Empirical Research on the Radical Subjective Solution of the Measurement Problem. Does Time get its Direction through Conscious Observation?

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Abstract. In a number of experimental studies we explored the so-called 'radical subjective', and rather controversial, solution of the measurement problem. This solution posits that an interaction with a conscious entity is required to complete the measurement. Thus the collapse of the wave packet is assumed to be causally linked to a conscious observation. Under the assumption that the brain is sensitive for the difference between observing a quantum (superposition) state and a classical state this radical solution can be tested. A radioactive source was used to trigger beeps that first were delayed for 1 second and then were observed by a (final) observer from whom a continuous recording of brain activity was made. In about 50% of the events, another (pre) observer got feedback of this quantum event *before* the final observer. In those cases, presumably the pre-observer's observation resulted in collapse of the wave-packet while in the other half of the cases the final observer was 'producing' the collapse. The brain signals of the final observer for the two types of events were compared. The ambiguous results of the studies will be discussed. If consciousness is the crucial ingredient for 'collapse' to occur, then this might also give a new anthropocentric hypothesis with regard to the 'arrow of time'. The projection postulate implies a irreversible process of reduction and hence can be seen as one of the few non time-symmetric processes in physics. If consciousness is required to have a collapse then it might follow that consciousness introduces time asymmetry into physics. New neuro-cognitive models of consciousness suggest that the neural correlate of conscious experience (rather than non conscious processing) is the occurrence of massive parallel recurrent (i.e. non linear) neural activation. Thus the collapse of the wave packet would become associated with a strong non-linear process. This fits, at least in a metaphorical sense, with the theoretical results where an introduction on a non linear term in the Schrödinger equation results in an 'objective' reduction of the wave packet.

Keywords: Measurement Problem, Subjective Reduction, Time's arrow, Retrocausality
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INTRODUCTION

Almost all physical formalisms are time-symmetric [1]. The equations produce pairs of solutions, one of them with time running forward, the other with time running ‘backward’. In the theory of electro-magnetism Maxwell’s equations produce a so-called ‘forward’ but also a ‘retarded’ wave [2]. In classical billiard-ball mechanics it is impossible for us to discriminate between a film showing billiard ball collisions and the same film running backwards as long as friction is left out of the picture.

The phenomenon of friction is generally taken as the starting point to explain where the preferred direction of time arises in physics. The formal embodiment of this is the second law of thermodynamics stating that closed systems always develop in the direction of increasing entropy. There is no way back. The explanation for the second law is generally phrased in probabilistic terms [3]. There are many more states with increased entropy than there are states with reduced entropy.

Some sophisticated criticism has been proposed [4] claiming that this and other ‘explanations’ fail because it introduces some time direction through the backdoor. In other words it assumes what it has to explain. Boltzmann himself, who is thought to be the source of the statistical argument, at a given moment contemplated an anthropocentric ‘explanation’ [5]. Of course this met with extreme hostility because of the ideal of a totally objective physics. In the current paper a further argument suggesting the anthropocentric nature of the origin of time direction, rooted in the measurement problem of quantum physics, will be presented. Subsequently a review is given of the experiments that aimed at testing the proposal.

The Collapse as Origin of Time Direction

Quantum Physics has formalisms (for instance the Schrödinger equation) that, like in classical electrodynamics, also allows for two solutions. But these solutions concern potentialities, not actualities. The transition between potentiality and actuality is called the collapse and since Bell [6] we are forced to interpret this as an actual and real event that happens at or at least is related to the measurement, whatever that is. We believe that the collapse, or transition from the potentiality into actuality, might also been seen as the origin of the second law of thermodynamics. It can be argued that the projection postulate in fact results in a loss of information and hence in an increase of chaos or entropy. Of course the collapse is a ‘process’ that applies to atomic states and has never been intended to describe multi particle systems that are generally the focus of the 2^{nd} law.

If this interpretation is correct then it can be seen as an extra argument to focus our efforts on the ‘collapse’ as the source of time-asymmetry. But even without this identification of entropy growth with ‘collapse’ the fact that the projection cannot be reversed intrinsically is reason enough to direct our attention on the collapse if we want to understand the source of the ‘times arrow’.

Measurement Problem

'The measurement is whatever physicists do with a measurement device'. This definition is practical but circular. Measurement should be defined with reference to an outside criterion because everything within the physical system, including the so-called measurement apparatus, is governed by the Schrödinger (or an equivalent) time symmetric formalism. It was von Neumann who was the most outspoken to make this argument explicit [7]. The specification of what constitutes a measurement and how 'collapse' occurred or is triggered is the source of the measurement problem. Many solutions have been proposed some of them, like the many world interpretation [8] apparently farfetched, others like the introduction of non linear terms in the Schrödinger equation leading to self-collapse [9], having unpleasant secondary effects. It at least indicates that there is a real problem if one wants to understand rather than just work with quantum theory.

The least popular among the solution of the measurement problem is the so-called 'radical subjective' solution. It proposes that a measurement is only a measurement if there has been an interaction with a conscious observer. This is only a solution if one assumes that consciousness is 'different' from physical systems and does not follow the physical formalisms. The proposal thus is dualistic at least till the time a deeper theory might unify the description of consciousness with physics. The skeptical position is that consciousness is not a fundamentally different system, it just is an epiphenomenon produced by an immensely complex physical system like our brains.

Rather than delving into this philosophical discussion we prefer to test this proposal empirically following the ideas originally put forward by Abner Shimony's group in Foundations of Physics [10].

Empirical Indications of Time Symmetry or 'Retro-Causality'

For many physicists the empirical fact that we don't seem to observe time symmetry, no advanced waves, is enough reason to declare ad hoc that although two solutions are mathematically possible in Maxwell's formalism, one is excluded. This is of course not very satisfactory for theoretically inclined and mathematically driven physicists like Wheeler and Feynman [11] but for almost all practical purposes this axiom will work. However, there are a few empirical instances where indeed it looks like 'advanced waves' are at work. The experimental evidence is slowly accumulating that humans and possibly other living organisms are showing behavior that seems to be driven by future conditions i.e. retro-causally, rather than in a normal forward causal way.

These experiments generally stimulate subjects in some random way and measure 'consequences' of that stimulation before the stimulus is presented. Timescales are in the seconds range. The results do suggest that under specific conditions time symmetry may be restored. In 1997, for instance, it was found that subjects did show increased skin conductance before they were presented with emotional pictures [12]. This hardly happened before neutral pictures in spite of the choice what type of picture to present was completely random (with replacement). Interestingly this effect was not present when the pictures' exposure time was short (~ 100 msec), too short for a full comprehension of the contents and meaning [13]. In other psychological research on the effect of emotional material on human behavior it had been found that subliminally presented emotional material could have stronger effects [14]. The results of this experiment however suggested that for retro-causality to appear, conscious observation was a requirement. Here we will present a short review of such an experiment with a slightly different approach recently done at the University of Amsterdam.

The Slotmachine experiment, an example of effect preceding cause.

Thirty-two subjects participated in a 128 trial slot machine task. The task was simply betting and observing the outcome and each trial was initiated by the subject. With intervals of one second the three windows of the slot machine froze.

FIGURE 1: Slot machine as presented to the subjects. The picture shows the final state after all three fruits had stopped spinning. This is an example of the XYZ condition (all three fruits different)

There were three types of clips with different outcomes: three subsequent different fruits (XYZ), two equal fruits followed by a different one (XXY) and three equal fruits (XXX). The clips were selected randomly with replacement from a limited pool of possible clips. The subject had to pay 0.5 euro (real money) for each trial and received 7 euro for winning (XXX) events. The a priori probability for an XXX-event was 12.5% throughout the experiment. The subject could not know nor learn what the next fruit to be displayed would be. The subjects kept the money they won at the end but never had to pay when they eventually lost money.

Following other brain research with slot machines [15, 16] we analyzed the pooled medio-frontal signals from the Fz, Cz and Pz lead, using pre-processing parameters specified in the literature. There was a significant difference between the slow wave preceding a 'win' and preceding a loss (XYZ) (t= 2.76, df=31, p=0.01). This difference can be explained by the fact that after the first fruit has been 'frozen' the subject is aware that in the XYZ condition the possibility for a win has vanished.

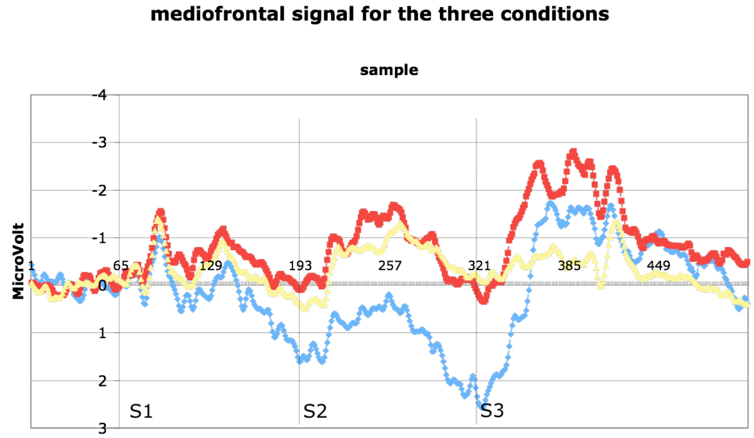

FIGURE 2. Average brain signal pooled from electrodes Fz, Pz and Cz. The slot machine freezes it's first fruit at -1.0 (s1), the second on 0.0 (s2) and the third at 1.0 seconds (s3). Yellow trace: XYZ condition (all fruits different). Red trace: XXY condition and Blue trace: XXX (win) condition.

However the difference was observed to develop before the second fruit froze i.e. before there was any visible difference between the conditions. This anomaly was confirmed by a comparison of the XXY and the XXX condition where, for the relevant period from 1 to 2 seconds, where the two types of clips were identical, nonetheless the brain signals differed by about 1.9 microvolt on average (t= 2.34, df=31, p=0.026).

These results were not significantly associated with 'perceived luckiness' although the 15 subjects who perceived themselves as 'lucky' did have a much larger effect of ~ 2.9 microvolt compared with the other subjects (~0.6 microvolt).

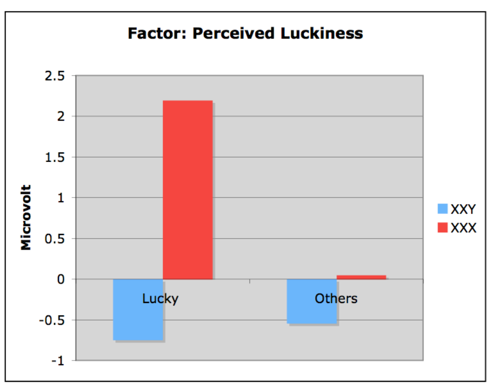

FIGURE 3. The results split for subjects that consider themselves 'lucky' or 'unlucky'

Exploratory analyses showed very suggestive evidence for the effect of sustained attention and of the belief to be able to 'influence' the slot machine. It is not unusual in the neuroscience literature to identify Consciousness with Attention.

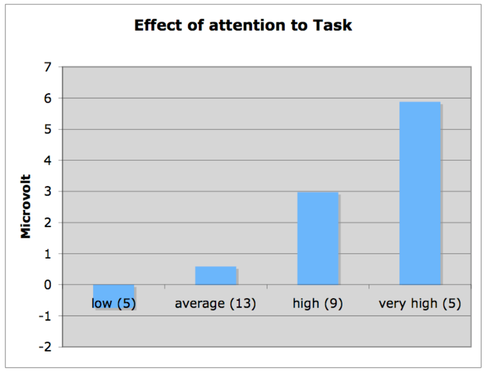

FIGURE 4. Results for subjects with low, average, high and very high attention to the task

The conclusion of this experiment was that these results, in combination with the growing database of similar experiments [17,18] suggests that under specific conditions cause and effect might be reversed. In order to understand this apparent restoration of time-symmetry it is mandatory to understand the origin of time's arrow.

SCHRÖDINGERS CAT AND RADIOACTIVE DECAY

In the quantum mechanical theory of (e.g. radioactive) emission from a single atom, a nucleus (or equally true, a collection of nuclei) is regarded as being in a superposition of an "undecayed" state and a "decayed" state. The Schrödinger evolution of quantum states does not place hard restrictions on ascribing this superpositioned state to the entire composite system of nuclei and their measuring apparatus. This gives rise to the "Schrödinger's Cat" thought experiment*: "A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The psi-function [the wave packet] of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts." (Schrödinger, 1983; translation by J. D. Trimmer)".*

Of course we don't perceive the world as composed of superpositioned states; so although the theory of quantum mechanics lets us predict the indeterminate behavior of (superpositioned) particles on the microscopic scale with remarkable accuracy, the same theory cannot account for the fact that we do get definite determinate results when a measurement is undertaken. An additional *projection postulate* has to be introduced. Schrödinger continues: *"It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be resolved by direct observation."* When, for instance, we observe a Geiger counter (or when we open Schrödinger's box and take a look) the states in superposition seem to have been collapsed into a singular state (the cat is either dead *or* alive). The Schrödinger evolution does not account for this transition, leaving the different quantum states evolving in a state described by a state vector. However, when the possible states of a physical system are known, these can be described as a wave packet[1], making possible the calculations of encountering the quantum system in a certain state (using Born rules). Measuring a property (e.g. magnetic momentum or 'spin') of this quantum system, will lead to the discovery of a certain value of this property (e.g. 'spin up') corresponding to one of the superpositioned quantum states. The value is then ascribed to the system –the projection postulate-, which somehow seems to have been transitioned into a singular state. This transition from a quantum- to a singular state, has been termed the "collapse of the wave packet" and it has been a problem ever since. This problem that for some time could be hidden by assuming that the state vector represented our 'lack of knowledge' rather than an actual and real state of affairs became explicit after Bell showed that not only our knowledge but also the physical situation of a system actually changed upon measurement. What constitutes a measurement thus has become an extremely important question.

Many attempts have been undertaken to remove the measurement problem, like the Relative State interpretation [8], leading to exotic proposals as the Bare Theory [19,20], the Many Worlds interpretation [21], the Many Minds theory [19] and the Many Histories theory [22]. Hidden variables are introduced in Bohmian Mechanics [24, 25] giving a deterministic character to Quantum Physics while substituting the measurement problem with a preparation problem. None of these attempts including the many attempts to introduce non linearity in the quantum formalism [9], with an automatic collapse as a consequence have received universal acceptation. This failure to clearly resolve the problem has left the physics community polarized with some contending the problem remains a fundamental shortcoming in the quantum formalism and others holding that there is no reduction of the wave packet at all [25, 26]. Costa de Beauregard [27], Walker [28,29,30] and later Stapp [31.3]) have argued, using arguments provided by a.o. von Neumann [7] and Wigner [33], that none of these solutions are acceptable and that subjective reduction is still a possible and even preferred alternative.

CONSCIOUSNESS AND QUANTUM PHYSICS

Most main stream physicists assume that relating Consciousness to Quantum Physics is an example of supposing a relation between two not well understood phenomena just because both are not well understood. Although this might often be the case in the popular literature there are two noteworthy exceptions. They are noteworthy because both proposals do result in testable predictions. And interestingly both are related to the Measurement Problem.

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[1] We use the terms 'wave packet' and 'state vector' both as referring to the superposition of potential outcomes.

Objective Reduction

Penrose [33, 34] proposed an Objective Reduction, in which the difference between the superpositioned states, expressed in space-time gravity, determines the moment of wave packet reduction. He even goes as far as proposing that our minds are capable of sustaining and selectively collapsing superpositioned states - coined Orchestrated Objective Reduction (OrchOR) -, giving rise to a.o. non-computable properties of conscious experience. In other words the conscious experience is a consequence of the 'collapse' of the state vector describing the non conscious brain states preceding a conscious moment. The idea here is that non conscious processing utilizes quantum computing and is highly parallel in nature while the conscious moments are like the outcomes of the preceding quantum computing. This model has been attacked on several grounds. First of all it seems not to fit well with the traditional chemical models of brain functioning that until now seem to describe processes underlying mental events rather satisfactorily. Secondly the proposal that coherent quantum events do play a fundamental role in the warm and wet environment of the brain has met lot of opposition. However ultimately any theory should be tested against empirical findings and the OrchOR model makes several testable predictions.

In the same vein the second 'subjective reduction' proposition that Consciousness is 'external' to physics and plays the crucial causal role in the collapse of the state vector can be tested empirically. Like Hall et al. [10], we do not wish to quarrel theoretically about positions with regard to the proper interpretation of the quantum formalism and the role of measurement therein, but like Hall and his collaborators we would like to investigate the issue experimentally.

Previous empirical Work on Subjective Reduction

In 1977, Hall, Kim, McElroy and Shimony addressed the measurement problem of quantum physics in an experimental way, investigating the rather radical proposal of subjective reduction [10]. Stating "*that the reduction of the wave packet is a physical event which occurs only when there is an interaction between the physical measuring apparatus and the psyche of some observer*", they proposed a dualistic ontology in which mental entities interact with the physical world, leaving both changed and consequently subjectable to scientific scrutiny.

In the Hall experiment, particles of a gamma emitter were detected and fed into two scalars, A and B, the latter getting a slightly delayed signal in respect to the first (see Figure 5).

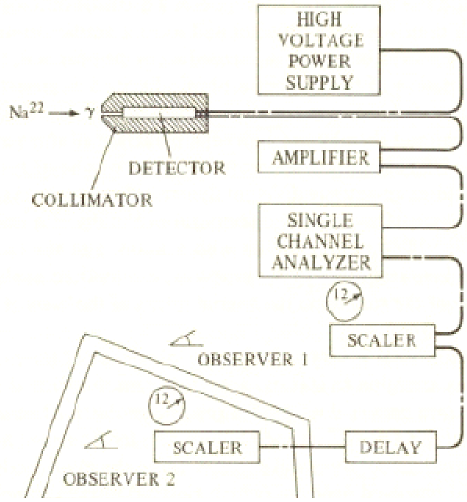

FIGURE 5. Halls Experimental SetUp. Reprinted from [10].

The observation of a radioactive decay by a subject on one of the scales will supposedly collapse the wave packet into the “decayed” state. When the decay has first been observed on scalar A and subsequently, after a short delay, by a different subject on scalar B, the latter is supposed to observe a then already singular state. Hall designed his experiment so that sometimes scalar A is observed before scalar B, and sometimes scalar A is not observed at all, leaving the quantum state to be collapsed only by observing scalar B. The subject at scalar A was asked to sometimes look at the scalar, and sometimes look the other way. Of the subject at scalar B (the final observer) he asked to report if he/she thought that he/she was observing a quantum or a singular state. The comparison between both subjects revealed a 50% (chance) agreement. It was concluded that the experiment did not provide support for the hypotheses that it is the interaction with consciousness that causes the wave packet to collapse.

However, the authors did not only assume that (i) the interaction of the psyche of an observer with the physical apparatus is responsible for the reduction of the wave packet, but also assumed (ii) that there is a phenomenological difference between making an observation which is responsible for the reduction of a wave packet and making one that is not. The second assumption led the authors to an implicit third assumption, namely (iii) that this difference can be communicated consciously.

In 2003, we further tested the hypothesis of subjective reduction. He noted that if consciousness is expected to collapse the wave packet (i), a conscious report will be based on the physical state of the wave packet after consciousness has developed. At that time, it was presumed, the wave packet will already be collapsed even if no pre-observation has taken place at all [36].

In Hall’s arrangement, the delay between the first and the second observer was a very short one (1 μsecs). Hall himself noted in the discussion of his article that it might be argued “*that the μsecs delay of the pulse to B’s scalar does not suffice for A to be unequivocally responsible for the reduction of the wave packet in case both of them make observations*”. Stated otherwise, the short time-delay between the pre- and second-observer may not give the pre-observer enough time to experience the quantum event consciously, not leading to the collapse of the wave function, before the second observation occurs. However according to the neuroscientist Libet [37] it takes far more time for an observation to be experienced consciously (300-500 ms), and therefore an experiment was designed accordingly. In this experiment, instead of asking the second observer for a consciously report of the state of the observed event, his/her EEG was measured. This measurement made it possible to tap into the pre-conscious experience of the subject, yielding objective measures of the (possibly but not necessarily phenomenological) experience (ii) of the quantum event before consciousness develops. This bypasses the inherent weakness of Hall's design (iii). Also, the time delay between the two observers was increased, far beyond Libet's interval, till 1000 milliseconds (1 second), giving the pre-observer ample time for conscious experience before the second observer comes into play. See Figure 6 for a conceptual presentation of both experiments.

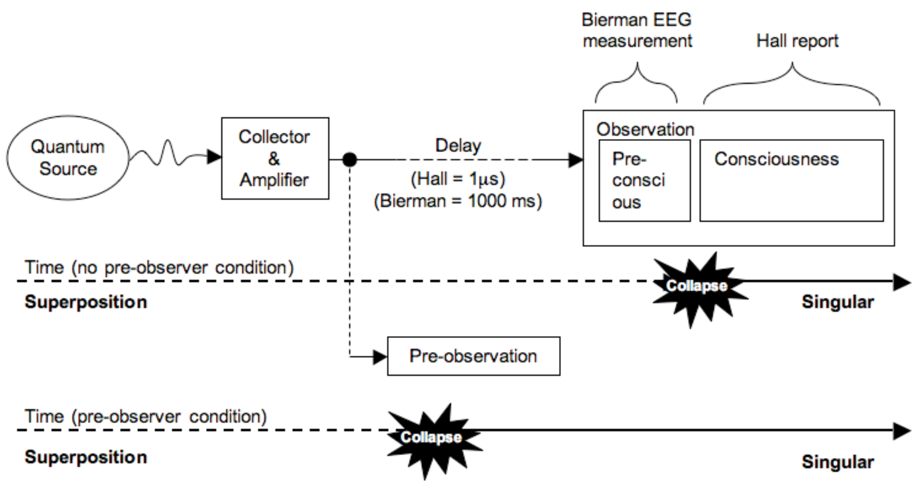

FIGURE 6. Design and time-line of the Hall experiment in which conscious report always occurs at the already singular state, and the first replication with a pre-conscious measurement in superposition-time.

The results of the first (2003) experiment of the University of Amsterdam group were very promising [36]. The differences in the ERP traces of the two pre-observer conditions reached statistical significance on three of the ten peaks that were analyzed. Namely the N20 ($p = 0.043$), P40 ($p = 0.013$) and N200 ($p = 0.0005$), at exactly 17, 41 and 212 ms after stimulus onset. We permitted ourselves to draw the following two preliminary conclusions: "(a) With regard to the signal from frontal and central leads there is a significant difference between the conditions in the very early peaks. This difference is gone after about 100 milliseconds. (b) On the parietal leads the difference is into the other direction and arises later with a clear maximum at 200 milliseconds. The results seem to support a solution of the measurement problem that gives a special status for conscious observation in the measurement process. Furthermore, the absence of significant differences in the late evoked potentials appears to be in line with the fact that in the original Hall experiment no differences were found when one asked the second observer to consciously express his feeling if the observed quantum event had already been observed. This finding should, however, be treated cautiously because of the lack of statistical power in the later phases of the response. This lack of power is caused by the increased variance with increasing latency times...” ([36] pp. 53-54).

The possibility of sensory cueing of the second observer should be considered. This was the reason behind the use of different modalities for presenting the quantum event. While the first observer was observing a visual representation, the second observer was hearing an audio-beep through a headphone. Although both observers were in different rooms, these were adjacent and not auditory or electromagnetically shielded. Ultrasonic or electromagnetic signatures from the monitor displaying the signal to the first observer might still have presented sensory cues to the final observer.

Although the results of the first experiment look pretty robust, they are not extremely improbable in terms of statistics. As the author himself noted, one may argue that the reported *p*-values might be inflated due to the analysis of 10 peaks without applying a Bonferoni correction for multiple analyses. Although peak N200 will easily survive this correction, as the author duly remarked: “*strong claims need strong evidence*”.

The Second Experiment

The second experiment further investigated the possibility of subjective reduction. Globally following the design of the first experiment an important extra condition was added comparing events originating from a pseudorandom classical source with quantum events. *We expecedt to have the differential EEG effect found in the first (2003) experiment to appear in the latter but to disappear in the former condition as the quantum character of the event is presumed crucial*.

In the first experiment [36], the analysis was cautiously restricted only to peak amplitudes. Of these peaks, the effect was strongest during the first 200 ms after stimulus presentation, specificly at N20, P40 and the N200. Our primary analysis will be focussed on these peaks. More explicitly, only in the quantum condition do we expect the peak amplitudes of N20 and P40 to be increased and the N200 to be decreased in the non pre-observer condition with respect to the pre-observer condition. We expect no significant differences in (any) peak amplitudes for the classic event trails.

In our new investigation of the role of consciousness in the collapse of the wave function, our independent variables will thus be the classical/quantum source, and the pre-observer condition. Our dependent variable will be the final observer’s auditive evoked potential (AEP) as measured by EEG on the scalp (see Figure 7). We expect to find a difference between the pre-observer conditions only for the quantum trials (*AEP III* minus *AEP IV*).

	NO Pre-observer	**pre-observer**
Classical event	*Final observer AEP I*	*Final observer AEP II*
Quantum event	*Final observer AEP III*	*Final observer AEP IV*

FIGURE 7. Dependent (italic) and independent (bold) variables

Experimental Design of the second experiment

The new design is schematically depicted in Figure 8. Quantum events will be generated by an alpha particle source (as used in smoke detectors; 2P40-76-18), mounted on a slider that allows the source to be moved with respect to a Geiger-Muller counter (Automess 6150-100). The distance is set so that on the average 1 particle about every 1,2 second will be detected. The counter pulse is then amplified and fed to the trigger channel of an EEG data acquisition system (*Biosemi Active-2*, 2003). *National Instruments LabView* software (NI, 2003) is used to detect this trigger and to transform it, after a delay of 1000 ms, into a 1500 Hz audio beep of 50 ms duration. It is followed by a subsequent delay (dead time) of 2000 ms. The software will randomly, on 50% of the trails, generate a visual stimulus of ~65 milliseconds duration *directly* upon the trigger. The visual stimulus therefore precedes the audio-beep by a time (1000 milliseconds) sufficient for the first observer for consciously experiencing the quantum event *before* the second observer. Both subjects will be asked to count the number of observed (quantum and classical) events.

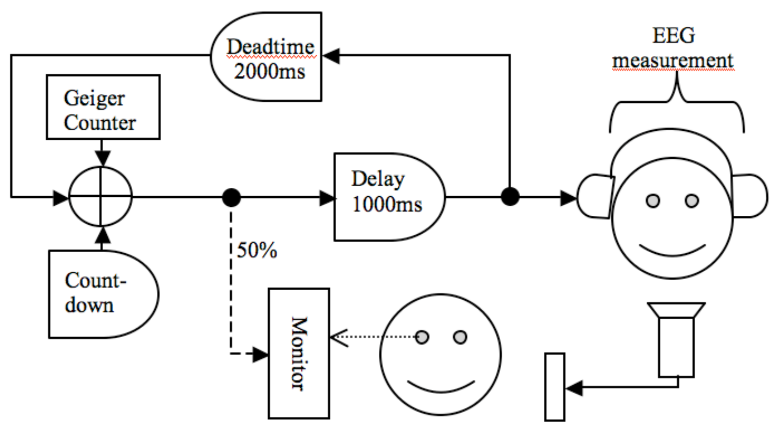

FIGURE 8. Experimental design of second experiment. Note that the separated locations of the subjects are not shown. The crosshair depicts the alternating choice of quantum/classical event (absent in the first experiment [36]).

For simulating the radioactive decay in a classical way we reasoned that computer processes could also be affected by quantum mechanical principles. This will make the classical attribution of the processor's internal randomizer questionable. So instead of simulation radioactive decay by using the internal randomizer, we recorded the radioactive decay, in milliseconds, continuously for some time using the exact same experimental constellation as would be used in the actual experiment. Forty inter-decay intervals were thus measured and put into a table (see Table 1).

The random decision to show the visual stimulus to the first observer, before submitting the beep to the second observer or not, is pseudo random with the seed determined by the computer clock. The argument of a possible quantum character of the randomizer does not apply here as it is a condition *within* a quantum/classical condition, not between. Following from our postulate, (pre-)observing will always collapse the wave function, also when it is prior decided to occur by quantum probabilities. Should the randomization create a quantum superposition of pre-presentation/no-pre-presentation (of the quantum or classical event to the pre-observer), this will occur in *both* classical and quantum condition and will not explain a resistant *differential* AEP effect.

TABLE 1. Decay times in milliseconds.

21	825	860	829
836	62	534	4564
1005	252	1161	2323
1703	1806	403	920
2096	1207	1824	1614
18	5302	1394	958
644	569	87	673
3477	535	305	171
421	163	264	2455
181	912	4809	1485

After each quantum event measured there is a dead time of 2000 ms during which the input of the Geiger-Muller counter will be discarded and after which a countdown starts with the time-delay as indicated by Table 1. Upon the generation of this singular event, *exactly the same procedure as for the quantum event* will be followed. The sequence of quantum/classical event is thus alternating in which the table is read successive. Randomization of the occurrence of these conditions was considered. We wanted, however, to replicate the previous experiment as accurately as possible. By using this setup, the classical condition could be an almost exact copy of the quantum condition. The Geiger-Muller input had only to be replaced by the table of decay times. See Figure 9 for a conceptual representation. We think this setup approaches a more formal replication.

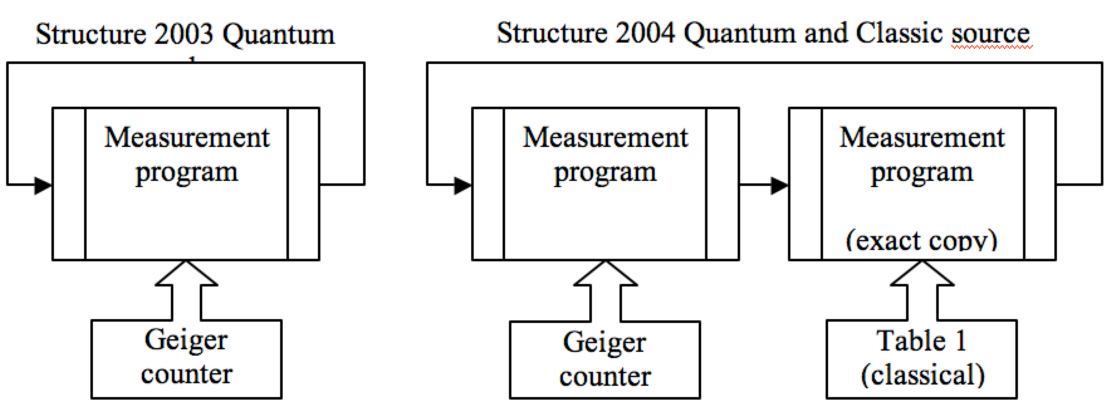

FIGURE 9. Illustration of internal program structure.

The video connection (see Figure 8), as was already implemented in the first experiment, will again be used in the current experiment. Were this visual connection not made, a transfer of information (e.g. by selectively collapsing the wave function by the pre-observer resulting in a difference in brain potentials of the second observer -an instant morse code) could transgress the light cone, violating the relativity theory.

Experimental Procedure second experiment

Subjects

Volunteer subjects were invited in pairs. They were generally freshman psychology students who participated for course credit. In total, 10 males and 53 females participated in the experiment providing useful data. One subject was removed from the analysis due to improper recording of the brain signals. The role of observers 1 and 2 were played by both subjects in two separate runs.

Physiological Measurement

Thirty-four sintered AgCl EEG electrodes (consisting of 32 leads and 2 reference electrodes) with active preamplifiers (*Biosemi Active 2*) are connected to the head of observer II using the standardized 10/20 system (Electrocap, see Appendix 1) for placement details. EEG recordings (2048Hz sample rate) are made using *National Instruments LabView* software (NI, 2003). The subject is then seated into a relaxing chair and given pneumatic earphones (Earlink; Aearo Company Auditory Systems). The experimenter and the other subject then leave the room.

Further Procedure

First, a short ‘calibration’ experiment is run consisting of an odd-ball task in which observer II is presented with an audio beep of 30 ms duration for every 3 seconds (with one second random jitter). Hundred beeps with either a frequency of 1200 Hz or a frequency of 2000 Hz will be presented. The choice of frequency is randomly determined with the probability for the higher frequency being 20%. The subject will be asked to count these higher frequency beeps. When the task is finished the experimenter asked for the number of beeps counted.

The ‘Schrödinger’ run will be started with observer I sitting in front of a computer screen in the experimenters room, observing the visual stimulus. The experimenter refrains from looking at the screen. The total run consists of 65 radioactive decay events and an equal amount of computer-generated events. This takes about 12 minutes. Afterwards both subjects will be asked about the number of events they witnessed. After a short break roles will be switched and the procedure repeated. The total experiment takes less than 1,5 hours, including the preparation of the subjects.

Data analysis

First a 50 Hz notch filter is applied. Then the data are filtered through a band pass filter between 1 and 45 Hz (slopes = 24 Db/Oct). The data is then down-sampled to 256Hz (as the original 2048Hz will only slow down computing).

The data is then manually inspected for non-eye artifacts after which the data is segmented into segments ranging from 2000 ms *before* until 1000ms *after* stimulus presentation. Those segments that contained manually selected artifacts are ignored and excluded from further analysis. This segmentation retains the maximum of valid EEG data for the subsequent ICA (independent component analysis) algorithm.

The ICA algorithm is thus run over as much data as possible. In our case this is the segmented data from which only the non-eye artifact were removed. No separation into conditions is yet made. The ICA algorithm then starts “learning” in the sense of *unsupervised competitive learning*, eventually coming up with the best solution for explaining the signal in independent components. This results in a component-electrode weight matrix. It is then to the experimenter to determine which components originate from eye-blinks or eye-movements. This is quite easily done after some practice, by comparing the components with the actual EEG-trace and by mapping the components on a head-model. However, when the EEG trace is only minimally disrupted by eye-artifacts, the algorithm will not always return suitable components as the variance, that will be explained by such components, will be small comparable to more dominant sources. This is also the reason that large non-eye artifacts must first be (manually) removed as they can take on a large part of the total variance. The more eye-artifact, then, the better the ICA algorithm will be able to identify their source. To finally clean up the signal, the weights of these components on the electrodes are made zero and the EEG trace is then again composed by linear derivation of the remaining components and the ICA matrix.

To remove those subjects that contributed most to noise in the total average, cross-correlations between the individual average AEP and the total average AEP signal (of all subjects) will be computed. Subjects that correlate low ($r < 0.80$) will be excluded from further analysis.

The data is then segmented and averaged *per condition*, after which a baseline correction (250 msec till 0 msec before stimulus) is applied over all segments.

In the analysis of the first experiment the electrodes were combined in a *Frontocentral* (C3, C4, Cz, F3, F4, F7, F8, Fp1, Fp2, Fz) and a *Parietal* (P3, P4) pool. As our data acquisition was done with a different number of electrodes (32 instead of 16), a different pooling will be used. Combinations will be formed on the basis of correlations between electrode signals in the oddball task.

Per pooling, the peak latencies of the average of all conditions are determined. These latencies are used to measure and compare the peak amplitudes of the different conditions.

Results second experiment

We calculated the correlations between all electrodes and from these we created four pools, namely a *Frontal* (AF3, AF4, F7, F8, Fp1, Fp2), *Frontocentral* (F3, F4, FC1, FC2, Fz), *Parietal* (C3, C4, CP5, CP6, FC5, FC6, T7, T8) and *Occipital* pool (CP1, CP2, O1, O2, Oz, P3, P4, P7, P8, PO3, PO4, Pz). All electrodes within one pool correlated at least 0.90.

The cross-correlation indexes between the individual average AEP signals and the total average AEP signal (of all subjects) were calculated. All those subjects with a correlation index r smaller than 0.80 were removed from further analysis. This resulted in the removal of 15 subjects in the Oddball task (leading to an average $r = 0.90$ with 48 subjects instead of $r = 0.85$ with 63 subjects) and 15 subjects in the

Schrödinger task (leading to an average r = 0.90 with 49 subjects instead r = 0.86 with 64 subjects). All subjects reported a close approximation of the number of beeps (give or take 5). The ICA algorithm resulted in nicely cleaned-up signals.

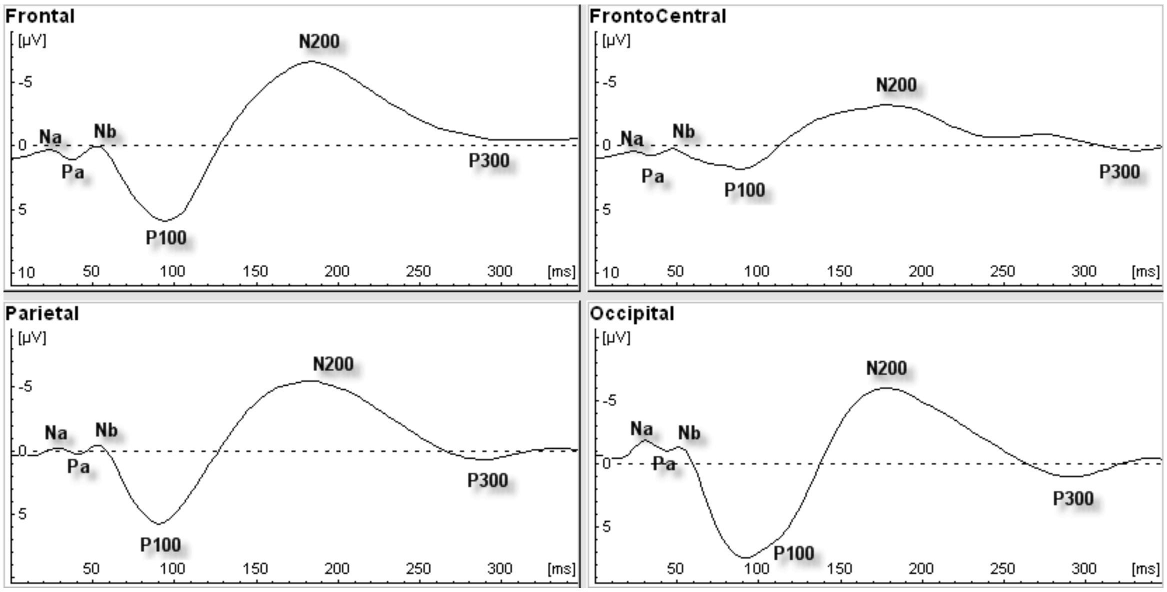

FIGURE 10. Peaks of the average of all conditions.

The peak latencies of the AEP trace, as measured from the average of all conditions, are shown in Figure 10. In Table 3, the peak amplitudes of the quantum and classical pre-observe conditions are compared.

Differences of amplitude on the peaks between the pre-observe conditions were tested for statistical significance using a standard t-test. The results are also shown in Table 2. None of the differences between peak amplitudes in pre-observed and not pre-observed condition did reach statistical significance in contrast with the first experiment.

TABLE 2. Peak latencies (in milliseconds), amplitudes (in μV) of all conditions per pooling. t- and (2 tailed) p-values of the difference between pre-observed and not pre-observed condition										
			Classic		***C-Diff***		***Quantum***		***Q-Diff***	
	Peaks	***Lat***	***I***	***II***	***t (df=49)***	***p***	***III***	***IV***	***t (df=49)***	***p***
Frontal	**Na**	23	-0.181	-0.169	-0.060	0.952	-0.175	-0.395	0.736	0.465
	Pa	39	0.536	0.757	-0.892	0.377	0.426	0.545	-0.435	0.665
	Nb	51	-0.502	-0.321	-0.674	0.503	-0.681	-0.44	-0.961	0.341
	P100	94	4.901	5.281	-1.284	0.205	5.800	5.65	0.386	0.701
	N200	184	-7.266	-7.335	0.145	0.885	-7.137	-6.748	-1.364	0.179
	P300	301	-1.131	-1.036	-0.255	0.800	-0.679	-0.933	0.778	0.440
FrontoCentral	**Na**	23	-0.134	-0.021	-0.816	0.418	-0.088	0.031	-0.589	0.559
	Pa	35	0.522	0.402	-0.798	0.429	0.149	0.183	-0.218	0.828
	Nb	47	-0.300	-0.198	-0.482	0.632	-0.450	-0.175	-1.264	0.212
	P100	90	1.064	1.195	-0.531	0.598	1.565	1.445	0.417	0.678
	N200	180	-3.819	-3.646	-0.742	0.462	-3.841	-3.542	-1.519	0.135
	P300	332	0.000	-0.056	0.198	0.844	-0.294	-0.119	-0.799	0.428
Parietal	**Na**	27	-0.396	-0.434	0.101	0.920	-0.475	-0.515	0.296	0.768
	Pa	39	0.005	0.137	-0.485	0.630	-0.013	0.056	-0.178	0.859
	Nb	55	-0.802	-0.601	-0.862	0.393	-0.747	-0.549	-0.636	0.528
	P100	90	5.208	5.415	-0.886	0.380	5.584	5.632	-0.212	0.833
	N200	184	-5.957	-6.019	0.246	0.807	-5.468	-5.528	-1.451	0.153
	P300	289	0.309	0.189	0.385	0.702	0.596	0.737	-0.537	0.594
Occipital	**Na**	31	-1.444	-1.534	0.261	0.795	-1.599	-1.384	-0.712	0.480
	Pa	43	-0.829	-0.639	-0.616	0.541	-0.666	-0.467	-0.68	0.500
	Nb	51	-1.146	-0.894	-0.890	0.378	-0.943	-0.795	-0.503	0.617
	P100	90	7.543	7.990	-1.474	0.147	7.425	7.81	-1.021	0.312
	N200	180	-5.707	-5.362	-1.052	0.298	-5.908	-5.373	-1.598	0.116
	P300	293	1.173	1.249	-0.417	0.678	1.322	1.833	-1.419	0.162

We also did an *explorative* analysis of the differences between de AEP from the quantum source and the classic source. No differentiation was made between the (pre-) observed states. The results are shown in Figure 11 and Table 3.

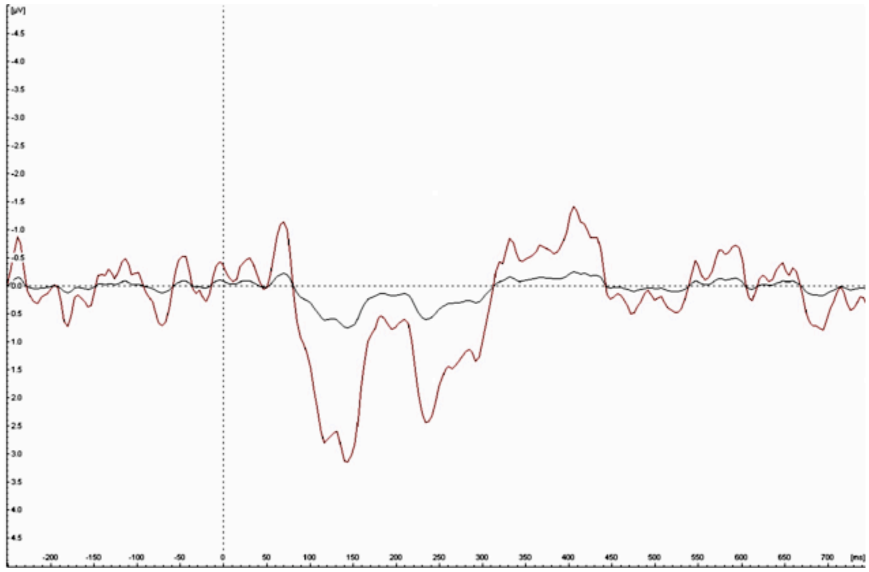

FIGURE 11. Difference wave of AEP of quantum (pre- and no-pre-observed) and classic (pre- and no-pre-observed) origin with t values overlaid in red.

TABLE 3. Differences of AEP peak amplitudes from the quantum and classic source.

	Peaks	Classic	Quantum	Classic -Quan	*t (df=49)*	*p (2-tailed)*
Frontal	**Na**	-0.287	-0.182	-0.105	-0.503	0.617
	Pa	0.485	0.642	-0.157	-0.808	0.423
	Nb	-0.554	-0.416	-0.138	-0.683	0.498
	P100	5.725	5.074	0.651	2.697	***0.010***
	N200	-6.956	-7.279	0.323	1.200	0.236
	P300	-0.834	-1.090	0.256	1.096	0.278
FrontoCentral	**Na**	-0.033	-0.066	0.033	0.230	0.819
	Pa	0.165	0.322	-0.157	-1.052	0.298
	Nb	-0.307	-0.258	-0.049	-0.447	0.657
	P100	1.503	1.126	0.377	2.457	***0.018***
	N200	-3.700	-3.718	0.018	-0.068	0.946
	P300	-0.237	-0.047	-0.190	-1.311	0.196
Parietal	**Na**	-0.508	-0.413	-0.095	-0.515	0.609
	Pa	0.006	0.070	-0.064	-0.352	0.726
	Nb	-0.659	-0.695	0.036	0.178	0.859
	P100	5.612	5.309	0.303	1.242	0.220
	N200	-5.477	-5.979	0.502	2.301	***0.026***
	P300	0.633	0.238	0.395	1.984	***0.053***
Occipital	**Na**	-1.513	-1.488	-0.025	-0.143	0.887
	Pa	-0.587	-0.742	0.155	0.687	0.495
	Nb	-0.888	-1.028	0.140	0.640	0.525
	P100	7.633	7.765	-0.132	-0.774	0.443
	N200	-5.652	-5.538	-0.114	-0.454	0.652
	P300	1.536	1.204	0.332	1.508	0.138

Conclusion

No significant differences were found between peak amplitudes of the auditory evoked brain potentials when a quantum event was first observed and when it was secondly observed. A difference of the N20, P40 (frontal leads) and N200 (parietal leads) was expected on the basis of the results of the first experiment [36]. To replicate these results, care was taken to minimize differences in experimental setting and data analysis. Some technical differences were made, though, so one could question if they could account for our inability to replicate the previous findings.

First, in order to reduce the total variance, quite a few subjects were removed from the analysis by comparing individual traces with the total average of all subjects. Subjects that correlated low were supposed to be noisy. One could argue, however, that the sought-for effect is only manifest in a minority of subjects who would therefore differ from the total average and be erroneously removed from analysis. We regard this as improbable because the difference would more likely consist of noise from bad recordings than of real signal. To be sure, however, we applied the same analysis on the 15 rejected subjects. We found no significant brain signal differences between the pre-observed and not pre-observed conditions.

Secondly, instead of removing all data that was confounded by eye-artifacts, we used the ICA algorithm to subtract the artifact from the EEG trace and therefore retained almost all of the recorded data. It remains difficult to assess which of the two procedures removes most of the error variance. A smaller error variance would of course result in larger *p*-values. However, if we focus on effect-size rather than p-value we observe that the amplitude differences in the current study are about 40% of the values obtained earlier. It is unlikely that amplitudes are systematically affected differently by the two procedures. However, we cannot exclude the possibility that the 'collapse' effect is in some way included in the eye-artifact components and thus (erroneously) removed.

There were also three differences that might have had a conceptual consequence.

Firstly, the presentation of the beeps by loudspeakers was replaced by air-pressure headphones. In our view it is not likely that this could account for a different response from the (post-) observer. It should be noted though, that the pre-observer in the previous experiment could remotely hear these beeps and thus the formal description in terms of observation was different.

Secondly, in the first experiment the subjects were made fully aware of the video connection between the two rooms. Therein care was taken that the pre-observer made some glances at the video monitor to ensure an interaction of 'states' of both observers enters the state description of the experiment. An instruction for this purpose or a thorough explanation about its implications was absent in our experiment.

Finally and possibly most importantly, there is a possible conceptual difference between the two experiments. The observation by the pre-observer in the second experiment was incomplete in the sense that this observer was unaware if (s)he observed a quantum event or a classical event. One could argue qualitatively that this lack in knowledge corresponds to only a partial collapse and hence a situation where pre-observation does not really makes a difference or makes a smaller difference for the final observer. Interestingly under this assumption one would expect a smaller of no difference between the pre-observed and not pre-observed condition but one still would expect a difference between the classical and the quantum events. This is exactly what was found; Some consistent differences were found when comparing the AEP of quantum events with those of classic events (see Figure 10 and Table 4). No differences were expected on the basis of identical beep frequency, duration or simulated decay-times between events. Only the latter could possibly differ between the two conditions. The table of classical latencies was generated by recording the radioactive decay in the same experiment. Radioactive decay, however, has such a large variance that it is difficult to ensure a perfect simulation. When we later compared the average of the table with the average of radioactive events that occurred during the recording of the subjects, we noticed considerable differences. The real quantum events had average latencies that sometimes fell below a tenth of those of the table. The selection was therefore unlucky. It is not, however, straightforward to attribute the differences to this difference in latency. When one expects a stimulus at a certain time, a Contingent Negative Variation (CNV) will precede the moment of stimulation after which the AEP will start at a more negative baseline. In the AEP of the frontal and frontocentral pooling this CNV is clearly seen (Figure 9 and 10 between 250ms and 0ms before stimulus), in which there does not seem to be a differential effect between conditions. A CNV will only have an effect on the amplitude, not on the latency of early endogenous components. Also, the difference wave (Figure 11) shows a consistent difference in the positive direction. This cannot be explained by a difference of latency for that would result in a difference wave that crosses the baseline. It must be explained in terms of a difference in surface. Interpreting this difference, however, is inappropriate at this stage of investigation and needs further investigation.

Further Research: Experiments 3 and 4.

Further investigation is needed to determine the conditions under which subjective reduction can take place. We differed in our experiment with the first one in the emphasis we placed on the video connection. Making hereby sure the 'states' of both observers are included in the state description of the experiment could very well be crucial, as was already remarked, and should be included as a variable in further investigations.

A question already posed in [36] remains unanswered: "*So far the concept of a conscious observation has not been worked out in detail. In Libet's work, which we used to estimate the delay between perceptual input and the conscious experience thereof, the conscious observation is by definition an observation which is stored in memory. However there is suggestive evidence, for instance from 'change blindness' experiments, that there is another form of 'faster' conscious experience directly related to perceptual input (Landman et al, 2003). This experience is not stored in memory. In further work it might be necessary to discriminate between these and possibly other forms of conscious experience.*" (pp. 55). To ensure a conscious memory of the observed events, several suggestions can be made. The observed events can be remembered by introducing differing stimuli. In other words; the stimuli can be made more complex so that they can be remembered at a later time. This could be accomplished by presenting words or pictures to both observers. Afterwards, conscious memory of these observed events can be tested with a recollection task. Another aspect of conscious experience apart from memory is meaning. The meaning of the pre-observation was vague in the second experiment because the pre-observer was unable to discriminate between classical and quantum events. Thus in a follow up study these two conditions should result in a different feedback for the pre-observer.

To get more control over the quantum events, especially regarding the moment of the event, a different quantum source can be used. For instance, using a Stern-Gerlach apparatus for measuring the magnetic moment (spin) of elemental particles, more clearly dichotomous ('spin-up' or 'spin-down') observations can be made instead of our 'decayed' or 'non-decayed' states.

Seven decades since Schrödinger's "Cat Paradox" (Schrödinger, 1935), the problem of the collapse of the state vector is still a major unresolved issue of modern physics. With the advance of scientific methods, however, we can be hopeful that future scientists can account for these issues that today seem paradoxical. Even now, John Archibald Wheeler, one of the founders of quantum physics, poses the question: *"(...) whether the universe really existed before you start looking at it*." (Wheeler, interview with Tim Folger, 2002). Along with a scientific community that is no longer afraid of these "*ideas for ideas*" as he himself puts it, we, in line with previous experiments [10, 36] show that among these questions, the role of consciousness on the reduction of the wave function can indeed be scientifically investigated.

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