Consciousness and Quantum Physics

Empirical research on the subjective reduction of the statevector

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Abstract

There are two major theoretical perspectives on the relation between Quantum Physics and Consciousness. The first one is the recent proposal by Penrose and Hameroff that Consciousness arises from the collapse of the statevector describing non conscious brainstates (). The second perspective is the proposition that Consciousness acts as the ultimate measurement device, i.e. a measurement is defined as the collapse of the state vector describing the external physical system, due to interaction with a conscious observer. The latter (dualistic) proposition has resulted in the thought experiment with Schrodinger's Cat and is generally considered as extremely unlikely. However that proposition is, under certain assumptions, open to empirical verification. This was originally done by Hall et al (1977). A refined experiment to test the 'subjective reduction' interpretation of the measurement problem in quantum physics was reported by Bierman (2003). In the latter experiment, Auditory Evoked Potentials (AEP's) of subjects observing (previously unobserved) radioactive decay were recorded. These were compared with AEP's from events that were already observed and thus supposedly already collapsed into a singular state. Significant differences in brain signals of the observer were found. In this paper we report a further replication which is improved upon the previous experiments by adding a non-quantum event as control. Differential effects of pre-observation were expected not to appear in this classical condition since the quantum character of the event is presumed crucial. No differential effects were found in either condition, however. Marginal differences were found between the quantum and classical condition. Possible explanations for the inability to replicate the previous findings are given as well as suggestions for further research.

1. Introduction

1.1 The Measurement Problem

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 superpositioned states 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 superpositioned 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

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

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 made to remove the measurement problem, like the Relative State interpretation (Everett, 1957), leading to exotic proposals as the Bare Theory (Albert and Loewer, 1988, and Albert, 1992), the Many Worlds interpretation (DeWitt, 1971), the Many Minds theory (Albert and Loewer, 1988) and the Many Histories theory (Gell-Mann and Hartle, 1990). Hidden variables are introduced in Bohmian Mechanics (de Broglie, 1927; Bohm, 1952) 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 (Ghiradi, 1986), 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 (Bohm and Hiley, 1997; Griffith, 2002; Dieks and Vermaas, 1998). Costa de Beauregard (1976), Walker (1971, 1988, 2000) and later Stapp (1993) have argued, using arguments provided by a.o. von Neumann (1955) and Wigner (1967), that none of these solutions are acceptable and that subjective reduction is still a possible and even preferred alternative.

1.2 Objective reduction and Consciousness

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 tea 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.

Penrose (1989, 1996) 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 (see other chapters in this volume).

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., 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.

1.3 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. 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 1). 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

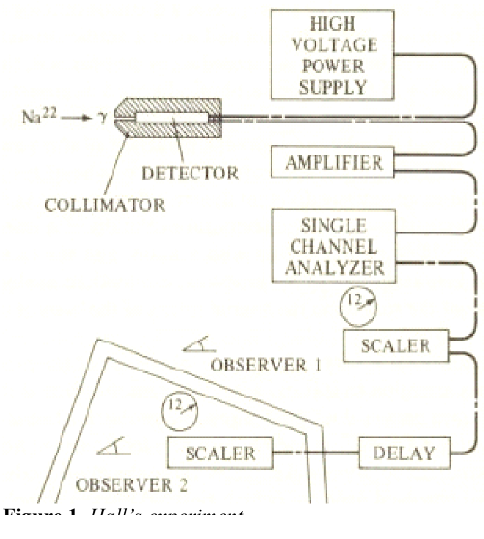

Figure 1. *Hall’s experiment*

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 superpositioned 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, Bierman 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, he presumed, the wave packet will already be collapsed even if no pre-observation has taken place at all.

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. Bierman noted that according to Libet (1991) it takes far more time for an observation to be experienced consciously (300-500 ms), and designed his experiment 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 2 for a conceptual presentation of both experiments.

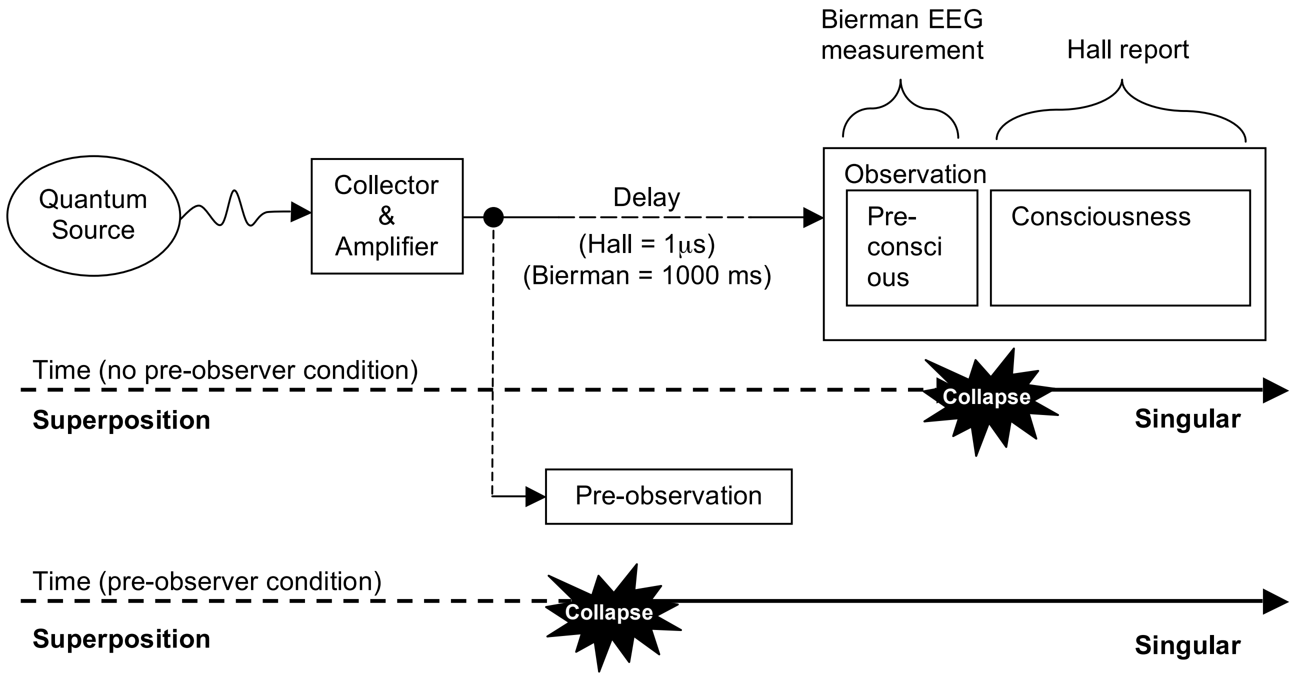

Figure 2. *Design and time-line of the Hall experiment in which conscious report* always *occurs at the already singular state, and the Bierman experiment with a pre-conscious measurement in superposition-time.*

The results of Bierman's (2003) experiment were very promising. The differences in the ERP traces of the two pre-observer conditions reached statistical significance on three of the ten analysed peaks. 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. The author permitted himself to draw the following two preliminary conclusions: "*(1) 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. (2) 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..." (pp. 53-54).*

The possibility of sensory cueing of the second observer should be considered. This was the reason behind Biermans 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 Biermans results 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 remarks: "*strong claims need strong evidence*".

1.4 Current Investigation

The current experiment will further investigate the possibility of subjective reduction. We will compare events originating from a pseudorandom classical source with quantum events. *We expect to have the differential EEG effect found in Biermans (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 Biermans experiment (2003), the analysis was cautiously restricted only to peak amplitudes. Of these peaks, the effect was strongest in 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 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 3). We expect to find a difference between the pre-observer conditions only for the quantum trails (*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 3. *Dependent (italic) and independent (bold) variables*

2. Experimental Design

The current design is schematically depicted in Figure 4. 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.

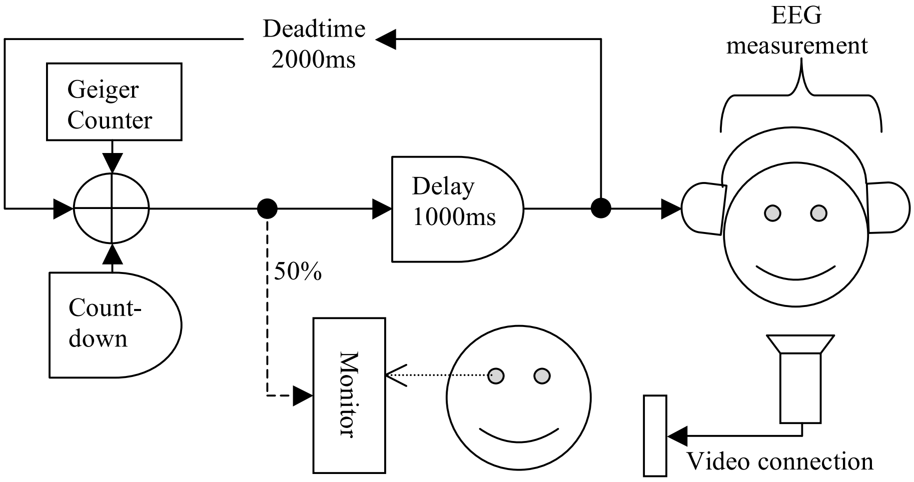

Figure 4. *Experimental design. Note that the separated locations of the subjects are not shown. The crosshair depicts the alternating choice of quantum/classical event (absent in Bierman, 2003).*

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 time-till-next-decay's were thus measured and put into a table (see Table 1).

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

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 randomising 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.

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. Randomising the occurrence of these conditions was considered. We wanted, however, to replicate the previous (Bierman, 2003) 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 5 for a conceptual visualisation. We think this setup approaches a more formal replication.

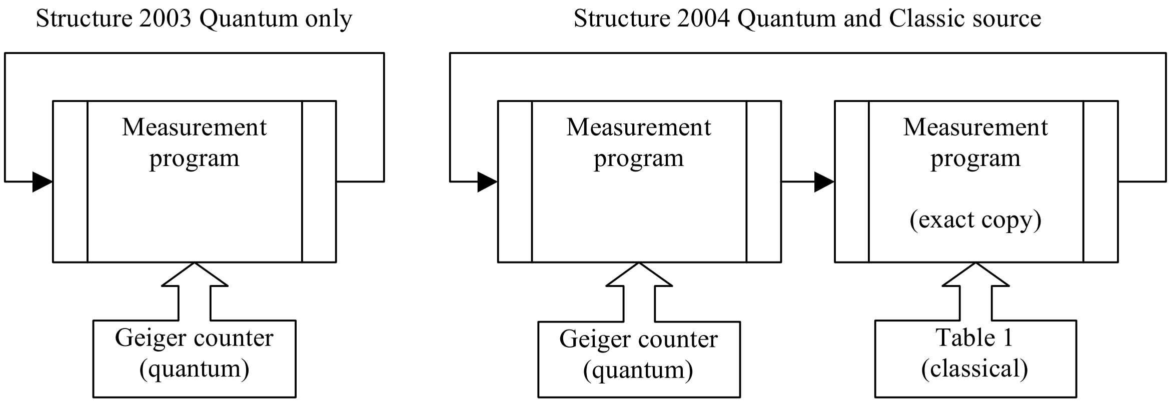

Figure 5. *Illustration of internal program structure.*

The video connection (see Figure 4), as was already implemented in Biermans 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.

3. Experimental Procedure

3.1 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.

3.2 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.

3.3 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.

4. 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 (See Figure 2) for the subsequent ICA algorithm.

The ICA algorithm (see Box 1) is thus run over as much data as possible. In our case this is the segmented data in which only 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.

Box 1. Independent Component Analysis
In the experiment, no electrodes for recording eye-blinks or eye-movements (saccades) are used. Instead, ICA, a recently developed technique for performing blind source separation, will be applied. The ICA algorithm is highly effective at performing source separation in domains where (1) the mixing medium is linear and propagation delays are negligible, (2) the time courses of the sources are independent, and (3) the number of sources is the same as the number of sensors; that is, if there are *N* sensors, the ICA algorithm can separate *N* sources (Makeig et al., 1996).
In our case, we assume that the recorded signals are mixtures of brain signals and artifact signals from eye-blinks and eye-movements. Since volume conduction is thought to be linear and instantaneous, assumption (1) is satisfied. Assumption (2) is also reasonable because the sources of eye activity are not generally time locked to the sources of EEG activity. Assumption (3) could be somewhat questionable when ICA is used for identifying an unknown number of sources. In our case, however, ICA is only used to extract known sources of interference from eye-blinks and eye-movements. For this purpose ICA has been shown to preserve and recover more brain activity than regression and Principal Component Analysis (PCA) (Jung et. al. 2000).

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 (250ms till 0ms before stimulus) is applied over all segments.

In Bierman (2003) 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.

5. Results

We calculated the correlations between all electrodes and decided to create 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) are plotted in Figure 6. 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. See Figure 7 for an example from the data (pp16, segment 25).

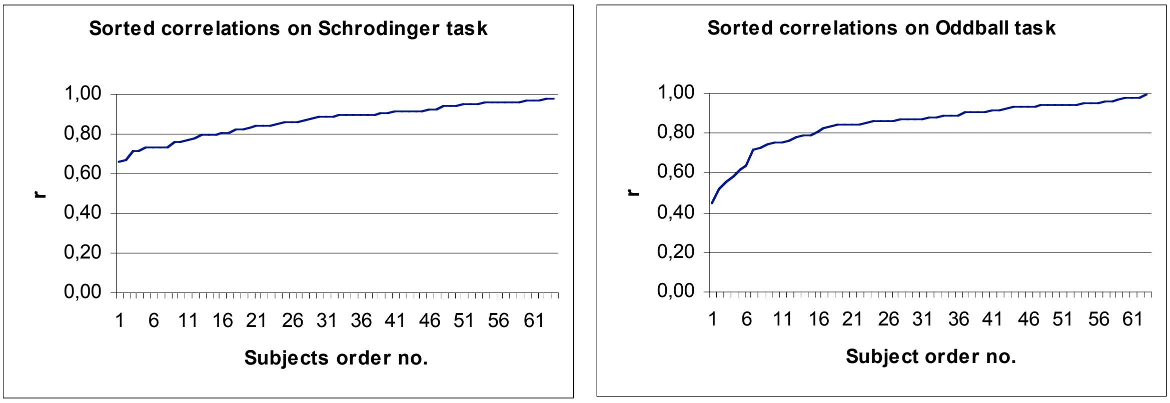

Figure 6. *Correlation of subject's AEP trace with average AEP over all subjects. Note that the subjects are sorted by ascending correlation index r.*

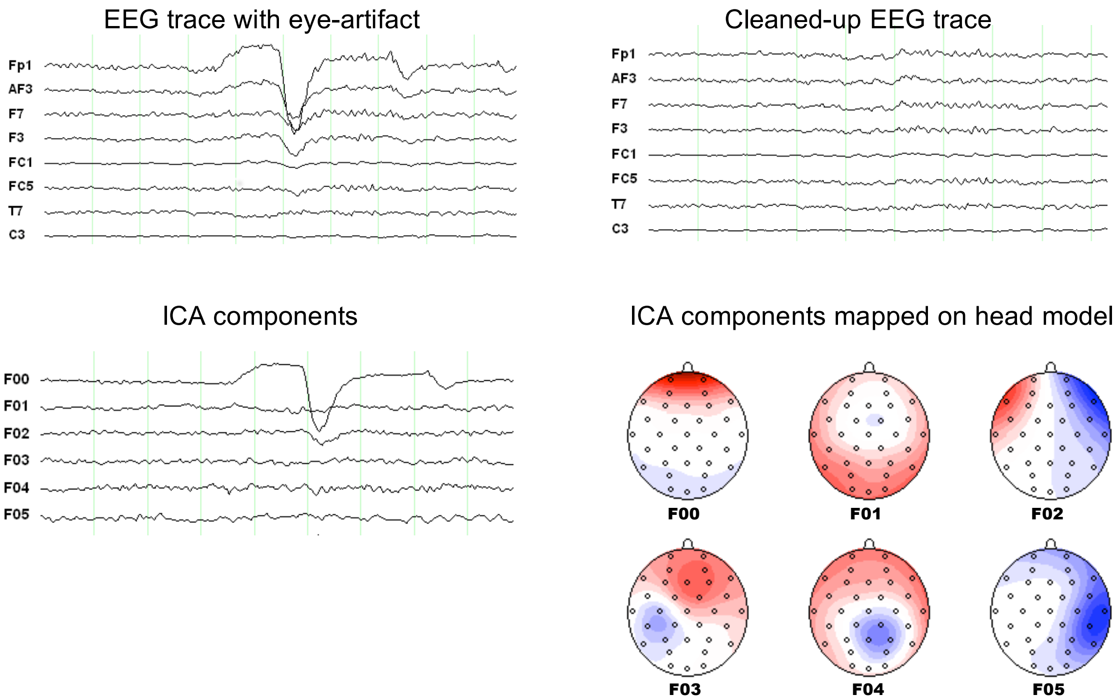

Figure 7. *An example of removing eye-artifact with ICA*

The peak latencies of the AEP trace, as measured from the average of all conditions, are shown in Figure 8 and Table 3. In Table 3, the amplitudes on those latencies of the quantum and classical pre-observe conditions are also compared.

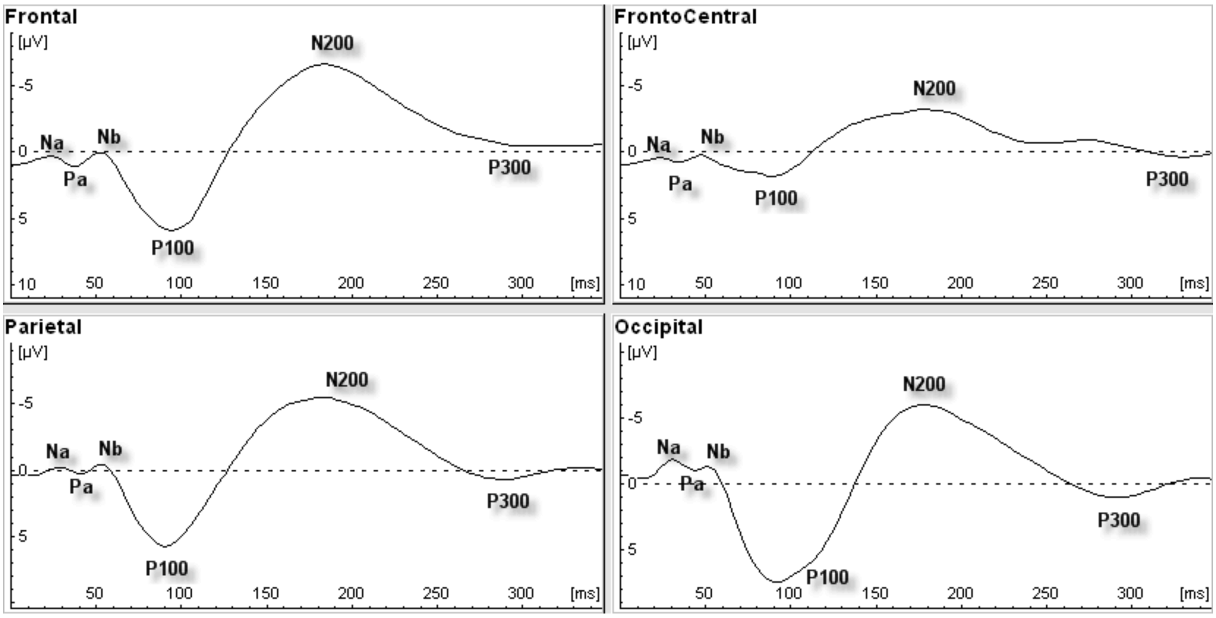

Figure 8. *Peaks of the average of all conditions.*

	Peaks	*Latency*	*I*	*II*	*I-II*	*III*	*IV*	*III-IV*
Frontal	**Na**	23	-0.181	-0.169	-0.012	-0.175	-0.395	0.220
	Pa	39	0.536	0.757	-0.221	0.426	0.545	-0.119
	Nb	51	-0.502	-0.321	-0.181	-0.681	-0.44	-0.241
	P100	94	4.901	5.281	-0.380	5.800	5.65	0.150
	N200	184	-7.266	-7.335	0.069	-7.137	-6.748	-0.389
	P300	301	-1.131	-1.036	-0.095	-0.679	-0.933	0.254
FrontoCentral	**Na**	23	-0.134	-0.021	-0.113	-0.088	0.031	-0.119
	Pa	35	0.522	0.402	0.120	0.149	0.183	-0.034
	Nb	47	-0.300	-0.198	-0.102	-0.450	-0.175	-0.275
	P100	90	1.064	1.195	-0.131	1.565	1.445	0.120
	N200	180	-3.819	-3.646	-0.173	-3.841	-3.542	-0.299
	P300	332	0.000	-0.056	0.056	-0.294	-0.119	-0.175
Parietal	**Na**	27	-0.396	-0.434	0.038	-0.475	-0.515	0.040
	Pa	39	0.005	0.137	-0.132	-0.013	0.056	-0.069
	Nb	55	-0.802	-0.601	-0.201	-0.747	-0.549	-0.198
	P100	90	5.208	5.415	-0.207	5.584	5.632	-0.048
	N200	184	-5.957	-6.019	0.062	-5.468	-5.528	0.060
	P300	289	0.309	0.189	0.120	0.596	0.737	-0.141
Occipital	**Na**	31	-1.444	-1.534	0.090	-1.599	-1.384	-0.215
	Pa	43	-0.829	-0.639	-0.190	-0.666	-0.467	-0.199
	Nb	51	-1.146	-0.894	-0.252	-0.943	-0.795	-0.148
	P100	90	7.543	7.990	-0.447	7.425	7.81	-0.385
	N200	180	-5.707	-5.362	-0.345	-5.908	-5.373	-0.535
	P300	293	1.173	1.249	-0.076	1.322	1.833	-0.511

Table 3. *Peak latencies (in milliseconds), amplitudes and differences (both in µV) of all conditions per pooling.*

The amplitudes of the AEP traces on these latencies were determined per condition. All four conditions are overlaid in Figure 9.

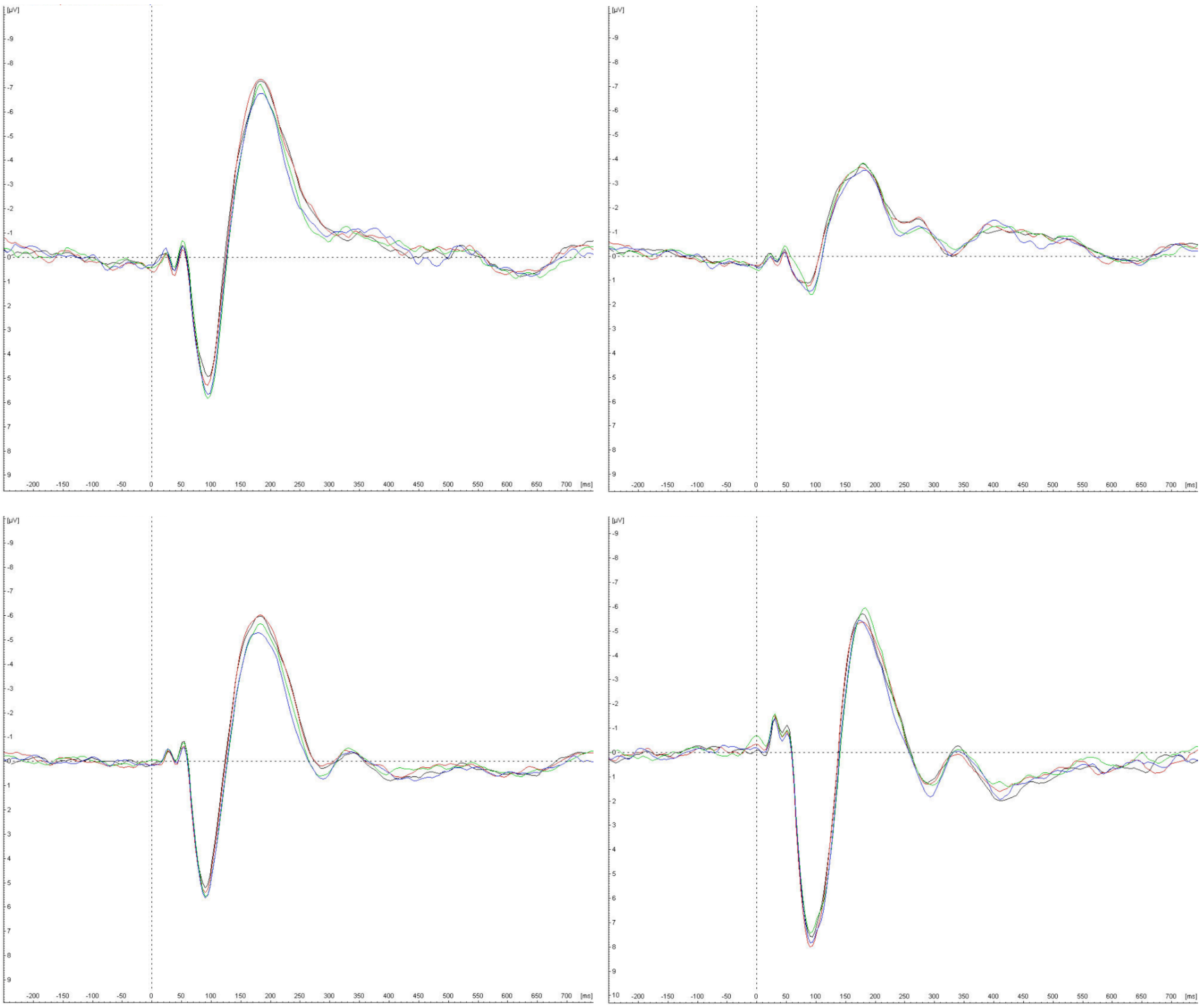

Figure 9. *EAP traces as measured in different pools (from top-left to down-right: frontal, frontocentral, parietal, occipital. (Black = Classic, Red = Classic pre-observed, Green = Quantum, Blue = Quantum pre-observed).*

Differences of amplitude on the peaks between the pre-observe conditions were tested for statistical significance using a standard t-test. The results are shown in Table 4.

		I-II (Classic)			**III-IV (Quantum)**		
	Peaks	***t***	***df***	***p 2-tailed***	***t***	***df***	***p 2-tailed***
Frontal	**Na**	-0.060	49	0.952	0.736	49	0.465
	Pa	-0.892	49	0.377	-0.435	49	0.665
	Nb	-0.674	49	0.503	-0.961	49	0.341
	P100	-1.284	49	0.205	0.386	49	0.701
	N200	0.145	49	0.885	-1.364	49	0.179
	P300	-0.255	49	0.800	0.778	49	0.440
FrontoCentral	**Na**	-0.816	49	0.418	-0.589	49	0.559
	Pa	-0.798	49	0.429	-0.218	49	0.828
	Nb	-0.482	49	0.632	-1.264	49	0.212
	P100	-0.531	49	0.598	0.417	49	0.678
	N200	-0.742	49	0.462	-1.519	49	0.135
	P300	0.198	49	0.844	-0.799	49	0.428
Parietal	**Na**	0.101	49	0.920	0.296	49	0.768
	Pa	-0.485	49	0.630	-0.178	49	0.859
	Nb	-0.862	49	0.393	-0.636	49	0.528
	P100	-0.886	49	0.380	-0.212	49	0.833
	N200	0.246	49	0.807	-1.451	49	0.153
	P300	0.385	49	0.702	-0.537	49	0.594
Occipital	**Na**	0.261	49	0.795	-0.712	49	0.480
	Pa	-0.616	49	0.541	-0.68	49	0.500
	Nb	-0.890	49	0.378	-0.503	49	0.617
	P100	-1.474	49	0.147	-1.021	49	0.312
	N200	-1.052	49	0.298	-1.598	49	0.116
	P300	-0.417	49	0.678	-1.419	49	0.162

Table 4. *T-tests of differences of AEP peak amplitudes for pre- and no-pre-observed conditions*

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 10, Figure 11 and Table 5.

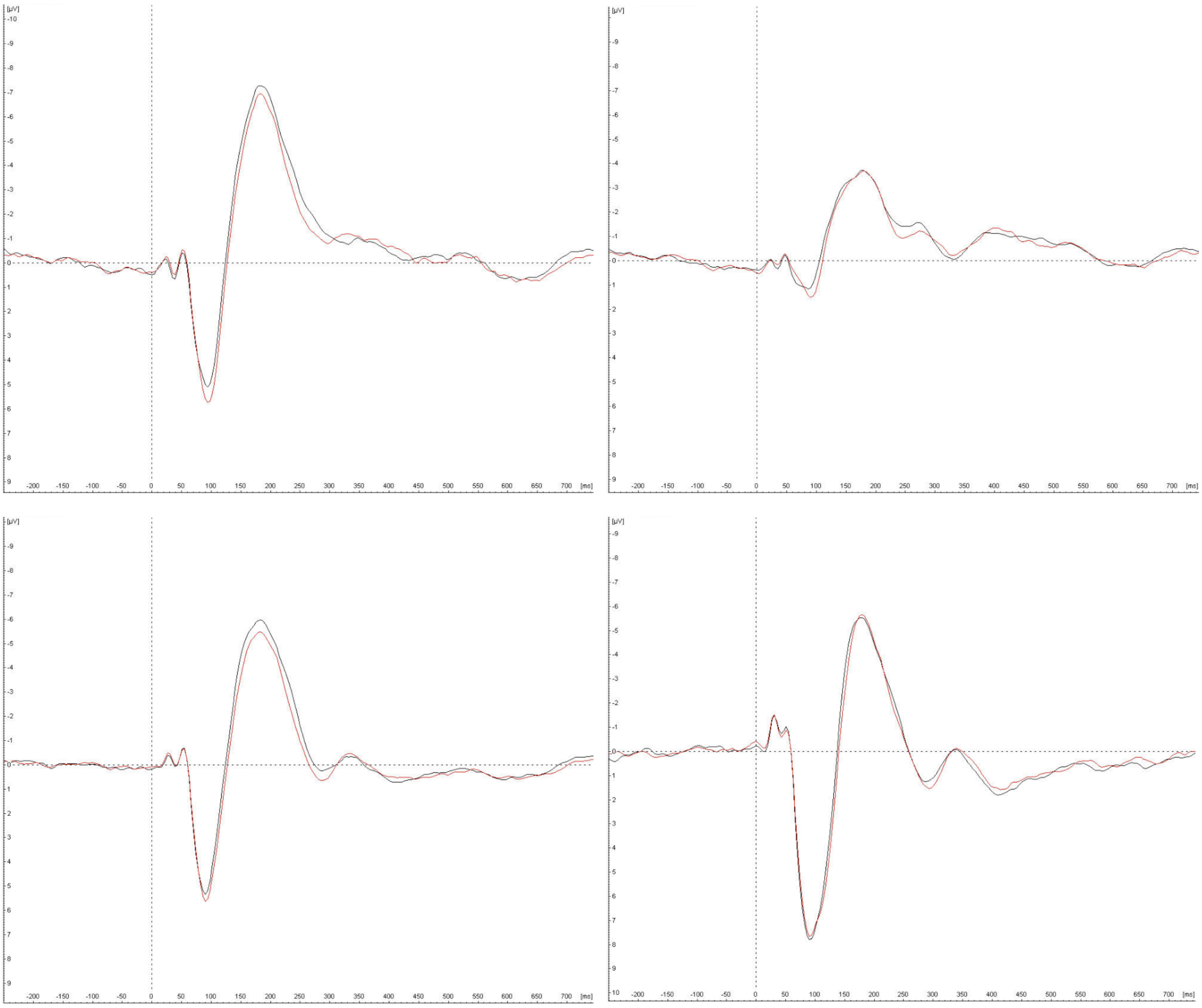

Figure 10. *EAP traces as measured in different pools (from top-left to down-right: frontal, frontocentral, parietal, occipital. (Black = Classic, Red = Quantum).*

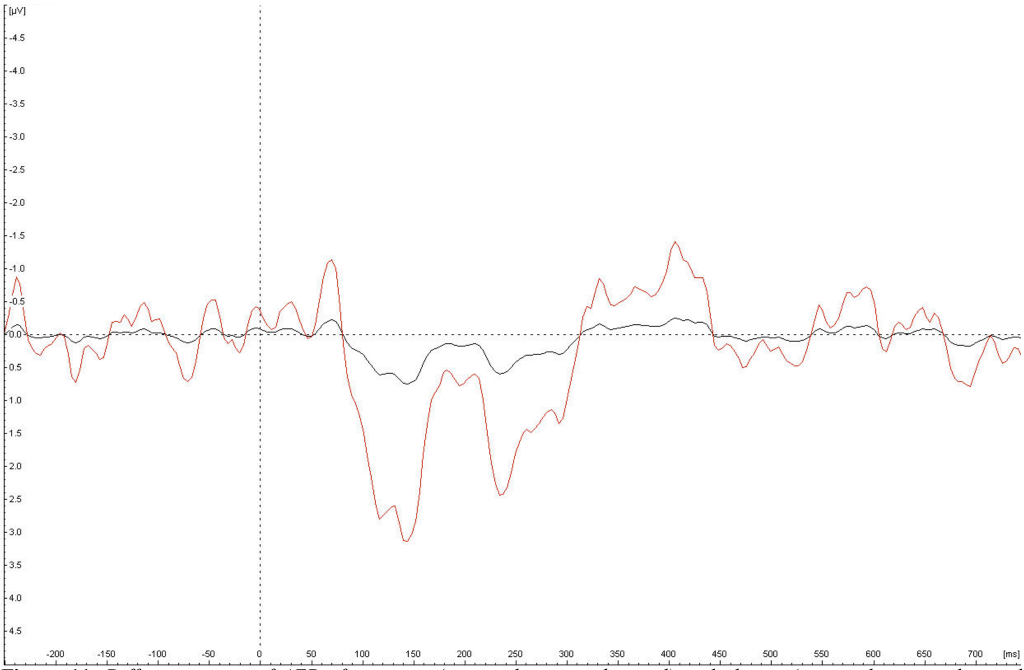

Figure 11. *Difference wave of AEP of quantum (pre- and no-pre-observed) and classic (pre- and no-pre-observed) origin with t values overlaid in red.*

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

Table 5. *Differences of AEP peak amplitudes from the quantum and classic source.*

6. 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 Bierman's (2003) results. 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 preobserved 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 (Bierman, 2003). 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 (Bierman, 2003) could remotely hear these beeps and thus the formal description in terms of observation was different.

Secondly, in Bierman's (2003) 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 preobserved and not preobserved 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 11 and Table 5). 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.

7. Further research

Further investigation is needed to determine the conditions under which subjective reduction can take place. We differed in our experiment with Bierman's (2003) 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 by Bierman (2003) 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 paradoxal. 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 (Hall et al. 1977, Bierman 2003) show that among these questions, the role of consciousness on the reduction of the wave function can indeed be scientifically investigated.

References

Albert, D. Z., Loewer, B. (1988), Interpretating the Many Worlds Interpretation, *Synthese* **77**, 195-213.

Albert, D. Z., (1992), *Quantum Mechanics and Experience*, Harvard University Press, Cambridge, MA.

Bierman, D. J., (2003), Does Consciousness Collapse the Wave-Packet?, MIND AND MATTER **1**, 1.

Bohm, D. (1952), A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables, I and II, *Physical Review* **85**, 166-193.

Bohm D. and Hiley, B. (1997). The Undivided Universe.

de Broglie, L. (1928), in Solvay (1928).

Costa de Beauregard, O. (1976). Time symmetry and the interpretation of Quantum Mechanics. *Foundations of Physics*, **6**, 539.

D. Dieks and P. E. Vermaas (eds), (1998) *The modal interpretation of quantum mechanics,* The University of Western Ontario series in philosophy of science, Vol. 60 (Dordrecht: Kluwer, 1998).

DeWitt, B. S. (1971), The Many-Universes Interpretation of Quantum Mechanics, *Foundations of Quantum Mechanics* (Academic Press, NY). Reprinted in DeWitt and Graham (1973), pp. 167-218.

DeWitt, B. S., Graham, N. (1973), *The Many- Worlds Interpretation of Quantum Mechanics* (Princeton University Press, Princeton).

Everett, H. (1957), 'Relative State' Formulation of Quantum Mechanics, *Reviews of Modern Physics* **29**, 454-462.

Folger, T. (2002), Does the Universe Exist if We're Not Looking?, Discover.com: http://www.discover.com/issues/jun-02/features/featuniverse/.

Gell-Mann, M., Hartle, J. B. (1990), Quantum Mechanics in the Light of Quantum Cosmology, in Zurek, W. H. (ed.), *Complexity, Entropy, and the Physics of Information*, Proceedings of the Santa Fe Institute Studies in the Sciences of Complexity, vol. VIII (Addison-Wesley, Redwood City, CA), 425-458.

Ghiradi, G., Rimini, A., and Weber, T. (1986). Unified Dynamics for Microscopic and Macroscopic systems. *Physical Review* D34, 470-491.

Hall, J., Kim, C., McElroy, and Shimoni, A. (1977). Wave-packet reduction as a medium of communication. *Foundations of Physics* **7**, 759-767.

Jung, T. –P., Makeig, S., Humphries, C., Wong Lee, T. –W., McKeown, M. J., Iragui, V., Sejnowski, T. J. (2000), Removing electroencephalographic artifacts by blind source separation, *Psychophysiology*, 37, 163-178 (Cambridge University Press).

Libet, B. (1991) Conscious vs Neural time. *Nature*, 352;27.

Solvay Congress (1927), 1928, *Electrons et Photons: Rapports et Discussions du Cinquième Conseil de Physique tenu à Bruxelles du 24 au 29 Octobre 1927 sous les Auspices de l'Institut International de Physics Solvay*, Paris : Gauthier-Villars.

Penrose, R. & Hameroff, S. () Proceedings Tucson….

Penrose, R. (1989), *The Emperor's New Mind*, American Philological Association.

Penrose, R. (1996), *Shadows of the Mind*, Oxford University Press, Oxford.

Stapp, H. P . (1993). *Mind, Matter, and Quantum Mechanics* . N. Y.

Stapp, H.P. (2001). Quantum Theory and the Role of Mind in Nature, *Foundations of Physics*, **31**, 1465-1499.

Trimmer, J. D. (1983). The Present Situation In Quantum Mechanics: A Translation Of Schrödinger's "Cat Paradox Paper". *Proceedings of the American Philosophical Society* **124**, 323-38. [Schrödinger, E. (1935) "Die gegenwärtige Situation in der Quantummechanik", *Naturwissenschaften* **23**, 807-812, 823-828, 844-849.]

Walker, E.H. (1971).Consciousness as a Hidden Variable. *Physics Today* **24**, 39, 1971.

Walker, E.H. (1988).Information Measures in Quantum Mechanics, *Physica B* **151**, 332-338, 1988.

Walker, E.H. (2000). The Natural Philosophy and Physics of Consciousness, in: *The PhysicalNature of Consciousness*, edited by Philip Van Loocke, John Benjamins, Amsterdam/Philadelphia pp. 63-82, 2000.

Wigner, E.P., (1967). Two kinds of reality. In: Symmetries and Reflections (Indiana Univ. Press, Bloomington, 1967)

Appendix 1. *Placement of elektrodes*