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COLLAPSE OF A QUANTUM FIELD MAY AFFECT BRAIN FUNCTION

C.M.H. Nunn,[1] *Department of Psychiatry, Royal South Hants Hospital, Brintons Terrace, Southampton, S09 4PE, UK; C.J.S. Clarke, Faculty of Mathematical Studies, and B.H. Blott, Department of Physics, University of Southampton, Southampton, S09 5NH, UK*

Abstract: Experiments are described, using electroencephalography (EEG) and simple tests of performance, which support the hypothesis that collapse of a quantum field is of importance to the functioning of the brain. The theoretical basis of our experiments is derived from Penrose (1989) who suggested that conscious decision-making is a manifestation of the outcome of quantum computation in the brain involving collapse of some relevant wave function. He also proposed that collapse of any wave function depends on a gravitational criterion. As different brain areas are known to subserve different functions, we argue that 'Penrose collapse' must occur in a particular brain area when performing a task that uses it. Further, taking an EEG from the area should amplify the gravitational prerequisite for collapse, so affecting task performance. There are no non-quantum theories which could lead one to expect that taking an EEG could directly affect task performance by subjects. The results of both pilot and main experiments indicated that task performance was indeed influenced by taking an EEG from relevant brain areas. Control experiments suggested that the influence was quantum mechanical in origin, and was not due to any experimental artefact. The results are statistically significant and merit attempts at replication in an independent laboratory, preferably with more sophisticated equipment than was available to us.

I
Introduction

It has been claimed (McGinn, 1990) that our brains are inherently incapable of understanding their own awareness, but this has not prevented an ever-increasing number of people from trying to do so. They occupy three main camps. There are the traditional dualists who believe that brain and soul are separate entities, only weakly linked, with awareness an attribute of the soul. It is an idea which has champions among contemporary scientists (e.g. Eccles, 1989).

Next is a mainstream group who are much impressed by computer technology and hold that mental life is an expression of information-processing aspects of neurological function. They believe that concepts already available to neurologists and artificial intelligence experts only need to be extended a bit in order to explain consciousness. Relevant concepts include self-modelling and loop functions (e.g. Hofstadter, 1979). The most convincing set of ideas falling within the same general paradigm as Hofstadter's, in our view, is that of Edelman (1989). His theory of neuronal selection accounts well for the development of perception and other brain functions; he argues that the concept of 're-entrant' patterns of activity in his neuronal groups can explain awareness.

The main problem with accounts like Edelman's is that they do not carry full conviction in relation to the distinction between understanding and information processing (shown by Searle, 1990, to occupy separate realms), or in explaining the existence of perceptual qualities (*qualia*). Recognizing the incapacity of ideas of this sort to account for qualia, Dennett (1991) took the desperate, and in our view mistaken, step of arguing that they do not really exist in quite the way that everyday introspection suggests.

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[1] Correspondence, please.

The third camp is occupied by those who think that the concepts required to account for the mental and neurological realms must themselves be very different, and that quantum physics could have a contribution to make to the ideas needed for dealing with the mental realm (e.g. Lockwood, 1989, Penrose, 1989). Early attempts to introduce quantum physics into study of the mental tended to deal either with extremely broad concepts (e.g. individual minds as part of universal consciousness) or extremely narrow ones (e.g. the theoretical ability of electrons to tunnel across synapses because their wave functions occupy an extended volume and their position is therefore uncertain). Neither approach commended itself to neuroscientists.

There is now a more satisfactory range of ideas available, of which only a few can be outlined in a brief paper. They involve mostly quantum objects called Bose-Einstein condensates (see Marshall, 1989, or Zohar, 1990), which may be capable of forming ephemeral but extended structures in the brain (Pessa, 1988). Marshall's original idea (based on the work of Fröhlich, 1968) was that the condensates which comprise the physical basis of mind, form from activity of vibrating molecules (dipoles) in nerve cell membranes. One of us (Clarke, 1994) has found theoretical evidence that the distribution of energy levels for such arrays of molecules prevents this happening in the way that Marshall first thought. However, the occurrence of similar condensates centring around the microtubules that are an important part of the structure of every cell, including nerve cells, remains a theoretical possibility (del Giudice *et al.*, 1986). Hameroff (1994) has pointed out that single-cell organisms such as 'paramecium' can perform quite complicated actions normally thought to need a brain. He suggests that their 'brain' is in their microtubules. Shape changes in the constituent proteins (tubulin) could subserve computational functions and would involve quantum phenomena of the sort envisaged by del Giudice *et al.* This raises the intriguing possibility that the most basic cognitive unit is provided, not by the nerve cell synapse as is usually supposed, but by the microtubular structure within cells. The underlying intuition is that the structures formed by Bose-Einstein condensates are the building blocks of mental life; in relation to perception they are models of the world, transforming a nice view, say, into a mental structure which represents some of the inherent qualities of that view.

We thought that, if there is anything to ideas of this sort, the quantum nature of awareness should be detectable experimentally. Holism and non-locality are features of the quantum world with no precise classical equivalents. The former implies that interacting systems have to be considered as wholes — you cannot deal with one part in isolation from the rest. Non-locality means, among other things, that spatial separation between its parts does not alter the requirement to deal with an interacting system holistically. If we could detect these in relation to awareness, we would show that consciousness cannot be understood solely in terms of classical concepts.

II

Experimental Design

There are two major obstacles in the way of designing an appropriate experiment. First, noone knows what consciousness actually does, so one cannot predict what effect it will have on performance of an experimental task. The work of Libet (1993) strongly suggests that awareness always lags around 0.4 seconds behind events in the objective present, so the effects of consciousness, if any, must be mediated through influences on functions like attention and the inhibition or facilitation of potential actions. The second difficulty concerns the uncertainty of physicists over what translates the range of potentialities in a quantum object into a single actuality (a process often referred to as collapse of the

Schrödinger wave function). It is generally thought that taking a measurement or making an observation of the object is what does it, but this is a very imprecise concept. All the same, it occurred to us that taking an ordinary electroencephalogram (EEG) might constitute a 'measurement' of a quantum field if such exist in the brain. Suppose that electrical brain state A corresponds to moving one's hand and state B corresponds to not moving it; then, if the occurrence of A or B depends on the outcome of collapse of a quantum field, observing with an EEG whether it was A or B that occurred ought to collapse the field. This is not in fact a very good argument because one should then consider whether one part of the brain might not be able to 'measure' other parts which quickly leads to that indicator of conceptual error — an infinite regress. Nevertheless, we pressed ahead because of Penrose's (1989) collapse theory which is described in Appendix A. This allows one to predict with mathematical precision that taking an EEG will affect any quantum collapse in the brain in a manner which has nothing to do with classical electrical phenomena.

We devised a simple test, described in Appendix B, which allowed us to ascertain whether taking an EEG from relevant brain areas affected performance of the test. EEGs were taken in random sequence from the left or right sides of the head (with a control condition of no recording) while subjects performed a task thought to use mainly one side of the brain. The test involved identifying numbers (a left parieto-temporal function) and pressing a button with the right thumb (a left motor cortex function). Outcome measures were: (a) frequency of failure to respond to a target stimulus, (b) frequency of mistaken responses to non-targets, (c) reaction times. Because of uncertainty over the functions of consciousness, we made no firm prediction as to which of these measures would be affected by taking an EEG from the relevant side of the head, though we hoped that it might be reaction time (as, according to Penrose, the effect of taking the EEG would be to cause earlier collapse of any relevant quantum field). In the event it was failure to respond to targets that was most sensitive to the EEG effect, in that taking an EEG from a relevant brain area appeared to reduce failure rate. This positive finding encouraged us to put extra work into tightening up and automating the experiment, as described in Appendix C, which provided confirmatory findings.

Two tests were employed in this second experiment; a mainly left-brain task equivalent to the first used, except that it required word identification (also a left-brain function) instead of number identification. The additional test exercised the right brain as it involved pattern identification (right parietal cortex) and responding with the left hand (right motor cortex). The outcome measures were the same as in the first experiment, but there was of course a separate set for each type of test.

III
Results and Discussion

On the face of it, we found evidence that an experimental set-up designed to induce collapse of any quantum field in the brain affects performance of tasks involving awareness, the implication being that awareness is associated in some way with a quantum field. Obviously one must consider carefully whether the finding might be spurious, due to experimental artefact or error. The best evidence that the result is genuine in the pilot (Appendix B) came from a confirmed observation that altering the left-sided EEG electrode placement reversed the results obtained. We had not expected this as we had been thinking in terms of global electrical states of each hemisphere as the relevant variables. In fact there is good evidence from many sources that performance of tasks of the type that we used is localized to quite small brain areas, while volume conduction within the brain does not spread to distant EEG electrodes, so we ought to have expected our test to be sensitive to electrode position, as was observed. In our second experiment (Appendix C) we conducted control observations which showed that the experimental effect did not depend on programming errors or any electrical or acoustical feedback to the subjects, while the fact that the experiment was fully automated eliminated any possibility that the experimenter might have influenced subjects' performance.

The overall probability that these findings may have been due to chance is around 1 in 500, small enough to be very suggestive but not conclusive. That our results were not more conclusive may have been due to deficiencies of methodology. This rested on the assumption that only the contralateral cortex controls hand movement, but it appears that the ipsilateral cortex is also sometimes involved (Kim *et al.* 1993). Further, the parietal scalp electrodes may not always have been sufficiently close to the relevant part of the motor cortex. We lacked the highly specialized apparatus that might have allowed us to check on this, so we may often have been influencing quantum fields irrelevant to performance of the experimental tasks.

The experiment was designed around Penrose's (1989) theory (Appendix A). As this predicts, it was EEG pen movement that appeared to be the relevant variable affecting performance. However, the concept of what constitutes a quantum measurement is so loose that it may encompass other explanations of our result. We can claim only weak support for the detail of Penrose's theory.

The lack of any experimental effect on reaction times is consistent with Libet's (1993) view that actions are initiated independently of awareness, which may only have a role in giving a final veto or go-ahead concerning whether they are to be actually performed. Average reaction times in the pilot were around half a second (523 msec.), in the word test of the second experiment almost identical (520 msec.) and in the pattern test a bit slower (618 msec.). We subsequently gave a series of subjects a range of more difficult tests giving average reaction times in the range 700–1400 msec. We were hoping to observe an effect on reaction time, but in fact found no experimental effect on any of the performance measures. This negative result can be explained on the basis of our hypotheses in two ways. It might be that the EEG, when undertaking more complicated tasks, no longer reflects electrical state changes dependent on quantum field collapse. Alternatively it may be that local blood flow changes in the cortex, which can occur quite fast in relation to use of a brain area (David *et al.*, 1994), become significant during a longer task and have similar 'measurement' or gravitational consequences to EEG pen movement which outweigh those of pen movement.

During the experiments reported in Appendices B and C, the EEG machine had been set to amplify as wide a range of frequencies as possible, as a sort of catch-all. In a final series of experiments (on a further 42 subjects using a fully automated simple pattern task on which the average reaction time was 588 msec.), we installed a variable bandpass filter in one (right-sided) EEG channel and examined the consequences of allowing through only a restricted range of frequencies. Significant results were again obtained overall (in relation to all three outcome measures there was a 1 in 100 possibility that the findings were due to chance but in relation to target misses only it was 1 in 1000, indicating that target misses were again the most sensitive measure). The most marked experimental effect occurred when amplifying frequencies were in the alpha band (8–13 Hz.), a lesser effect was seen at 1.5–7 Hz. and at 14–30 Hz., but no effect whatsoever at 35–45 Hz. As alpha activity is often reciprocally related to activity in neighbouring frequency bands, one would not expect a tight relationship of frequency to experimental effect but our finding is suggestive and consistent with views that alpha activity reflects attentional functions (e.g. Ray and Cole, 1985) which were certainly involved in our experimental task.

IV
Conclusions

Our method appears to offer a straightforward experimental approach to studying the nature and functions of consciousness. It has produced evidence that awareness may be associated with collapse of a quantum field and that these fields are reflected in activity in the lower part of the range of EEG frequencies. It may also be of interest to physicists concerned with the mechanisms of wave function collapse. However, it requires confirmation by independent researchers. If its validity should be confirmed, the method would benefit from various refinements needing technical resources unavailable to us.

APPENDIX A:
The Quantum Gravity Theory of Consciousness

The ingredients of the theory are as follows.

1. The entire universe is describable by a modification of quantum theory (called by Penrose *correct quantum gravity*) in which there is a wave-function ψ for the universe. The evolution of ψ is determinate but non-algorithmic. The entire dynamics of the universe and everything in it is expressed through this evolution.
2. In so far as the evolution of ψ can be approximated to the evolution of the wave-function in conventional quantum theory, the former can exhibit either Hamiltonian-like evolution or collapse-like evolution. The non-algorithmic nature of the evolution is manifested in the collapse-like behaviour (hereafter referred to simply as 'collapse').
3. As far as its macroscopic content is concerned, the wave function is concentrated on a classical state. It does not, except momentarily, correspond to a state such as a superposition of a live and a dead cat. This property is ensured by collapse.
4. Collapse involves gravitation in an essential way. In particular, the state $\psi_1 + \psi_2$ collapses (to either ψ_1 or ψ_2) when ψ_i is concentrated on a classical state x_i ($i = 1, 2$) and the gravitational fields g_i of the x_i are such that a quantum state corresponding to the difference field $g_1 - g_2$ has a value for the expected number of longitudinal gravitons greater than 1. This criterion can be translated into an inequality involving an integral operator acting on $g_1 - g_2$.
5. Problem-solving by the human brain can be non-algorithmic. In such cases, the brain is utilizing the collapse aspect of the evolution of the wave function, and hence it involves gravity. This is psychologically manifested as 'insight'. While this can happen subconsciously, it is typically a conscious process. This suggests that consciousness is associated with collapse of the form described in 4.
6. It is therefore hypothesized that conscious problem-solving involves in an essential way the evolution of ψ into a superposition of states $\psi_1 + \psi_2$ (or more states), in which each individual state is concentrated on a classical state; the classical states involve macroscopically differing physical conditions of the brain in question; and the difference between the gravitational fields of these classical states satisfies the conditions of 4. This is followed by a collapse into one or other of the constituents.

Some remarks on this are required in order to remove possible misunderstanding. Penrose's arguments (which are too technical to summarize here) involve quantum cosmology in an essential way. Thus it is important that ψ refers to the entire universe and not just to some sub-system such as the brain. This is the point at which the essential holism of quantum theory enters. The evolution of the brain (to paraphrase the formulation of 6) into a superposition is not necessarily the result of the brain being presented with a stimulus that is itself a quantum superposition. In other words we are not specifically concerned here with a 'Schrödinger's cat' situation. Rather, in *any* conscious decision-making a superposition is involved: the decision process itself is based on an evolution in which microscopic superpositions always present in the brain (since collapse does not act at the microscopic level to iron them out) become amplified by brain functions to the point where the collapse mechanism of 4 can take place. While consciousness (or at least conscious decision-making) involves collapse, the reverse is clearly not the case: consciousness is the result of some particular combination of collapse with cognitive processes.

The details of the process are unspecified and cannot be determined by the very general arguments that Penrose uses. While it is likely that in a decision-making process the states in the superpositions are the different possible outcomes for the decision, it is not to be supposed that their amplitudes are similar and that the main part of the decision takes place in the collapse phase; it could rather be the case that the collapse merely provides a readout mechanism for a quantum-computer calculation in which the brain first reduces the amplitude of the incorrect component to a low value. In this case the procedure would be non-computable classically, but quantum-computable.

The essential feature of this theory that we shall use to build an experimental test is that conscious decision-making involves in an essential way the gravitational field of every object in the universe that is correlated with the brain-states involved in the decision. We now show that, as a result of this, it is to be expected that, by coupling to the brain an EEG with massive pens, the decision-making process will be altered.

We will write the quantum state of the universe at time 0 (somewhat schematically — we are ignoring issues such as the role of quantum statistics in requiring states not to be simple tensor products) as

$$\psi(0) = \psi_B(0) \otimes \psi_g(0) \otimes \psi_E(0) \otimes \psi_R(0)$$

where the subscripts denote: B the brain, g the gravitational field, E the EEG apparatus, R the rest of the universe. We assume that $\psi(0)$ is not a superposition of macroscopically distinguishable states (in particular, that $\psi_g(0)$ is not decomposable into a sum of states concentrated on gravitational fields that differ by more than the Penrose criterion). The theory holds that in the course of conscious decision-making the brain state will evolve at some time $t > 0$ to one of the form $\psi_{B1}(t) + \psi_{B2}(t)$, so that, by reversing the evolution, the initial state could be written as $\psi_B(0) = \psi_{B1}(0) + \psi_{B2}(0)$ with no macroscopic distinction between the two components. We stress again that on this theory the initial superposition is intrinsic and not the result of stimulating the brain by an external superposed state. The gravitational field is coupled to the brain state and to all matter, and by the usual measurement theory the part of the state describing the brain and the gravitational field evolves to

$$\psi_{B1}(t) \otimes \psi_{g1}(t) + \psi_{B2}(t) \otimes \psi_{g2}(t)$$

in which, for $t > t_1$, say, the gravitational parts differ sufficiently for collapse to take place at that stage; the decision is consciously reached at this point.

We suppose that an EEG is connected to the appropriate hemisphere so that it is correlated with the brain in such a way that $\psi_{B1}(t)$ and $\psi_{B2}(t)$ produce significantly different EEG pen traces. The initial state $\psi_B(0) \otimes \psi_E(0)$ then evolves to $\psi_{B1}(t) \otimes$

$\psi_{E1}(t) + \psi_{B2}(t) \otimes \psi_{E2}(t)$ and, if the gravitational field is included, $\psi_B(0) \otimes \psi_E(0) \otimes \psi_g(0)$ evolves to

$$\psi_{B1}(t) \otimes \psi_{E1}(t) \otimes \psi'_{g1}(t) + \psi_{B2}(t) \otimes \psi_{E2}(t) \otimes \psi'_{g2}(t)$$

where now the ψ'_g terms reflect the EEG pen movements.

On the other hand, if the EEG is connected to the 'wrong' hemisphere, so that it is not correlated with the brain state involved in the decision, then no measurement takes place and in that case $\psi_B(0) \otimes \psi_E(0)$ evolves to

$$\psi_{B1}(t) \otimes \psi_E(t) \otimes \psi'_g(t) + \psi_{B2}(t) \otimes \psi_E(t) \otimes \psi'_g(t)$$

The basis of Penrose's theory (which he supports by detailed field theoretic calculations) is that the criterion for collapse will only be marginally met for superpositions of different brain states, so that in normal functioning collapse only occurs when a large part of the brain is involved in the states in question. It is easy to see that the EEG will then cause a much larger effect and thereby invariably exceed the one-graviton threshold. Indeed, if we assume a 1% w/w concentration of sodium ions in the intercellular fluid, and a shift as a result of the conscious activity of the centre of gravity of these in relation to potassium ions amounting to 10% of their concentration with a length-scale of 0.5 cm. maintained homogeneously over a volume of 50 ml. (surely a gross over-estimate), then the resulting dipole moment of 5×10^{-2} gm.cm. is clearly less than the dipole moment change of at least 0.5 gm.cm. due to the excursion of a large pen of mass at least 4 gm. through 0.5 cm. at its tip.

Thus the gravitational fields associated with the pens will pass the Penrose criterion before the time t_1 at which collapse began when the EEG was not correlated with these states. In this case a decision will be 'forced' much earlier than would be the case if the EEG were not correlated with the brain state.

On the other hand, where the 'wrong' hemisphere is used, there is no difference between the gravitational fields of the two states and so no enhancement of collapse.

APPENDIX B: Pilot Experiment

Subjects

Subjects were selected from staff at the Department of Psychiatry, Royal South Hants. Hospital. Most were nurses. The inclusion criterion was willingness to volunteer; the exclusion criteria were left-handedness or a good ability to read musical scores (because the experiment depended on laterality effects). After preliminary work had ensured that the apparatus was working properly, the experiment was carried out using 28 subjects (4 male, 24 female; average age 34 years; age range 20 to 58 years).

Methods

The experimental task was to press a button with the right thumb in response to some (2, 5 or 8) out of a series of random digits (0–9) flashed at one second intervals onto a small screen placed about four feet in front of the subject. Each subject was tested for about 40 minutes. Subject, apparatus and experimenter were all in the same room but displays of results could not be seen by subjects. While undertaking the task, music (the Brandenburg Concertos by J.S. Bach) was played through a headphone to the left ear only. The purpose of this was to activate subjects' right hemispheres and there was a subsidiary benefit in that it tended to mask sounds from the switching relays and the EEG machine. In addition, in order to increase the error rate on the task, which was low, subjects who normally wore spectacles were tested without them while those with normal sight were asked to wear spectacles. This increased the difficulty of the task and the error rate. People were given a brief practice period before testing started and mistakes were distributed throughout the period of testing with surprisingly little tendency to accumulate early on (during familiarization) or at the end (due to fatigue).

The EEG machine was a Grass 4-channel apparatus with relatively massive pen recorders. Two bipolar channels were taken from each side of the head. The right-sided electrode placement for both channels was always posterior temporal to mid-parietal, while the left-sided placement was varied as described in the Results section (below). Relays placed in the EEG headbox intercepted each channel and could either be closed so that the EEG signal reached the machine normally, or open so that the signal was interrupted. These relays were controlled by a random number generator which could either open all four channels so that no signal reached the EEG machine, or open the two right-sided channels or the two left-sided channels.

Results

Results were automatically analyzed for blocks of numbers shown to the subject which could be varied in length. The length of time between changes of relay closure status could also be varied. The results presented for each block were subdivided according to the three EEG recording conditions. They were number of targets (i.e. 2, 5 or 8) shown; number of targets hit; number of ‘false hits’ i.e. button presses when a non-target was on the screen; averaged reaction times.

All statistical results shown are Chi squares calculated from 2 × 2 contingency tables comparing target hits with target misses; *t*-testing was used to examine reaction times but, as no relevant significant differences were found in these times, no *t*-test results are given.

The frequency of target misses (i.e. number of targets shown minus number hit) often showed significant variations that appeared to be dependent on the EEG recording condition. Reaction times and false hits, on the other hand, showed only minor, non-significant, variations. The results presented, therefore, mainly relate to target misses. People showed a huge variation in the number of misses that they made relative to the number of targets presented, ranging from 0.2% to 52%.

The mode was 3.1% and the mean 6.7% (SD 11%). Reaction times were around 0.5 seconds, but there was a tendency for those with faster average reaction times to make fewer mistakes. In keeping with the pilot, exploratory nature of this experiment, the effect of varying some of the conditions was investigated. The left-sided EEG was taken either between anterior occipital and frontal positions (condition ‘N’) or between posterior temporal and anterior parietal (conditions of type ‘P’); while, within the latter type three different choices were used for the average time between changes of EEG connections, the three conditions being designated PB (8.5 seconds), P (17 seconds) and PL (39 seconds). For condition N 17 seconds was used throughout.

The overall tendency was for fewer misses to take place during the left-side recording. The pattern of misses varied, however, with the conditions, indicating complexity underlying the significant effects. Table 1 gives the aggregated results, while Table 2 tabulates the results for different conditions, excluding some subjects with outlying overall performance. The normalized percentages shown here were calculated by multiplying the actual percentages by the ratio between the average error percentage for the subjects in each series and the average error percentage for all 18 subjects. Table 2 shows a marked contrast between the N and the P series, a similarity of the PL series to the N series and of the PB series to the P series.

TABLE 1
All Subjects (n = 28)

	Target hits	Misses	False hits
No EEG	4212	312	111
Right EEG	4651	343	121
Left EEG	4557	286	110

Significant Differences No EEG v Left (mis
Right EEG v Left (misses) $P <.05$

TABLE 2
Normalized Percentage of Target Misses in relation to number of targets presented. (Subjects who showed misses in the range 1% to 18%)

	N series (n = 8)	P series (n = 5)	PL series (n = 3)	PB series (n = 2)
No EEG recording	4.1	7.0	4.3	7.6
Right sided EEG	6.6	5.7	6.3	5.3
Left sided EEG	5.5	3.6	5.7	3.5
Significance levels (Chi Square 1df)				
No EEG v Right	< .02	ns	ns	ns
No EEG v Left	ns	< .002	ns	< .05

TABLE 3: Subjects N1, 2, 3, 4, 5

	Target hits	Misses
No EEG	765	13
Right EEG	820	30
Left EEG	839	20

Significant Difference No EEG v Right

TABLE 4: Subjects P1, 2, 3, 5, 6

	Target hits	Misses
No EEG	775	48
Right EEG	814	40
Left EEG	772	23

Difference No EEG v Left

The first group of subjects to be tested were designated N1 to 5. Their right-sided EEG was recorded between posterior temporal and mid-parietal electrodes as described in the methods section, while their left-sided EEGs were recorded between anterior occipital and frontal electrodes.

Table 3 shows that these people made fewest errors when no EEG was being recorded and there were significantly more errors during right-sided recordings.

As there was more machine noise during left-sided recordings (because the EEG machine was picking up frontalis muscle activity), we wondered whether these findings might be artefactual due to some noise (as in the right-sided recording condition) distracting subjects, while a further increase in noise improved their performance by causing an alerting effect. The left-sided electrode placement was therefore changed to posterior temporal to anterior parietal (the anterior parietal placement was decided on in order to allow the electrodes to pick up activity from the left motor cortex which controls right thumb pressing).

The results given in Table 4 were obtained which, in contrast to the previous series, show fewest errors during left-sided recordings and most in the control condition. It will

TABLE 5
Subjects N6, 7, 8, 10, 11

	Target hits	Misses
No EEG	763	33
Right EEG	875	56
Left EEG	795	49

Difference No EEG v Right P< .1

TABLE 6
Subjects P7, 8, 9

	Target hits	Misses
No EEG	431	27
Right EEG	537	18
Left EEG	510	18

Difference No EEG v Left P< .1

TABLE 7
Subjects PL, 1, 2, 3, 4

	Target hits	Misses
No EEG	677	24
Right EEG	736	33
Left EEG	780	37

No significant differences

TABLE 8
Subjects PB 1, 2, 3, 4

	Target hits	Misses
No EEG	591	25
Right EEG	687	20
Left EEG	690	12

Significant Difference
No EEG v Left P< .005

be noticed that subject P4 was excluded from Table 4. The reason for this was that she apparently used a different strategy for performing the task from most subjects which resulted in her obtaining an error rate, made at random with respect to EEG condition, of nearly ten times the average (52 %). Her results would have swamped the remainder if she had been included.

In order to try to confirm the surprising differences between the N and P series, further subjects were tested as shown in Tables 5 and 6.

It will be seen that the results are broadly similar to those obtained previously. Subject N9 was omitted from Table 5 for reasons similar to those for omitting P4 from Table 4. N9 appeared to be performing quite atypically, and made 33% errors at random.

Retaining the P series electrode placement, further subjects were tested while varying the length of time between changes of EEG condition. During the N and P series, changes of condition had nominally occurred every 10 seconds though, because changes were made randomly, similar conditions sometimes succeeded one another and the average time between changes of condition was approximately 17 seconds. During the PL series, the nominal time between changes of EEG condition was increased to 23 seconds and during the PB series it was decreased to 5 seconds. The results are shown in Tables 7/8. The distribution of misses in the PL series resembles the N series, but differences are not significant. The PB series closely resembles the P series.

Discussion

This was a pilot experiment which is methodologically imperfect in a number of ways. The main criticism could be that inadvertent 'cueing' could not be excluded, mediated by changes in the sound of the EEG being subconsciously audible to either subject or experimenter. Nevertheless we felt that these preliminary results were sufficiently sound to warrant presentation, discussion and development of a better methodology. Because of the simplicity of the experimental task, it was probably unrealistic to expect that consciousness might significantly influence reaction times since subjects appeared to perform largely automatically, with awareness playing only a sort of 'supervisory' role. Most of the processes involved in task performance may in any case have occurred before conscious awareness of the target was available.

The overall finding that people missed fewer targets when the EEG was being recorded from the left hemisphere is consistent with the experimental hypotheses. Let us suppose that the effect of enhancing the onset of wave-function collapse is to enhance consciousness. If consciousness were enhanced on the right or was not altered, subjects may have been more inclined to listen to the music and less inclined to press their button. However, many sources of experimental bias or error could have produced this result, quite independently of any hypothetical wave function collapse.

It is less easy to claim that the differences between the N and P series might be due to bias or error. The only methodological difference between the two series was in the position of the left-sided electrodes, and the contrast between the two series (which is significant at the <.001 level) was a complete surprise to us. It is difficult to see how any source of experimental error could have produced such differences. In particular, machine noise cannot be responsible as performance contrasts between the right and left conditions were greater in the P series while noise differences were greater in the N series, and the largest contrast of all between the two series is in the control condition. The fact that the findings in the first subgroups tested in the two electrode positions (Tables 3 and 4) could be approximately replicated (Tables 5 and 6) adds further weight to them.

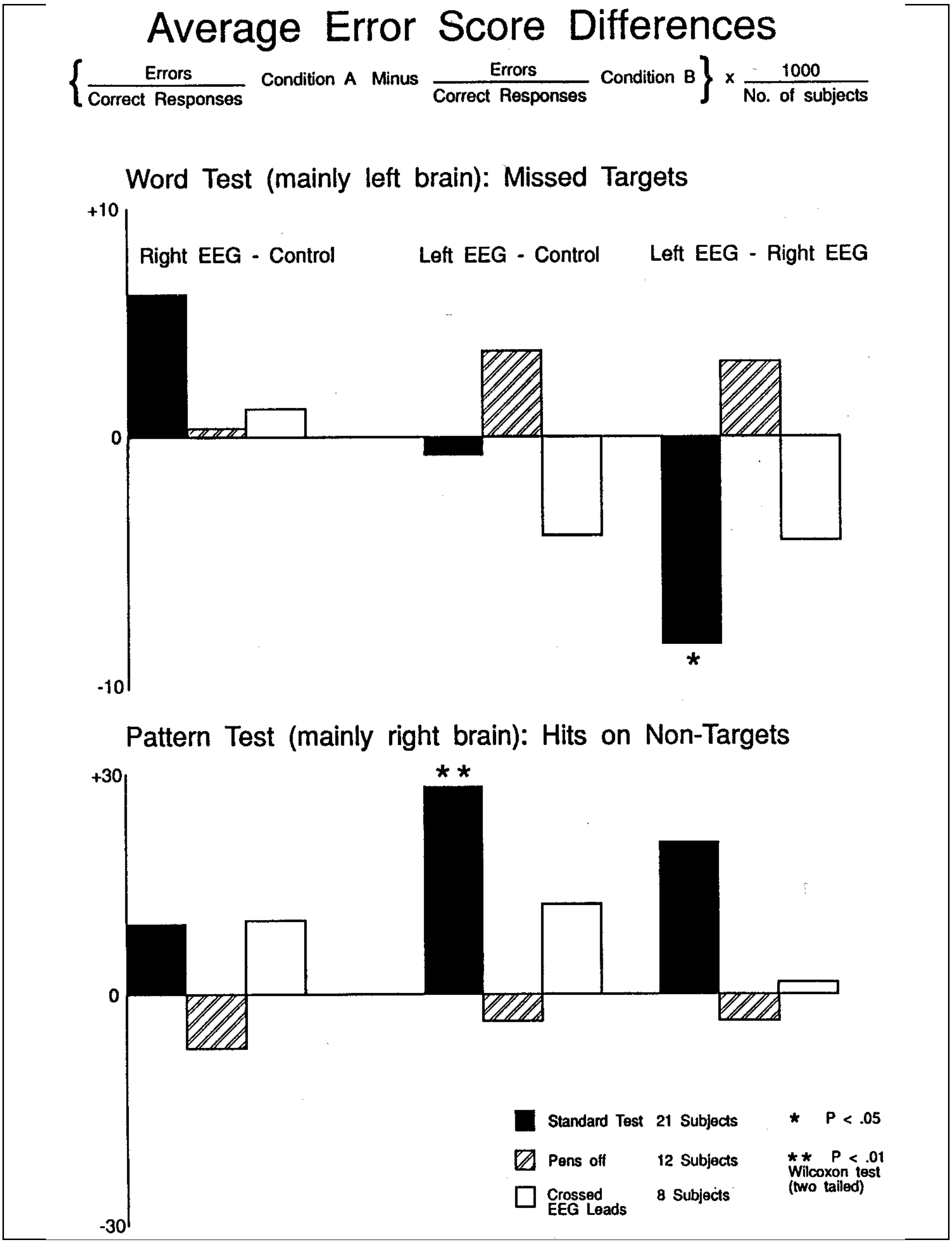
The hypotheses do provide a natural explanation. Performance is worse when consciousness is enhanced in areas of the brain not directly involved in task performance and better when it is enhanced in the left motor region responsible for task performance. To account for the different findings in the 'no EEG' conditions in the N and P series one might claim that a rebound 'scatterbrainedness' occurs if consciousness has been too tightly tied to task performance. This suggestion could follow naturally from Marshall's (1989) hypothesis which implies that consciousness makes quite high energy demands on particular brain areas. Alternatively, it might be the case that the N series electrode placement on either side impaired performance (though more so on the right), while the P series placement improved it on the left. The results from the PL series may support the first explanation as they may reflect an exhaustion with increased time of the energy supply needed to keep consciousness localized to one area. The PB series tends to confirm the results provided by the P series.

APPENDIX C
Second experiment

Methods

In our new experiment, subjects, selected as before, were placed in a room separately from the experimenter and EEG machine. They were given both mainly left-hemisphere and mainly right-hemisphere tasks. The left task was to respond with the right hand to certain words out of a small vocabulary flashed in random order onto a screen. The right task was to respond with the left hand to identical pairs of patterns from a random series of patterns containing some identical pairs and some non-identical. During the left task, music to the left ear was again used as a distracter and during the right task a recorded lecture was played to the right ear.

The control of the experiment and the recording of the results was entirely automated, with the computer screen being used to display the target words and patterns. Electrode placements on both sides were always parietal to posterior temporal (C3–T5 and C4–T6).



Results

The figure shows that the left-brain task gave essentially the same result as had the pilot experiment (see 'Standard test' results). There were fewer misses when the recording was from the left hemisphere. The significance level was much the same ($p = 0.025$ with a one-tailed Wilcoxon test), but of course the combined probability of the results from the two experiments is less than 0.002. Most of the difference in the new experiment appeared to be due to excess errors during the right EEG condition. During the pattern task subjects hit significantly more non-targets during the left EEG condition than during the control condition. This provides a pleasing, though imperfect, symmetry to the results. We think that the lack of complete symmetry may have been due to subjects using different cognitive strategies to perform the two different tasks.

In order to check on the validity of the findings, some subjects were tested with the EEG pen motors switched off, but the rest of the apparatus functioning normally ('pens off'), while others were tested with each EEG lead connected to all EEG channels ('crossed leads') instead of the standard configuration of having one channel for each pair of leads. No significant differences in any error rates were found in either of these groups. The 'pens off' result suggests that the positive findings in the standard test were due to pen movements and not to impedance changes in scalp electrodes, noise from relays closing the EEG channels or programming errors. The 'crossed leads' result provides an important control experiment which helps to rule out the possibility that subconscious awareness of noise from the EEG machine itself might have influenced the standard test. The possibility of the subjects' being influenced by electrical feedback from the EEG was highly implausible because of its large input impedance. In the absence of any alternative explanation of the results, we are left with the conclusion that a quantum-mechanical effect was observed during these experiments and that it depended on the ability of the EEG pens to move. The pattern of the results suggests that the differences may have been due to the experiment influencing subjects' level of awareness of the distracters provided, with a consequent secondary effect on task performance.

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References

Clarke C.J.S. (1994), 'Coupled Molecular Oscillators Do Not Admit True Bose Condensations'. To appear in *Journal of Physics A*.

David A., Blamire A. and Breiter H. (1994), 'Functional Magnetic Resonance Imaging', *British Journal of Psychiatry*, **164**, pp. 2–7.

del Giudice E., Doglia S., Milani M. and Vitiello G. (1986), 'Solitons and Coherent Electric Waves in a Quantum Field Theoretical Approach', in *Modern Bioelectrochemistry*, ed. F. Gutmann and H. Keyzer (Plenum: New York).

Dennett D.C. (1991), *Consciousness Explained* (Penguin: London).

Eccles J.C. (1989), *Evolution of the Brain: Creation of the Self* (Routledge: London).

Edelman G.M. (1989), *The Remembered Present: a Biological Theory of Consciousness* (Basic Books: New York).

Fröhlich H. (1968), 'Long Range Coherence and Energy Storage in Biological Systems', *International Journal of Quantum Chemistry*, **42**, pp. 641–9.

Hameroff S.R. (1994), 'Quantum Coherence in Microtubules: a Neural Basis for Emergent Consciousness', *Journal of Consciousness Studies*, **1**, pp. 91–118.

Hofstadter D.R. (1979), 'Gödel, Escher, Bach: an Eternal Golden Braid' (Basic Books: New York).

Kim S-G., Ashe J. and Geogopoulos A.P. (1993), 'Functional Imaging of the Human Motor Cortex at High Magnetic Field', *Journal of Neurophysiology*, **69**, pp. 297–302.

Libet B. (1993), 'The Neural Time Factor in Conscious and Unconscious Events', in Ciba Foundation Symposium: *Experimental and Theoretical Studies of Consciousness* (Wiley: Chichester).

Lockwood M. (1989), *Mind, Brain and the Quantum: the Compound I* (Blackwell: Oxford).

McGinn C. (1990), *The Problem of Consciousness: Essays Toward a Resolution* (Blackwell: Oxford).

Marshall I.N. (1989), 'Consciousness and Bose-Einstein Condensates', *New Ideas in Psychology*. **7**, pp. 73–83.

Penrose R. (1989), *The Emperor's New Mind* (Oxford University Press: Oxford).

Pessa E. (1988), 'Symmetry Breaking in Neural Nets', *Biological Cybernetics*, **59**, pp. 277–81.

Ray W.J. and Cole H.W. (1985), 'EEG Alpha Activity Reflects Attentional Demands and Beta Activity Reflects Emotional and Cognitive Processes', *Science*, **228**, pp. 750–2.

Searle J.R. (1990), 'Who is Computing with the Brain?', *Behavioural and Brain Sciences*, **13**, pp. 632–41.

Zohar D. (1990), *The Quantum Self* (Harper Collins: London).