CONSCIOUSNESS COLLAPSE OF THE STATE VECTOR AS DIRECT SUPPORT FOR THE QUANTUM OBSERVATIONAL THEORY

Dick J. Bierman
University of Amsterdam, NL
and
Evan Harris Walker
WCRI, Aberdeen, USA

Abstract

One of the basic ingredients of the Observational Theory, the collapse of the state vector by means of observation is tested. The experiment amounts to a conceptual replication of the Hall-experiment published in the seventies in *Foundations of Physics*. In that experiment, final observers of a quantum event had to guess if a pre-observation had taken place. Although framed as a physical experiment, the authors did explicitly refer to the possibility of a relation with parapsychological phenomena like telepathy.

Two improvements are introduced. First the delay between pre-observation and final observation of the same quantum event is increased from a few *microseconds* in the original experiment to 1 second in this replication. Second, rather than using the observers' verbal response as the dependent variable, we use objective measurements, the early brain responses of the observers as measured by EEG as the dependent variable. These early responses cover the period of incipient conscious observation of the quantum event.

Results support the 'subjective reduction' hypothesis because a significant difference between the brain responses of the final observer are found dependent upon the pre-observer looking or not looking at the quantum event. Alternative 'normal' explanations are discussed and rejected. It is concluded that the present results lend support to the Quantum Observational Theory.

1. Introduction

The Quantum Observational Theory (QOT) as originally formulated (Walker, 1971) is based upon what physicists call the *measurement problem* in Quantum Physics. In the QOT it is assumed that a conscious observation is one of the crucial ingredients. In 1977 Hall et al (Hall et al, 1977)) reported an experiment that, according to their description, tested this solution to the measurement problem, in which *the state vector collapse* [aka: 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 defended their experiment writing: *although we concur that there is a genuine problem of the reduction of the wave packet, we do not intend in our paper to defend this opinion against those who maintain that it is a pseudo problem.* We point out that despite the fact that the measurement problem arose naturally from within physics itself and has a body of literature amounting to thousands of technical papers in physics, its obvious implications for and even application to parapsychology has fostered great opposition to it.

In spite of many attempts, like the relative state solution (Everett, 1957) and the introduction of non-linear terms in the Schrödinger equation (Ghiradi, 1986; Walker, 1988), the measurement problem seems still not be solved. The well-known Bell's theorem was originally developed to prove quantum mechanics to be incomplete explicitly so as to dispose of this problem. Instead, it succeeded only in making the measurement problem all the more bizarre. 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 state vector collapse 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 von Neumann (1955) and Wigner (1967), that none of these prior solutions are acceptable and that observational collapse or reduction is still a possible and even preferred alternative.

We, like Hall *et al*, would like to investigate the issue experimentally. The Hall experiment is conceptually easy to understand. A quantum event, in this case a radioactive decay, is measured in a counter and the signal is displayed on a scale. An observer, *Observer 1*, observes the scale. The scale signal is transmitted through a delay unit and displayed again. This second scale is observed by 'final' observer, *Observer 2*.

Moreover, Observer 1 sometimes observes and sometimes does not observe his scale. Observer 2 is then required to 'guess' if a quantum event observed by him has already been observed by observer 1 (see fig.1 from the original publication)

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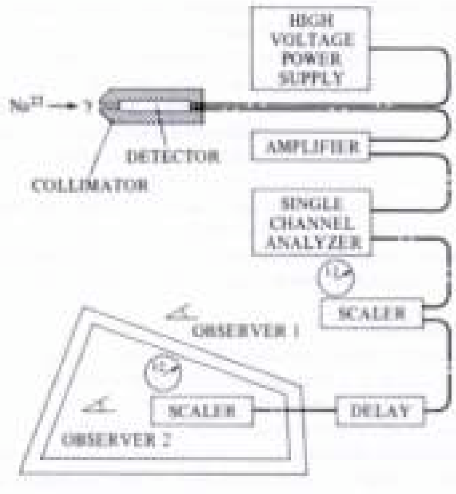

Figure 1. Experimental arrangement (not drawn to scale).

The results of Hall's experiment were precisely at chance—the second observer guessed 50% correct. Hence it was obvious that this observer was unable to detect if the observed signal had already been observed earlier. It was concluded that the experiment does not provide support for the hypothesis that it is the interaction with consciousness that causes the wave packet to collapse.

It should be made explicit that there is an implicit assumption of Hall et al that our brains in some way are able to detect the difference between a superposition state and a singular state, and also that this difference can be communicated consciously.

In a comment later added to the article the authors note that the delay they used was extremely short and that "*The delay time should be in the order of psychologically discriminable intervals…*" Since the original Hall paper has been widely acknowledged as evidence against the!hypothesis that it is the interaction with consciousness that causes the wave packet to collapse, it is essential that this serious error in the Hall experiment be corrected by means of improved testing methods. It is important that both the time delay be of a physiologically significant duration and that the determination as to whether the observers have been affected differently by the two conditions be placed on an objective foundation—something more than the verbal report used by Hall.

In the present conceptual replication the time between the first observation and the second one was set to 1000 msecs. The hypothesis being tested requires that the first observation be a conscious observation. Libet's (1991) seminal work on the brain's processing time needed for brain stimulation to become a conscious perception gives a lower interval of about 300-500 msecs. However, the difference from the original experiment goes further than just adjusting this interval.

Rather than asking the second observer for a conscious guess, we measure the brain responses to the stimulus. This is done for the following reason: If consciousness is the crucial element for state vector collapse, the conscious decision, used as dependent variable in the original experiment will be based on the physical state of the state vector *after* consciousness in the second observer has developed. At that time, the state vector according to the hypothesis under investigation, has already collapsed even if no pre-observation has taken place. Thus, the manipulation of the pre-observer will not induce any difference in the final observer with regard to his conscious behavior.

By measuring brain potentials of the second observer one can however also tap into the early (<300-msec) non-conscious processing of the brain. At that time the State vector is supposedly still in superposition, but only if no pre-observation has taken place.

2. Design of the experiment

Quantum events were generated by an alpha particle source (as used in smoke detectors; 2P40-76-18) that was attached onto a slide-adjustable mounting allowing the source to be moved with respect to a lead shielded Geiger-Muller counter (Automess 6150-100). The distance was adjusted so that on average approximately 1 particle was detected each second. The counter pulse was amplified and fed to the trigger channel of an EEG data-acquisition system (*Biosemi Active-1*, 2003). We used *National Instruments LabView* software (NI, 2003) to detect this trigger and to transform it into a delayed audio beep of 1500 Hz and 50 msecs duration. The audio-delay was 1 second. The software would randomly generate a visual stimulus of ~65 msecs duration directly upon occurrence of the trigger signal. The visual stimulus therefore preceeds the audio-beep by a time sufficient for the first observer to have a conscious experience of the quantum event *before* the second observer (see fig.2). The random decision to show or not to show this visual stimulus to the first observer before submitting the beep to the second observer was *pseudo-random* with the seed determined by the computer clock. After each quantum event thus measured there was a dead time of 2 seconds during which input from the Geiger-Muller counter was discarded. Additionally, the subjects were asked to count the number of observed quantum events in order to check for and assure attention to that task.

The quantum mechanical theory of radioactive decay describes the emitting particle as a superposition of two states, the decayed and the non-decayed state. Although our measurement system is a composite many particle system it can be regarded as being in a superposition of a 'decayed' and a 'non-decayed' state, the so-called state vector. According to the 'radical' proposition under consideration, a reduction of this superposition occurs only when an observer 'looks' at (so as to consciously observe) one of the two indicators of the emission. Either observation of the visual or the audio representation would collapse the state vector (i.e., reduce the wave packet).

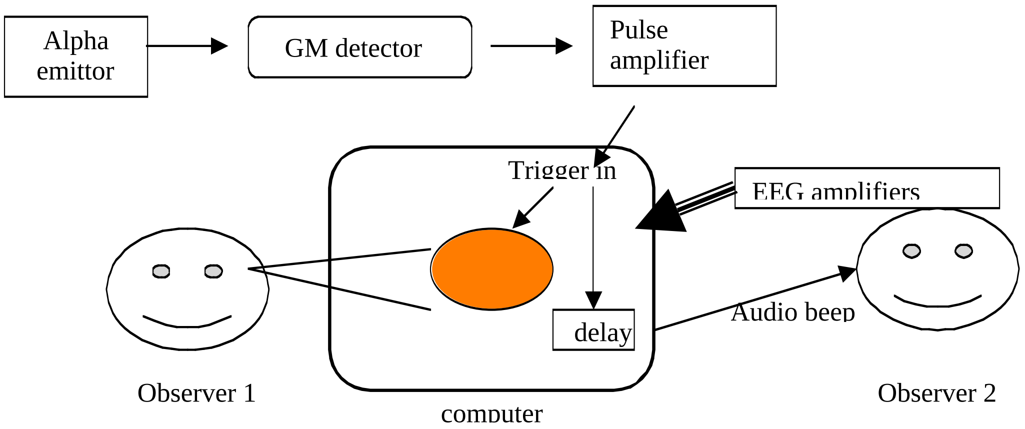

Figure 2. The experimental set-up of the present replication experiment. (Note that this figure doesn't show the video connection from Observer 2 to Observer1).

3. Experimental Procedure

Subjects

Volunteer subjects were invited in pairs. These were generally freshman psychology students who participated for course credit. In total 9 male and 21 females, providing useful data, participated in the experiment (mean age=21.4, sd=4.7).

Upon arrival they were fully informed about the purpose and potential implication of the experiment. First they participated in a so-called odd-ball task used to test the equipment. Then the crucial task, which we, for obvious reasons, called the '*Schrödinger-task*' was presented. The role of observer 1 and 2 were played by both subjects in two separate runs.

Physiological measurement and further procedure.

Sintered AgCl EEG electrodes with active preamplifiers (*Biosemi Active 1*) were connected to the head of observer-2 using the standardized 10/20 system (see appendix 1). No temporal electrodes were used. Then observer 2 went to a neighboring room and was seated in a relaxing chair while observer 1 stayed at the computer screen with the experimenter. A short 'calibration' experiment was run consisting of the above-mentioned odd-ball task in which observer-2 was presented each 3 seconds (with one second random jitter) audio beeps of 30 msecs duration. A hundred beeps with either a frequency of 1200 Hz or a frequency of 2000 Hz were presented. The frequency was randomly determined with the probability for the higher frequency being 4 times lower than for the presentation of the lower frequency sound. The subject was asked to count the number of higher frequency beeps. If the resulting average evoked brain potentials conformed to the well know average auditory brain potential (Picton et al, 1974), the actual 'Schrödinger' run was started with observer 1 sitting in front of the computer screen observing the visual stimulus that appeared in about 50% of the cases directly upon a radioactive decay. The experimenter refrained from looking at this screen. The total run consisted out of 120 radioactive decay events. This took about 8 minutes.

After a short break roles were switched and the procedure was repeated. The total experiment took less than one hour.

4. Results

To prevent ourselves from data snooping and data selection with the goal to 'find what we were searching for', we first analyzed the results of the standard, and completely unrelated, odd-ball task. Once we had fixed the complete procedure on the basis of exploration of these odd-ball task data we would allow ourselves to analyze the actual data.

On the basis of the explorations of the odd-ball data it was concluded that two of the 32 subjects were not providing valid EEG data. They were removed before further analyses. The electrodes O1 and O2 turned out to produce very noisy signals and thus these were also dropped from the analysis. Furthermore these odd-ball data were used to establish an optimal preprocessing procedure. The thus established preprocessing procedure consisted of 4 steps. All signals were referenced to (compared to) the signal at the Pz electrode. First a 50 Hz notch filter was applied, then the data were filtered through a band pass filter between 1 and 30 Hz (slopes = 24 db/Oct). Then (eye) movement artifacts were removed from the data. The criteria used were 'absolute value' and 'derivative'. On the average this algorithm removed about 5-10% of the available segments. Because there is a high correlation between the results obtained from different leads (electrodes) we did a factor analysis to see how we could combine the signals of different leads into a compound signal. This analysis gave two clear factors, one consisting of the central and frontal leads with a mean factor load of 0.87 and one for the parietal electrodes with a mean factor load of 0.93. We called the two combined signals 'FC' which is the average of 11 leads (Fpz, Fp1, Fp2, Fz, F7, F3, F8, F4, Cz, C3, C4) and 'P' which is the average of two leads (P3 and P4).

After having thus established the data to be used and having a well-specified preprocessing procedure, we applied this without further adaptation to the EEG data obtained in the 'Schrödinger' part of the experiment. First we averaged all the data pooled over subjects and pre-observer condition per sample for the FC- and P-signal separately.

The thus obtained evoked potentials were submitted to an automatic peak detection procedure. Results are given in fig. 3.

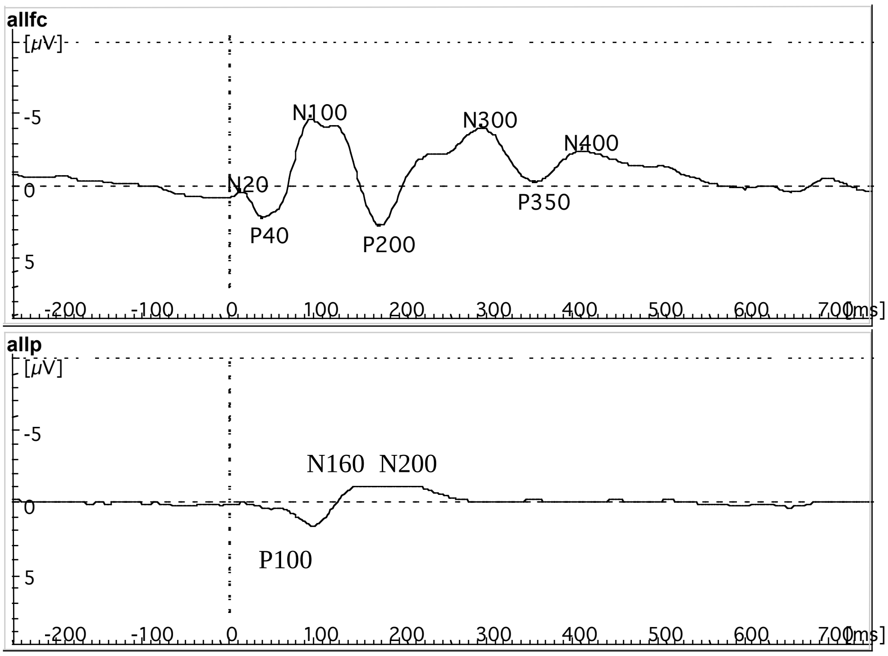

Figure 3. The mean evoked response for all subjects. Upper trace: all frontal and central leads (FC leads). Lower trace: two parietal leads (P-leads).

Note that in figure 3 the evoked potentials are still pooled over all data, pre-observer and non pre-observer conditions. In order to check if the pre-observation by a first observer makes a difference for the brain signals of the final observer we have to split the data for the two pre-observer conditions.

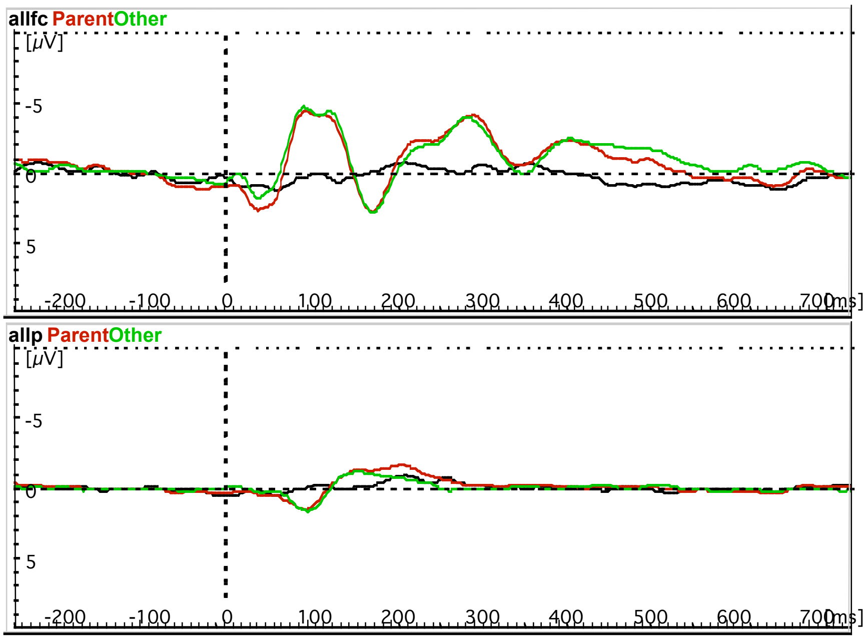

Figure 4. The mean evoked responses split for pre-observation condition (green = pre-observed; red = not pre-observed; black is the difference between the two conditions).

In figure 4 the same evoked potentials are plotted but this time separately for the two pre-observer conditions. The black curve is obtained by subtracting the not-pre-observed mean evoked potential form the mean pre-observed evoked potential. Under the null-hypotheses (that pre-observation doesn't matter) this difference should be nill.

Statistical Analysis of peak amplitudes

As usual in these EEG data, the two traces for the two conditions do not completely coincide. In order to assess if the observed differences are statistically meaningful we did a simple comparison between the signal value at peak position for the pre-observed and the non pre-observed trials.

All peaks obtained by the automatic peak detection procedure were analyzed:

For the combined frontal and central leads: N20, P40, N100, P200, N300, P350 and N400. At exact 17, 41, 95, 178, 292, 357 and 411 msecs after stimulus onset. (The convention in EEG plots is generally that positive voltage is plotted "down", i.e. to the bottom of the page.) For the two combined parietal leads, P100, N170 and N200 at exact 99, 160 and 212 msecs after stimulus onset.

In Table I, column 3, we give the differences for the peak amplitudes between the two observer-conditions. As said before these differences should be negligible under the assumption that the fact that someone has observed the same quantum event earlier doesn't matter. A standard t-test was run to find the probabilities that the observed differences are due to chance (column 5).

In addition to the results of the parametric t-test we also calculated the results of the non-parametric binomial tests. In this latter test the magnitude of the difference is not relevant, only the direction for each subject. It can be argued that the non-parametric test is more suitable since the differences between two evoked potentials are not necessarily normally distributed.

			df = 29		
	Peak	Difference (microvolts)	t	p	Non-parm p N=30
FC-leads	N20	1.002	2.12	*0.043*	19-11: 0.20
	P40	0.903	2.64	*0.013*	22-8: 0.016
	N100	0.350	0.66	0.52	15-15
	P200	-0.09	-0.18	0.86	15-15
	N300	-0.04	-0.08	0.93	15-15
	P350	-0.54	-1.17	0.25	12-18: 0.36
	N400	0.098	0.25	0.80	16-14: 0.86
P-leads	P100	-0.16	-0.67	0.50	12-18: 0.36
	N160	-0.152	-0.84	0.41	13-17: 0.58
	N200	-0.956	-3.93	*0.0005*	7-23: 0.005

Table I: Results of the differential analysis of the peak amplitudes.

From these results the following preliminary conclusions may be drawn:

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 in the other direction and arises later with a clear maximum at 200 milliseconds.

Post hoc Spatial analysis

EEG is not the most optimal tool to draw conclusions about the spatial locations of effects. All leads, to some degree, do get their signal from all parts of the brain. That is also evident from the factor analysis. Nonetheless global spatial trends like lateralization between the two hemispheres can be observed. In fig. 5 the effect for the P40 peak is graphically projected on the head. The electrodes on the left hemisphere give a larger size effect supporting the hypothesis than do the electrode signals from the right, while the central electrodes give intermediate effects.

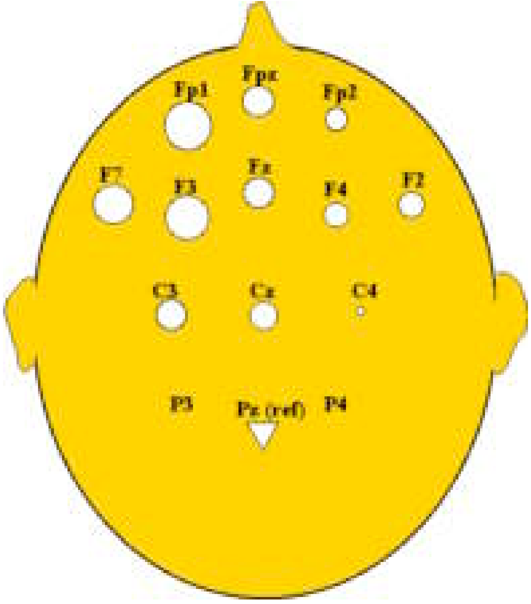

Figure 5. Differential effect at different lead locations. The size of the circle corresponds to the effect size.

This finding should, however, be considered with great caution because the signals at the different leads are by no means independent. Another way to get information about the brain regions involved is to look at the specific components in the evoked response. For auditory stimuli, like beeps, it is well known that the early peaks like the N20 do originate in the brain stem. Later peaks like P40 can be attributed to the thalamus while everything occurring with a larger latency than 100 msec is generally coming from the cortex.

5. Discussion

The results of these experiments support the observer causation of state vector collapse as the solution of the measurement. The absence of significant differences in the late evoked potential 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 however should be treated cautiously because the lack of statistical power in the later phases of the response. This lack of power is caused by increased variance with increasing latency times.

Before drawing far reaching conclusions we should first check if there are no more mundane explanations for the current findings.

Alternative explanations

Spurious sensory cueing of the second observer has been considered. The reason for having the first observer observe a *visual* representation of the quantum event rather than a audio-beep was indeed to prevent any audio leakage to the second observer. Both observers were in adjacent and not auditory or electromagnetically shielded rooms. Ultrasonic or electromagnetic signatures from the monitor displaying the signal for the first observer!might still have!presented sensory cues. Thus the second observer might have produced a slightly different auditory evoked potential due to this earlier pre-observation related ultra-sound.!This scenario, however, is not very plausible in that it would result in affecting the peaks in the evoked potential in a systematic way. The timing of the visual stimulus to the first observer and the delayed audio beep to the second is not precise and therefore one can hardly expect a well-defined effect in time.

A second explanation might be found in improper randomization of the pre-observer condition. It is well known that evoked potentials on simple stimuli like beeps tend to habituate (decline). Thus the amplitude of the signal becomes smaller in the course of the experiment. If, for some reason, the randomization did result in a non-balanced distribution of conditions in time this could artificially induce a differential effect due to habituation. We tested this idea using the actual sequence of stimulus conditions as they occurred in the experiment with several habituation models. None of these models gave any effect (p-values around 0.77). As a further test on the validity of the peak differences that we found between the two pre-observer conditions, we ‘randomly’ relabeled the markers so that we created two pseudo-conditions for which we did exactly the same peak difference analysis. The result of this analysis was at chance level. (the mean difference found was 0.16 microvolts at the P40. This is 6 times smaller than the real effect).

Although the current results look pretty robust, they are not *extremely* improbable in terms of statistics. It is to be noted that in spite of our conservative approach (assessing the analysis procedure on other data, not searching in any of all leads but pooling the leads etc.) one can argue that the reported p-values might be inflated due to the analysis of 10 peaks without applying a Bonferoni correction for multiple analyses. Of course peak N200 would easily survive this correction (adjusted p-value of the t-test is 0.005). Depending on how serious one takes these objections one could argue that the current findings might be attributable to chance with a probability of 1 in 50. Although this figure satisfies the criterion of 5% which is generally accepted as the significance criterion, additional data is to be sought to give unequivocal acceptance to the hypothesis based on this type of experiment. It is to be kept in mind, however, that there are other argument for this hypothesis that consciousness collapses the state vector, arguments that come both from the formalism of quantum mechanics and from the explanatory power of the QOT in parapsychology.

EEG Transfer as an explanation?

Recently several labs have reported (conceptual) replications of the original EEG transfer potential work by Grinberg Zylberbaum (Richards et al, 2002; Wackermann et al, 2003). It was found that a subject whose EEG was measured showed changes in this EEG depending on stimulation of another (remote) subject. It should be noted that the anomalous ‘transfer’ was more of an energetic effect than of an informational nature. That is to say, it was not the form of the evoked potential that was ‘transferred’, but rather the power in the EEG signal of the ‘receiver’ that was found to be correlated with the remote stimulation. Moreover, this correlation was found to be synchronized in time.

In the present experiment we have also two subjects with one stimulated while the EEG from the other subject is being measured. However there are also major differences. In the first place, unlike in the EEG transfer experiments, our second subject is also stimulated, and with a delay of one second. So we find delayed correlations rather than simultaneous ones, a significant difference from the Grinberg Zylberbaum experimental results. Further we find a systematic directional effect. Thus, the peaks are larger (more positive or more negative) in one condition compared to the other. In the EEG transfer experiments there is no systematic directional effect. Only an effect in power. Thus we feel that although we cannot exclude an explanation in terms of EEG transfer potential, the probability for this explanation is low.

Further work

The further crucial experiment in which the radioactive source is sometimes replaced by a pseudorandom source is presently underway. In this experiment, the differential effect should largely disappear in the latter (classical) condition as the quantum character of the observed event is crucial. Differential results will also exclude alternative explanations in terms of sensory leakage and EEG transfer potential. If however effects are found for classical as well as quantum events we would be forced to consider the EEG transfer potential explanation for these results after having excluded all potential sources of sensory leakage.

In these replication studies we now are also able to predict more precisely where and when to look for differences in the brain signals.

So far the concept of a conscious observation has not been worked out in detail. In Libet’s work, which was used in the present study to estimate the delay between perceptual input and the conscious experience thereof, he takes conscious observation to be a perception some part of which is stored in memory. This number can also be obtained from the quantum consciousness theory of Walker (2000) by calculating the mean time for a randomly selected neural stimulation to become a part of the intersynaptic quantum interaction that is part of the ongoing consciousness. There is further evidence from ‘change blindness’ experiments, that memory incorporation plays no essential role in consciousness.

In work in the field of ‘Artificial Intelligence’, the question has arisen if future computers might become conscious. The present results suggest that such a question can become empirically testable.

Acknowledgements

BioSemi offered generous support by loaning the EEG equipment. Chris Duif was helpful in setting up the software. Ronald van der Ham ran this experiment as a part of his master’s thesis. Dennis Dieks helped to understand and describe the experiment in a formal way. The experiment was originally designed at *Starlab*. All former Starlab personnel are thanked for providing the unique climate for real scientific enquiry.

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Raw Data:
http://a1162.fmg.uva.nl/~djb/research/eeg_data

Equipment:
National Instruments' Labview (2003) http://www.ni.com

The 10-20 electrode placement system:
http://faculty.washington.edu/chudler/1020.html

Biosemi Active-1, (2003):
http://www.biosemi.com/

APPENDIX I

The 10/20 EEG electrode placement system