t = 0$ a skin stimulus is applied (*SS*). A quantum wave vector, $|S\rangle$, travels forward in time to the thalamus where a thalamus signal is initiated at $t = 0_{+}$ (15 msec) Next the quantum wave vector, $|L\rangle$, elicits a time marker signal occurring at $t = 0_{++}$ in the somatosensory cortex arrival area *SI*.

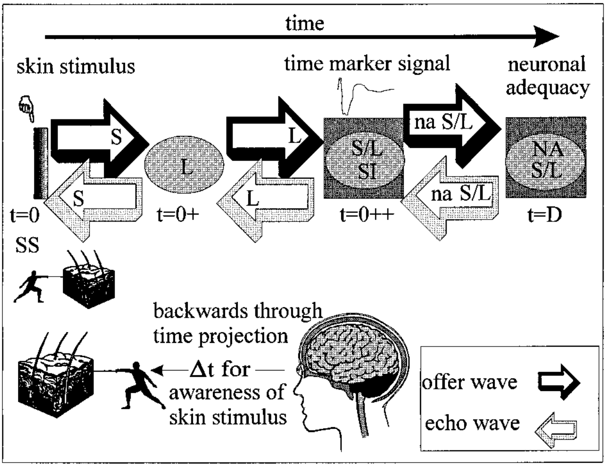

Fig. 10. A possible explanation of the relationship between the specific projection mechanism involving the thalamus and Libet's hypothesis/paradox.

As time continues the state vector, $|na\ S/L>$, representing the wave train signal involving both the thalamus and SS is elicited leading to neuronal adequacy at SI which occurs after the delay time D (taken to be 0.5 sec). Next, the time reversed echo state vector, $<na\ S/L|$, goes back in time to $t = 0_{++}$ where it initiates the backwards-through-time state vector, $<L|$, that returns to the thalamus initiating the backwards-through-time state vector $<S|$ that returns to the site of the skin stimulus completing the whole cycle. The actual event for conscious awareness occurs in the interval Δt between time $t = 0$ and $t = 0_{+}$.

A Comparison of Figure 9 and Figure 10 shows that direct thalamic stimuli leading to awareness as phantom skin experiences occur in the interval between $t = 0_{+}$ and $t = 0_{++}$ *after* the explicit time marker signal arrives ($t = 0_{+}$) at SI, while skin stimuli leading to awareness as real skin experiences are experienced between $t = 0$ and $t = 0_{+}$ *before* $t = 0_{+}$.

In each figure the setup occurs between the appearance of the time marker signal and the achievement of neuronal adequacy. However, the projections are different. One setup (Figure 9) $[L\ SI \rightarrow NA\ L]$ projects the imagined or phantom conscious experience $[L\ SI \rightarrow PL]$ forward-through-time and the other setup (Figure 10) $[S/L\ SI \rightarrow NA\ S/L]$ projects the real conscious experience backward through time in two steps $[L \leftarrow S/L\ SI]$ and $[S \leftarrow L]$.

The key factor is the eliciting of the time marker signal. This fact suggests a reason based on evolutionary theory for the projection mechanism itself.

7. The Space-time Projection Mechanism: Evolution and Experimental Data

One could speculate about the reasons nature would allow such a seemingly bizarre projection mechanism and its early appearance in the lower mid-brain. The answer seems to be connected with perception, evolution, and survival — the ability to orientate within space and time. All peripheral sensory inputs to the brain (with some slight alteration in the case of smell) must pass through the thalamus before they reach the cortex, where any mechanism leading to interpretation or perception can occur. Evolutionary studies of the brain itself indicate the cortex, was a later development and that the order of the brain's evolution lies within its structure. Hence the thalamus was a primordial development, probably part of the early hominoid brain, and it would follow that the ability to project spatial and temporal experience was vital for the further evolution of the species.

The main function of the thalamus appears to be the provision of time marker signals which act as reference markers enabling a being to orientate in space and time — to determine just where and when a particular stimulus occurs. Relativity has taught us that a single event cannot be referred; only a pair of events can possess referrals — one to the other. Any absolute time or location of an event would not have any meaning. While this is certainly true in physics, it may be a surprise that a similar referral structure involving pairs of events occurs in the conscious operation of the brain. Before there is any awareness there must be referring pairs of events, leading to the projection of a temporal/spatial interval. This has surprising consequences. (See Table 1.)

The theory predicts that real stimuli are experienced as a result of backwards-through-time projections from the event of the achievement of neuronal adequacy to the occurrence of a time marker signal (first event pair, $SSI \leftarrow NA\ S$) and an earlier backwards through time projection to the actual skin site (second event pair, $SS \leftarrow SSI$). Phantom stimuli are experienced as a result of forward through time projection either [$C\ SI \rightarrow NA\ C$] or [$LSI \rightarrow PL$] to the stimulus site from the cortex. Since cortical stimuli do not elicit time markers the time difference between a real and a cortically induced phantom stimulus will be easy to detect and Libet's experiment certainly shows this.

But what about comparing skin and thalamic stimuli? It should be possible to measure this time difference by arranging for simultaneous time marker signals from stimuli to the skin and thalamus. The predicted temporal shift in conscious perception could be as much as 20 msec but is more likely to be in the neighborhood of 10 msec with the thalamic stimulus being perceived slightly later than the skin. Although this is very close to call, the experimental results obtained by Libet appear to confirm this result.

Subjective timing orders of experiences for skin and thalamus stimuli (taken

TABLE 1
Subjective timing orders, indicated in msec,
of experiences for skin and thalamus stimuli (taken from p. 210, Table 2a of Libet *et al.,* 1979).

Test	Subject[9]	Lag time	Corrected lag time	No. of trials	Skin first	Tie	Thalamus first
1)	D(H)	–250	–265	6	0	0	6
2)	B(H)	–200	–215	10	0	0	10
3)	C(G)	–200	–215	10	0	4	6
4)	B(G)	–200	–215	8	0	2	6
5)	D(H)	–150	–165	4	1	0	3
6)	B(H)	–100	–115	10	1	6	3
7)	B(G)	–100	–115	8	0	8	0
8)	C(G)	–100	–115	10	0	8	2
9)	B(H)	0	–15	10	1	9	0
10)	D(H)	0	–15	4	0	4	0
11)	B(G)	0	–15	9	4	2	3
12)	C(G)	0	–15	10	2	6	2
13)	B(H)	100	85	10	1	8	1
14)	B(G)	100	85	7	4	2	1
15)	C(G)	100	85	10	6	3	1
16)	D(H)	150	135	5	3	2	0
17)	B(H)	200	185	10	10	0	0
18)	B(G)	200	185	10	8	1	1
19)	C(G)	200	185	10	8	1	1
20)	D(H)	250	235	5	5	0	0

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[9] Subject D(H), *e.g.*, means a particular block of tests labeled *D* for a particular subject labeled *H*. There were two subjects listed here, *G* and *H*. There were four blocks of tests, *A* through *D*. In some blocks both subjects were used while in others only one was used.

from p. 210, Table 2a of Libet *et al.,* 1979, p. 210) are shown in Table 1. Stimuli were applied to the sub-cortical thalamus or medial lemniscus and to the skin. Three sets of data were taken. Tests were arranged for the stimuli to be delivered simultaneously, with the skin stimulated after the thalamus (negative lag time), and finally with the skin being stimulated earlier than the thalamus. Lag times ranged between 250 msec to zero. A positive lag time indicates the skin stimulus was applied first. A negative lag time indicates the thalamus signal was applied first.

To compare the results of the experiments with my theory we need to be concerned with when the time marker signals elicited by each stimulus arrives at the somatosensory cortex. Thus I have added a *corrected lag time* (CLT) column to indicate the separation in time between the time markers arriving at *SI* from each stimulus. Taking into account the longer time it takes for a skin stimulus to reach *SI* ($\approx$15 msec) as compared to a thalamic stimulus, all "true" lag times should be as indicated in this column, *i.e.,* conservatively corrected by –15 msec from the previous column.[10]

Since the theory predicts that skin stimuli will be perceived slightly before the arrival of their time marker signals while thalamic stimuli will be perceived slightly later than their time marker signals, this would tend to move the thalamus perception slightly forward in time ($\approx$15 msec) and the skin perception slightly backward (≈ -15 msec) of their respective time markers. Consequently, if the theory is correct, in the first 12 tests we will find the stimuli appearing closer in time with more ties indicated while in the last 8 tests they will appear farther apart in time with less ties indicated.

If the theory is incorrect and there is no time difference associated with the space-time projections as predicted by the theory the sets of data should correspond with equal percentages in corresponding brackets, *i.e.,*

a) the specific percentages of ties and skin firsts in 1) through 8) (CLT ≤ -115) should be the same or slightly greater than the specific percentage of ties and thalamus first in 16) through 20) (CLT ≥ 135).
b) the overall percentages of ties and skin firsts in 1) through 12) (CLT ≤ -15 msec) should be the same or slightly greater than the overall percentage of ties and thalamus first in 13) through 20) (CLT ≥ 85)

The experimental results are:

a) In 66 trials comprising tests 1) through 8) when CLT ≤ -115 msec we see 28 ties and 2 skin first measurements (45%). In the 40 trials comprising tests 16) through 20) when CLT $\geq$ 135 msec (the skin stimulus

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[10] The conduction velocity for a neural pulse is rarely 300 ft/sec. Hence, with this speed, an *SS* pulse from the back of the hand should reach the thalamus in about 11 msec. I have used 15 msec as a very conservative latency to take into account the roughly 1-10 msec delays occurring at synaptic junctions (vesicle emission velocities). I have no idea how many synapses there are between the skin and the thalamus. This number could be significantly high and the conduction velocity could be significantly slower. Lowering the conduction velocity or increasing the number of synapses clearly increases the latency and makes the theory even more tenable.

was applied first) we find only 6 ties and 2 thalamus first indications (20%) in agreement with the theorized projections and contrary to a) above. We point out that the agreement here could partially be due to the unsymmetrical time distribution (-115 *vs.* $+135$ msec). This is perhaps too close to call as favorable to the theory. However, the CLT ≤ -115 data shows 2.25 *vs.*1 ratio to the CLT ≥ 135 data. This, I believe, is too large a difference to be accounted for by the failure of the theory and the slight change in the time symmetry.

b) In tests 1) through 12) (where the thalamus time marker arrives first) 59% (58 out of 99) show ties or skin firsts while in tests 13) through 20) (where the skin time marker arrives first) 33% (22 out of 67) show ties or thalamus first in agreement with the theorized projections contrary to b) above.

One might argue that we have weighted our swings in the above analysis and that we should compare the original time lags data not the corrected data. This would tend to dismiss tests 9) through 12) since they are all simultaneous and only compare tests 1) through 8) with tests 13) through 20). In this case the theory predicts more trials showing ties or skin first in tests 1) through 8) and fewer trials showing ties or thalamus first in tests 13) through 20) than would be expected if the theorized projections did not occur (equal percentages). Nevertheless, comparing the data we find 45% of tests 1) through 8) showing ties or skin first as compared to 33% showing ties or thalamus first in tests 13) through 20) in tentative agreement with the theorized projections.

On the other hand, an increase of the CLT to 25 msec which could imply a neural conduction velocity of 200 ft/sec and approximately 18 synapses between skin and thalamus (I do not think this unreasonable) would render the data of a) above completely symmetrical indicating more tenability to the theory (see Footnote 10).

8. Causality Violation in Sensory and Cortical Stimuli Experiences

Figure 11 illustrates a TTOTIM explanation of Libet's hypothesis/paradox temporal reversal relationship between the timings in cortical and skin stimuli.

The comparison with Figures 2(e) and 3(c) shows what transpires when two stimuli are applied with a delay of fD ($0 \leq f \leq 1$) between them. At $t = 0$ a cortical stimulus is applied (*C SI*). C leads to a quantum wave vector, $|na\ C>$, initiated at the cortical stimulus site *SI* travelling forward in time. As time continues, a train of pulses is elicited leading to neuronal adequacy at $t = D$. This elicits a phantom state vector, $|pS>$, that travels forward in time arriving at $t = D_+$ at the area of the skin associated with the particular site *SI*. The time reversed echo state vector, $<pS|$, goes back in time to $t = D$ where it initiates the backwards-through-time state vector, $<na\ C|$, that returns to the onset site of the original cortical stimulus at $t = 0$, completing the cortical cycle. At $t = fD$ a skin stimulus is applied *(SS)*. This leads to a quantum wave vector, $|S>$,

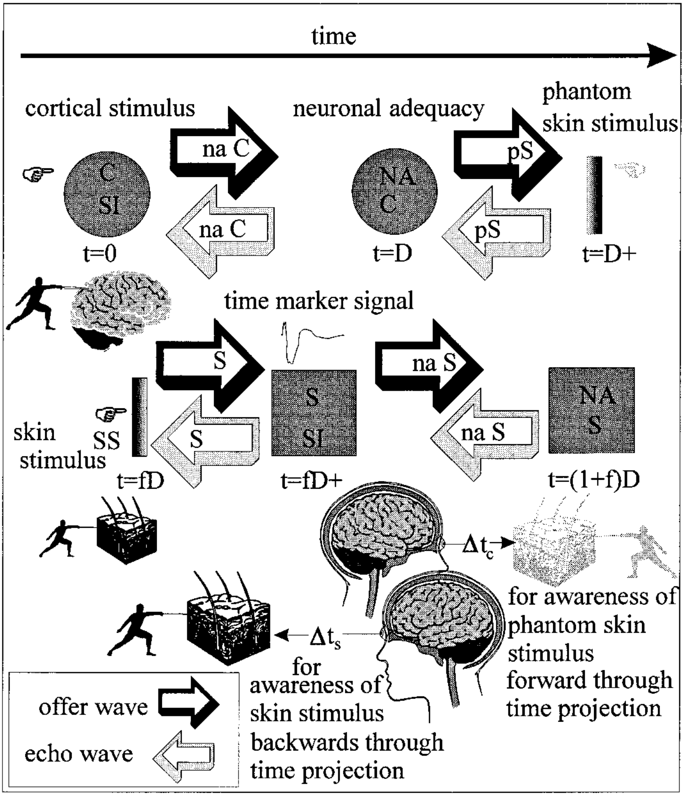

Fig. 11. An explanation of Libet's hypothesis/paradox temporal reversal relationship between the timings in cortical and skin stimuli. Subjectively, the event for conscious awareness of the skin stimulus occurs earlier than the phantom awareness of the cortical signal even though the cortical signal was applied first.

travelling forward in time to time to $t = fD_{+}$ at the somatosensory cortex arrival area *SI* where it initiates a time marker signal. As time continues, the state vector, $|na\ S>$, propagates forward in time leading to neuronal adequacy at *SI* which occurs after the delay time $(1+f)D$. The time-reversed echo state vector, $<na\ S|$, goes back in time to $t = fD_{+}$ where it initiates the backwards-through-time state vector, $<S|$, that returns to the site of the skin stimulus completing the cycle. Subjectively the phantom awareness of the cortical signal appears to occur in the interval Δt_c between $t = D$ and $t = D_{+}$ while the event for conscious awareness of the skin stimulus occurs somewhere in the earlier interval, Δt_s, between $t = fD$ and $t = fD_{+}$.

Since the cortical stimulus does not elicit a time marker signal, the corresponding phantom skin projection occurs well after the skin stimulus. It is only when the fraction $f = 1$, corresponding to the skin stimulus being applied D later, are the stimuli sensed to be simultaneous.

9. Conclusion

We have explored a quantum physical theory of the paradox of the relationship of awareness and associated physical events, including application of stimuli and the achievement of neuronal adequacy that elicit it. This paradox was first pointed out by Libet in a series of experiments involving human subjects where a comparison of timings associated with direct cortical and subcortical stimulation along with peripheral stimulation was possible. I have shown that a reasonable argument exists showing that quantum physics pertains to the operation of the brain and nervous system. In particular the operation of synaptic vesicle emission and gating function within the neural wall and the spread in its wave packet are governed by the uncertainty principle. I have shown that the phenomenon of "wave function collapse" or the change in the probability of a process associated with the action of a measurement affects neural operation and leads to an uncertainty in timing of conscious events. I conclude that the action of conscious awareness occurs as a result of this collapse mechanism.

Next we examined a model of the supposed collapse based on Cramer's TI and the TTO of Aharonov *et al.,* (1990). The model explains the relationship between physical — exterior — events, mental events, and their projection into space-time. We have discovered both stimulation and neuronal adequacy (two events) are needed for the apparent conscious (one event) experience. The apparent time and location of a physical sensation are projected into time and space: the time and the location of the experience are referred to the associated peripheral sensation whether phantom or real.

The question, "Is there *really* an 'actual time' at which a conscious experience takes place?" I have answered *negatively* indicating, however, that while a precise timing for such an event does not occur, awareness of peripheral, passive, sensory input must take place before the cortex has achieved neuronal adequacy while awareness of phantom or "fill-in" experience produced by cortical stimuli must take place after. Sub-cortical stimuli, applied to the thalamus or to the medial lemniscus, lie on the borderline between peripheral and direct cortical stimuli. Stimuli applied here result in the generation of time marker signals which play a role as referents for both temporal and spatial projection — the specific projection system. Passive, peripheral, sensory inputs are perceived slightly before a time marker arrives at the somatosensory cortex (*SI*) and direct thalamic or lemniscal stimuli are perceived slightly after. We have come to this conclusion using the TTOTIM which indicates both initial and final events are necessary to determine what occurs in the time interval between them.

One of the new and exciting predictions of this theory is the difference between the timings of phantom (thalamic) and real sensory stimuli. The theory predicts and experiments appear to confirm that phantom or projected images of sensations originating in the thalamus must become conscious *after* the arising of the temporal markers elicited at *SI* while "real" external sensory sensations must reach awareness *before* the time markers arise. We will sense "real" things before we project our mental maps of these experiences onto them but will compare these sensations slightly later. If two time markers are made to simultaneously arise at $t = 0$ one coming from L and the other from *SS*, the *SS* sensation will become conscious 15 msec *before* $t = 0$ and the L sensation will become conscious about $\approx$15 msec *after*. This appears to be tentatively borne out by experiment (see Table 1). The results are close, to be sure, and it is natural and necessary that they be close, to be encouraging for the theory. Assuming that images, memories of sensory inputs, and real sensory data involve the thalamus and the specific projection system within (and consequently elicit time markers), it would follow that the overlap between what we sense "out there" and what we project "out there" as experience must occur in reasonably close proximity. This may be the reason for the early development of the specific projection (lemniscal) system. Clearly any long delay as between real sensory inputs and cortical projections (memories or sensory images) that do not elicit time markers could lead to extinction of the species.

Finally I would like to add some thoughts regarding peripheral somatic stimuli, Parkinson's disease, and some prospects for further experimental research regarding the TTOTIM. Libet has already indicated that when the body is subjected to synchronous stimuli, the subject responds without any indication of asynchrony or subjective jitter. Given that a variety of stimuli would produce a variety of intensities and pulse/train duration one would expect, if there was no backward-through-time projection from the time when neuronal adequacy was achieved, to experience a lot of jitter due to the various times when adequacy would be achieved. Since this does not occur it indicates support for the theory.

It is now known that people suffering from Parkinson's disease suffer from what appears to be asynchronous jitter. I suggest that for some reason a Parkinsonian subject's thalamus in response to somatic stimuli has lost the ability to provide adequate time marker signals. Consequently, synchronous stimuli result in asynchronous behavior or the familiar jitter observed. When electrical stimuli are delivered to the thalamus it is known that the subject's jitter stops or is minimized considerably. I suggest the reason for this is the artificial supply of time markers provided by electrical stimulation. Experiments with Parkinsonian subjects may offer a new source of experimental information regarding the specific projection mechanism and the proposed projection timings indicated by the TTOTIM.

10. Speculations

When it comes to *time* in physics, we are somewhat at a loss. All of our equations are unique in one very real sense, there is no specific order to the sequences of events we label as the passage of time. Both Newtonian physics and quantum physics share this apparent fault in disagreement with our common sense experiences. We could just as well write equations and set up appropriate spatial and temporal boundary conditions of retrodiction in place of prediction and feel equally satisfied that we had the correct equations. Indeed, if we do simple enough experiments we find that retrodicting is as good as predicting when it comes to determining what shall be happening in the next sequence of events either following or preceding.

In life, with all of its complexity and its ultimate human measure, *time* marches on. Fallen cracked eggs do not jump off the floor into our outstretched hands. Dead loved ones do not reconstitute themselves and resurrect. We grow older each day not younger. How are we to ever explain this scientifically and fundamentally? It would seem that we are missing something essential when it comes to time.

Two bits of data we know. Conscious experience of events and the second law of thermodynamics. The first bit is subjective in its context while the second is purely objective. We certainly know that we can think a thought, write a sentence, and find the words are uniquely time ordered. We certainly know of the fact that hot bodies cool down and cold bodies warm up. Is there some connection between these data bits?

So far we have no theory that connects them. While much as been done in the objective arena to connect thermodynamics and statistical mechanics to quantum mechanics, even some remarkably clever insights, we still do not have a fundamental theory connecting them. Given Planck's constant, the speed of light, the gravitational constant, and the mass of any particle you wish to mention, we cannot derive Boltzmann's remarkable constant of nature.

In the world of subjective experience very little has been done by physicists and for probably very good reason; no one knows what to do, what to measure, or even if it is ethical to perform such measurements even if we knew what we were looking for. Here Libet's remarkable experiments need special mention. At least in them we are provided with a clue concerning subjective time order. Perhaps there is something fundamental in the notion that our equations are not time order unique and the theory given here that according to subjective experience we need two or more separate events to have a single perception. Perhaps this theory that a perceived event requires information flowing from end points coming before it and after it, much like a stringed musical instrument requires information coming from its nodal end points to set up standing wave patterns of musical harmony, is a fundamental requirement for both time order uniqueness and subjective experience.

It would seem to me that now we need to look toward altering our concept of time in some manner, not that this is an easy thing to do. Perhaps we should begin with the idea that a single event in time is really as meaningless as a single event in space or a single velocity. Meaningful relation arises as a correspondence, a relationship with some reference object. Hence an object's velocity is meaningfully measurable with respect to another object's velocity as the relative velocity between them. In a similar manner as I point out in this paper, the timing of an event is also only meaningful in reference to another timing event. When the end points or reference times for the events are not specified, then only the relative interval becomes relevant. When that interval lies within the limitation of quantum uncertainty, the event referred to within the interval must also lie within that uncertainty. Failure to note this leads to apparent timing paradoxes.

The resolution of temporal paradoxes particularly as they show themselves in future quantum physical objective experiments and in subjective timing experiments will continue to require a new vision of time. Perhaps this paper will assist us in our search for a new theory of time.

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