Intersubjective Agreement in a Quantum-like Model of "Paradoxical" Experiments in Biology

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ABSTRACT

In previous articles, we proposed to describe the results of Benveniste's experiments using a theoretical framework based on quantum logic. This formalism described all characteristics of these controversial experiments and no paradox persisted. This interpretation supposed to abandon an explanation based on a classical local causality such as the "memory of water hypothesis. In the present article, we describe with the same formalism the cognitive states of different experimenters who interact together. In this quantum-like model, the correlations observed in Benveniste's experiments appear to be the consequence of the intersubjective agreement of the experimenters.

An unresolved scientific controversy

The expression "memory of water" refers to the hypothesis that specific biological information could be "imprinted" in water samples in the absence of the biologically active molecules that served as "template". This hypothesis became famous in 1988 when the journal *Nature* published an article from Benveniste's team and other scientists reporting that high dilutions of antibodies apparently kept biological activity when added to white blood cells called basophils despite no molecule from the initial solution could possibly be present (Davenas *et al.,* 1988). The story of water memory and the

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arguments exchanged by Benveniste and Maddox, the director of *Nature,* have been described elsewhere (de Pracontal, 1990; Alfonsi, 1992; Schiff, 1998; Benveniste, 2005; Beauvais, 2007). This episode belongs now to the history of sciences and, for many scientists, the "memory-of-water" story ended when *Nature* concluded that these experiments were a delusion (Benveniste, 1988; Maddox, 1988a; b; Maddox *et al.,* 1988).

To be exact, Benveniste's team was not the first to report such results. Indeed, the idea that high dilutions of pharmacological compounds could have biological effects is one of the pillars of homeopathy (Walach *et al.,* 2005). As a matter of fact, the early experiments in Benveniste's laboratory were performed in the context of scientific contracts with homeopathy firms (Davenas *et al.,* 1987; Poitevin *et al.,* 1988). Less known are the devices and biological systems that Benveniste's team set up after 1988 until his death in 2004. These innovative devices were most probably

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related to the determination of Benveniste for standing out from homeopathy and putting the debate on scientific grounds. Two models emerged from this period and very promising results, which were regularly communicated to scientific congresses, were obtained (Hadji *et al.,* 1991; Benveniste *et al.,* 1992; Aïssa *et al.,* 1993; Benveniste *et al.,* 1994; Aïssa *et al.,* 1995; Benveniste *et al.,* 1996; Benveniste *et al.,* 1997; Benveniste *et al.,* 1998; 1999). The first model was the isolated rodent heart model (using Langendorff device) and the other one was the *in vitro* coagulation model, which was thereafter completely automated. The two biological models and the results that were obtained have been described in details elsewhere (Beauvais, 2007).

The methods for "imprinting" information in water were also "improved" during this period and Benveniste's team built up different electronic devices that allowed "transferring molecular information" from one vial containing target molecule to another vial containing "uninformed" water. The "imprinted" water sample was tested on a biological system. For the first attempts, the electronic transfer was performed using two electric coils (one for input and the other for output) wired at a low-frequency electronic amplifier (Aïssa *et al.,* 1993; Benveniste *et al.,* 1994; Aïssa *et al.,* 1995). Then Benveniste's team showed that the "information" captured by the electric coil at input could be recorded on the hard disk of a computed via its sound card and then "replayed" to water samples placed in the electric coil at output (Benveniste *et al.,* 1996; Benveniste *et al.,* 1997; Benveniste *et al.,* 1998). The term "digital biology" was coined by Benveniste to describe these new experiments. As previously described, very impressive and clear-cut experiments were obtained (Beauvais, 2007). However, if these experiments were so spectacular, why Benveniste did not convince other scientists of the reality of these phenomena?

The paradoxes of Benveniste's experiments

The simplest answer to the question raised in the last paragraph is that an unexpected and puzzling phenomenon poisoned the experiments, more particularly some blind experiments performed with the participation of other scientists (Beauvais, 2008). We have described in details these experiments and a comprehensive analysis of one of them has been recently published (Beauvais, 2013c).

In order to easily describe this issue, a biological effect not different than background noise (no significant change of the biological parameter) will be symbolized with "↓" and biological signal (significant change of the biological parameter) with "↑". Suppose that the expected results were ↓↓↓↓↑↑↑↑ (*i.e.* 4 "inactive" samples and 4 "active" samples in this order). When open-label experiments were performed, expected results were obtained, namely: ↓↓↓↓↑↑↑↑. This was also the case for in-house experiments blinded by an observer that we call a "type-2 controller" (Figure 1). These results were therefore in favor of Benveniste's claims. The concerns mainly occurred during "public demonstrations". Indeed, when Benveniste's team considered that the devices and the biological model were mature, gave the expected results and were free of external disturbances, a meeting with other scientists was set up in order to provide a definite proof of concept on the reality of the biological effects related to "memory of water" and "digital biology". For these blind experiments with the participation of observers that we call "type-1 controllers" (Figure 1), something like that was obtained: ↓↑↑↓↓↑↓↑, *i.e.* a signal was observed at the expected places not better than random. Nevertheless, the important point is that we should expect: ↓↓↓↓↓↓↓↓, *i.e.* only background noise and no signal.

The fact that a signal (↑) was observed – whatever its place – was nevertheless a fascinating result (Beauvais, 2012). Initially, the apparent mismatches between "inactive" and "active" samples in these experiments were interpreted by Benveniste as errors during handling of samples. Then, it appeared that such trivial explanation was false and "jumps" of activity from one tube to another were thought to be due to electromagnetic cross-contamination of samples. Note that a series of samples prepared and treated in the same conditions but not blinded by a type-1 controller gave "expected" results. Therefore, the explanation by "electromagnetic contamination" was limited. It was as if the conditions of blinding (type-1 vs. type-2 controllers) influenced the outcomes (Beauvais, 2008; Beauvais, 2013c). In a next section, we will precisely define the role of the different observers who participated to the blinding of the experiments.

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The unexplained emergence of a "signal" from background noise (in other words, a biological parameter significantly changed) was the main reason why Benveniste's considered that these experiments merited to be continued. Contamination whatsoever (from water or from the electromagnetic environment) were then called to the rescue to explain *a posteriori* these mismatches. As a consequence, after each failure of a "public demonstration", Benveniste's team engaged in a headlong rush to improve electronic devices and biological models. The quest of the crucial experiment became the main objective.
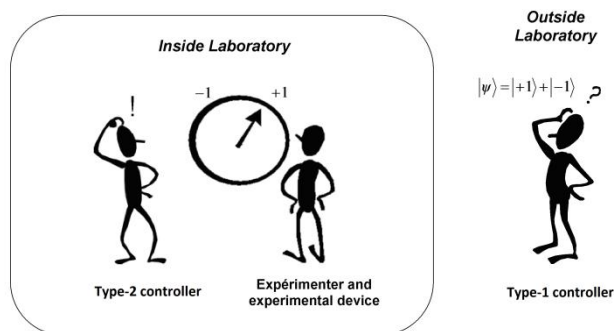

Figure 1. Type-1 and type-2 controllers. In Benveniste's blind experiments, success or failure depended on the conditions of blinding. Therefore, we defined two types of controllers whose role was to supervise and to check the results. These observers replaced the initial label of all the experimental samples by a code number. The type-2 controller was inside the laboratory where he/she could interact with the experimenter and the experimental system. As a consequence, the type-2 controller was always in the same "reduced" state as both the experimenter and the experimental device. In contrast, the type-1 controller was outside the laboratory and he/she did not interact with the experimenter or experimental device and had no information on the on-going measurements. When all the samples had been tested, the results of the experiments for each sample (no effect or significant effect) were sent to the type-1 controller. The controllers (type-1 or type-2) assessed the rate of concordant pairs by comparing the two lists for each sample: state of the biological model (no change, "↓" or significant change, "↑") and corresponding label under code number ("inactive" or "active" sample).

These efforts culminated in 2001 when a team commissioned by the United States Defense Advanced Research Projects Agency (DARPA) investigated a robot analyzer designed by Benveniste's team to automatically perform "digital biology" experiments with the coagulation model. In an article published in 2006, the team of investigators reported that some effects supporting "digital biology" had been observed when Benveniste's team was

present, but they concluded that they had been unable to reproduce these results after the departure of the team (Jonas *et al.,* 2006). According to the authors of the article, experimenter's effects could explain these results of Benveniste's experiments, but they concluded that a theoretical framework was necessary before continuing this research.

Therefore we face a dilemma: we can consider that "memory of water" (and its avatars) exists or does not exist; but, in both cases, we are uncomfortable. We can deem that "memory of water" exists because biological signal emerged from background noise and because there were numerous coherent results, particularly in some blind experiments. On the contrary, we can judge that "memory of water" does not exist because this hypothesis is not compatible with our knowledge of physics of water, because reproduction of these experiments by other teams was generally not convincing or because blind experiments during "public demonstrations" were not better than random.

Quantum-like correlations of the "cognitive states" of the experimenter

To solve the dilemma described in the previous section, we proposed in a series of articles to describe these experiments using notions from quantum logic (Beauvais, 2012; 2013a; Beauvais, 2013c; b). In the model that we described, there is no need of postulating "memory of water". Taking into account the experimental context allows describing "success" and "failure" as two facets of the same phenomenon. The paradoxes described in the above section are therefore dissolved in this model. The use of quantum logic is reasonable since classical probabilities are only a special case of quantum probabilities and, at worst, calculations would show that classical probabilities are sufficient to describe these experiments.

In quantum logic, the term "observable" refers to a physical variable. To each observable corresponds a set of possible "pure states". Before any measurement/observation, the quantum system is in a "superposed" state of all possible pure states. The states are represented in a Hilbert space (*i.e.*, a vector space with a finite or infinite number of dimensions and with a complex or real inner product). Note that the superposed state is not a simple

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mixture of the pure states; indeed, the unique pure state selected randomly by the measurement is undetermined before the measurement (there are no hidden variables that determine the outcome).

We define the "cognitive state" A of an experimenter/observer as the information on all possible measures/observations (with their respective probabilities) performed by this experimenter/observer on this system. Mathematically, A is represented by a vector $|\Psi_A\rangle$ in a Hilbert vector space. In Figure 2, the state vector of the cognitive state A is the superposition of the two pure states A_{-1} and A_{+1}, which are the tw$|\Psi_A\rangle = a|A_{+1}\rangle + b|A_{-1}\rangle$o possible outcomes of a measurement: with $|a|^2 + |b|^2 = 1$.

The norm a of the vector obtained after projection of $|\Psi_A\rangle$ on the axis of the pure state A_{+1}, is assimilated to a probability amplitude; therefore, the probability for the cognitive state to be associated with A_{+1} is $|a|^2$.

In our model of Benveniste's experiments, the first set of observables is the cognitive state A associated with expected results, in other words the "labels" of the samples: *i.e.* A associated with sample designated as "inactive" (A_{IN}) or A associated with samples designated as active (A_{AC}); all experimental samples are physically equivalent, only their "labels" differ. The numbers of inactive and active samples are defined for a series of experiments. For example, if the numbers of inactive and active samples are equal, then $P(A_{IN}) = P(A_{AC}) = 0.5$.

The second set of observables is the cognitive state A associated with the concordance of pairs: the experimenter observes the outcome with the biological system (background noise "↓" or signal "↑") and compares with the expected result (*i.e.*, the label of the sample: "inactive" or "active"). The pure states of the second set of observables are A_{CP} if pairs are concordant and A_{DP} if pairs are discordant. Pairs are concordant if "expected" results fit observed results: *i.e.*, $A_↓$ associated with A_{IN} and $A_↑$ associated with A_{AC}. Otherwise, pairs are discordant. Note that the probability associated with $A_↑$ must be different of zero even though this probability can be low (signal must be present in background noise).

The use of quantum logic outside quantum physics has been already described;

many authors have proposed to describe cognitive mechanisms and information processing in human brain by using notions and tools initially developed for quantum mechanics. These new quantum-like tools allowed addressing problems in human memory, decision making, personality psychology, etc, which were paradoxical in a classical frame (see for example the special issue of *Journal of Mathematical Psychology* in 2009) (Bruza *et al.,* 2009; Busemeyer *et al.,* 2012)
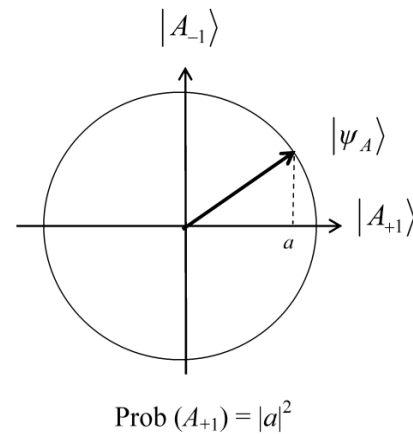

Figure 2. Superposition of quantum states. In quantum logic, a quantum system is a "superposed" state of all possible pure states. The states are represented in a Hilbert space (*i.e.*, a vector space). In this formalism, the cognitive state A is symbolized by Ψ_A. The probability associated with the pure state A_{+1} is the square of the probability amplitude a (which is the norm of the projection vector of the vector Ψ_A).

In our previous articles (Beauvais, 2013a; b; c), we showed that the paradoxes of Benveniste's experiments disappeared if the possible "cognitive states" of the experimenter were described according to some principles from quantum physics (superposition and probability interferences). We obtained equations that correctly described the characteristics of Benveniste's experiments, namely emergence of signal from background noise, disturbance of blind experiments (type 1 vs. type 2) and difficulties for other teams to reproduce the experiments.

The cognitive state of A was described as:

$$|\psi_A\rangle = (\sqrt{p}\cos\theta + \sqrt{q}\sin\theta)|A_{CP}\rangle + (\sqrt{q}\cos\theta - \sqrt{p}\sin\theta)|A_{DP}\rangle$$

(**Eq. 1**)

where p and q are the rates of "inactive" and "active" labels, respectively; θ is the angle of the

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rotation matrix for change of basis (from A_{IN}/A_{AC} basis to A_{CP}/A_{DP} basis).

According to Eq. 1, the probability to observe concordant pairs is:

$$\text{Prob}_{quant}(A_{CP}) = (\sqrt{p}\cos\theta + \sqrt{q}\sin\theta)^2$$

This probability is maximal (equal to 1) if $\sin\theta = \sqrt{q}$.

Why pairs were concordant remained however unexplained. Technically speaking, the couple of observables A_{IN}/A_{AC} and A_{CP}/A_{DP} behaved as noncommuting observables. In this article, we address this issue by considering what happens if several experimenters – not only one – perform experiments.
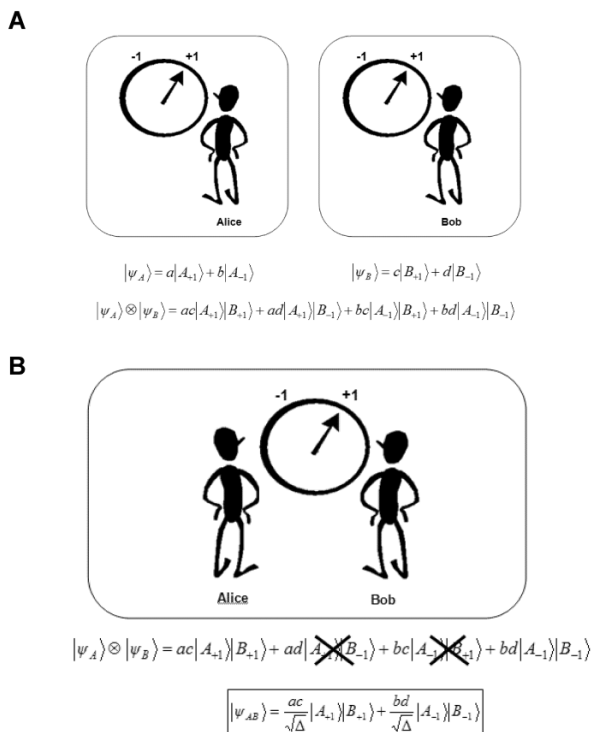

$$|\psi_A\rangle = a|A_{+1}\rangle + b|A_{-1}\rangle \qquad |\psi_B\rangle = c|B_{+1}\rangle + d|B_{-1}\rangle$$

$$|\psi_A\rangle \otimes |\psi_B\rangle = ac|A_{+1}\rangle|B_{+1}\rangle + ad|A_{+1}\rangle|B_{-1}\rangle + bc|A_{-1}\rangle|B_{+1}\rangle + bd|A_{-1}\rangle|B_{-1}\rangle$$

$$|\psi_A\rangle \otimes |\psi_B\rangle = ac|A_{+1}\rangle|B_{+1}\rangle + ad|A_{+1}\rangle|B_{-1}\rangle + bc|A_{-1}\rangle|B_{+1}\rangle + bd|A_{-1}\rangle|B_{-1}\rangle$$

$$\boxed{|\psi_{AB}\rangle = \frac{ac}{\sqrt{\Delta}}|A_{+1}\rangle|B_{+1}\rangle + \frac{bd}{\sqrt{\Delta}}|A_{-1}\rangle|B_{-1}\rangle}$$

Figure 3. Experiments with two experimenters. The pictures describe (A) two experimenters doing Benveniste's experiments in two separate places and (B) two experimenters doing joint experiments. Due to the intersubjective agreement, the state vectors that describe the cognitive states of the experimenters in these two experimental situations are different (see text).

Two experimenters doing experiments in two separate places

First, we consider a simple situation with "Benveniste's experiments" performed in two separate places by two experimenters: Alice with cognitive state A and Bob with cognitive state B (**Figure 3**A). We suppose that Alice and Bob make experiments in their respective laboratories with two experimental devices. They observe the rates of concordant and discordant pairs for the same series of samples (labeled "inactive" or "active").

According to the quantum logic, we can describe the two cognitive states A and B of Alice and Bob. Eq. 1 described in previous section is simplified with $a = \sqrt{p}\cos\theta + \sqrt{q}\sin\theta$ and $b = \sqrt{q}\cos\theta - \sqrt{p}\sin\theta$:

$$|\psi_A\rangle = a|A_{CP}\rangle + b|A_{DP}\rangle \qquad \textbf{(Eq. 1)}$$

$$|\psi_B\rangle = c|B_{CP}\rangle + d|B_{DP}\rangle \qquad \textbf{(Eq. 2)}$$

Note that the probability amplitudes a, b, c and d are real number (not complex numbers) in our quantum-like model. The cognitive states of the experimenters can be jointly described by a unique state vector that is the tensor product of $|\psi_A\rangle$ and $|\psi_B\rangle$:

$$|\psi_A\rangle \otimes |\psi_B\rangle = ac|A_{CP}\rangle|B_{CP}\rangle + ad|A_{CP}\rangle|B_{DP}\rangle$$
$$+ bc|A_{DP}\rangle|B_{CP}\rangle + bd|A_{DP}\rangle|B_{DP}\rangle \qquad \textbf{(Eq. 3)}$$

A and B are now described in a new Hilbert subspace defined by the four orthogonal bases $|A_{CP}\rangle|B_{CP}\rangle$, $|A_{CP}\rangle|B_{DP}\rangle$, $|A_{DP}\rangle|B_{CP}\rangle$ and $|A_{DP}\rangle|B_{DP}\rangle$. Eq. 3 shows that Alice and Bob observe the same results with a probability $(ac)^2$ for concordant pairs and with a probability $(bd)^2$ for discordant pairs. The outcomes of their respective experiments are different (concordant for one, discordant for the other) with a probability $(ad)^2 + (bc)^2$.

These results are trivial, but this presentation allows defining the formalism of a joint description of two experimenters before introducing the next section.

Two experimenters doing the same experiments

We now suppose that Alice and Bob are doing the same "Benveniste's experiments" at the same place with a unique experimental device (Figure 3B). The state vector that describes their cognitive states is the same tensor product as above:

$$|\psi_A\rangle \otimes |\psi_B\rangle = ac|A_{CP}\rangle|B_{CP}\rangle + ad|A_{CP}\rangle|B_{DP}\rangle$$
$$+ bc|A_{DP}\rangle|B_{CP}\rangle + bd|A_{DP}\rangle|B_{DP}\rangle \qquad \textbf{(Eq. 3)}$$

However, there is now a major difference: we must assume *intersubjective agreement* of

the two experimenters. In other words, Alice and Bob must agree on the results they observe together. It is not possible that for one experiment with a given label (*IN* or *AC*), Alice observes a concordant pair, whereas Bob observes a discordant pair. After a quantum toss, Bob could not observe that outcome is tail, whereas for the same coin Alice observes that the outcome is head. In Eq. 3, the "branches" of the state vector with the bases $|A_{CP}\rangle|B_{DP}\rangle$ and $|A_{DP}\rangle|B_{CP}\rangle$ do not comply with intersubjective agreement and therefore we write:

$$|\psi_{AB}\rangle = \frac{ac}{\sqrt{\Delta}}|A_{CP}\rangle|B_{CP}\rangle + \frac{bd}{\sqrt{\Delta}}|A_{DP}\rangle|B_{DP}\rangle \qquad \textbf{(Eq. 4)}$$

With $\Delta = (ac)^2 + (bd)^2$ since total probability must be equal to 1.

Therefore, due to intersubjective agreement, we have defined an operation (Eq. 4) that joins two cognitive states of experimenters observing the same experiments. We can easily calculate that there is a unique state vector $|\psi_B\rangle$ that is a *neutral element* for any state vector $|\psi_A\rangle$ for this operation:

$$|\psi_B\rangle = \frac{1}{\sqrt{2}}|B_{CP}\rangle + \frac{1}{\sqrt{2}}|B_{DP}\rangle$$

$$|\psi_A\rangle \otimes |\psi_B\rangle =$$

$$\left(a|A_{CP}\rangle + b|A_{DP}\rangle\right) \otimes \left(\frac{1}{\sqrt{2}}|B_{CP}\rangle + \frac{1}{\sqrt{2}}|B_{DP}\rangle\right)$$

$$\rightarrow |\psi_{AB}\rangle = a|A_{CP}\rangle|B_{CP}\rangle + b|A_{DP}\rangle|B_{DP}\rangle$$

In other words, if the cognitive state of Bob is "neutral" (as defined above), the probability for concordant pairs observed by Alice and Bob together or observed by Alice in the absence of Bob are the same.

We also easily see that $|\psi_B\rangle = |B_{CP}\rangle$ and $|\psi_B\rangle = |B_{DP}\rangle$ are two *absorbent elements* for any state of *A*. Thus, if $|\psi_B\rangle = |B_{CP}\rangle$ (*i.e.*, $c = 1$, $d = 0$, $\Delta = a$):

$$|\psi_{AB}\rangle = \frac{ac}{\sqrt{\Delta}}|A_{CP}\rangle|B_{CP}\rangle + \frac{bd}{\sqrt{\Delta}}|A_{DP}\rangle|B_{DP}\rangle = |A_{CP}\rangle|B_{CP}\rangle$$

In other words, if the cognitive state of any experimenter is associated with only concordant pairs, then both experimenters observe only concordant pairs (conversely, if all pairs are discordant for one experimenter, then both experimenters observe only discordant pairs).

Intersubjective agreement as the source of concordant outcomes

Eq. 4, which is the consequence of intersubjective agreement, has important consequences. Thus, suppose that Alice observes concordant pairs with probability 0.51 when she performs the experiments alone and suppose that Bob observes concordant pairs with probability 0.52 when he performs the experiments alone:

$$P_{quant}(A_{CP}) = 0.51$$

$$P_{quant}(B_{CP}) = 0.52$$

According to Eq. 4, when Alice and Bob perform joint experiments, the probability that they both observe concordant pairs is: $P_{quant}(AB_{CP}) = (0.51 \times 0.52) / (0.51 \times 0.52 + 0.49 \times 0.48) = 0.53$.

Therefore, the probability to observe concordant pairs changed for both Alice and Bob, simply by interacting and doing joint experiments.

In real physical world, a measurement is submitted to microscopic random fluctuations. Thus, when light is reflected or transmitted through a beam splitter, each state is associated with a certain probability amplitude, *a* or *b*; these variables are characteristic of the beam splitter for a given adjustment. Since the beam splitter is not an isolated object, it is submitted to many influences of the environment. Therefore, the ratio of probabilities for the reflected and transmitted light is submitted to tiny variations around a^2/b^2 due to thermal or mechanical noise.

In our model of Benveniste's experiments, we hypothesize that, for similar reasons, random microscopic fluctuations lead to random changes of probability amplitudes. At a given time *t*, Eq. 1 is modified with ε, a positive or negative real number << 1:

$$|\psi_A\rangle = \sqrt{a^2 + \varepsilon}|A_{CP}\rangle + \sqrt{b^2 - \varepsilon}|A_{DP}\rangle$$

We model this situation by beginning with the initial cognitive states *A* and *B* as neutral states:

$$|\psi_A\rangle = \frac{1}{\sqrt{2}}|A_{CP}\rangle + \frac{1}{\sqrt{2}}|A_{DP}\rangle$$

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$$|\psi_B\rangle = \frac{1}{\sqrt{2}}|B_{CP}\rangle + \frac{1}{\sqrt{2}}|B_{DP}\rangle$$

The random microscopic fluctuations associated with A and B are independent (the portions of environment around Alice and Bob are different) (**Figure 3B**). We define ε_1 and ε_2 as infinitesimal random changes (positive or negative) of $P_{quant}(A_{CP})$ and $P_{quant}(B_{CP})$, respectively:

$P_{quant}(A_{CP}) = 0.5$ at $t = 0$ and $P_{quant}(A_{CP}) = 0.5 + \varepsilon_1$ at first random microscopic fluctuation;

$P_{quant}(B_{CP}) = 0.5$ at $t = 0$ and $P_{quant}(B_{CP}) = 0.5 + \varepsilon_2$ at first random microscopic fluctuation.

The intersubjective agreement must be guaranteed and the common probability is calculated using Eq. 4. The common probability for A and B is now $0.5 + \varepsilon$. For the next random microscopic fluctuation, we define ε_3 and ε_4 as infinitesimal random changes (positive or negative) of $P_{quant}(A_{CP})$ and $P_{quant}(B_{CP})$, respectively:

$$P_{quant}(A_{CP}) = (0.5 + \varepsilon) + \varepsilon_3$$

$$P_{quant}(B_{CP}) = (0.5 + \varepsilon) + \varepsilon_4$$

The same calculation is repeated several times by reinjecting at each step the updated common probability of A and B. In Figure 4, the evolution of $P_{quant}(A_{CP})$ is shown after several calculation steps with a very small random variation of $P_{quant}(A_{CP})$ at each step ($[-0.5; 0.5] \times 10^{-15}$). We see that a divergence occurs after several iterations with two possible outcomes: all pairs are concordant with $P_{quant}(A_{CP}) = 1$ or all pairs are discordant with $P_{quant}(A_{CP}) = 0$.

Therefore, the probability amplitudes associated with each state of A (or B, C, etc) dramatically change during joint observations with other experimenters

$$|\psi_A\rangle = \frac{1}{\sqrt{2}}|A_{CP}\rangle + \frac{1}{\sqrt{2}}|A_{DP}\rangle \rightarrow 1\times|A_{CP}\rangle + 0\times|A_{DP}\rangle$$

or

$$|\psi_A\rangle = \frac{1}{\sqrt{2}}|A_{CP}\rangle + \frac{1}{\sqrt{2}}|A_{DP}\rangle \rightarrow 0\times|A_{CP}\rangle + 1\times|A_{DP}\rangle$$

Eq. 4 can be easily adapted for three or more experimenters and the divergence occurs after a lower number of iterations when the number of experimenters increases (Figure 4).

If many teams of two, three or more experimenters perform the experiments, *the overall mean of probability for concordant pairs remains equal to 0.5, but two populations appear*: experimenters X with $P_{quant}(X_{CP}) = 1$ and experimenters Y with $P_{quant}(Y_{CP}) = 0$. In other words, the random outcomes of concordant pairs and discordant pairs are distributed in two populations of experimenters: those who "turn down" and those who "turn up" as depicted in Figure 4. However, for symmetry reasons, nothing in the formalism allows choosing one of the two solutions for a given team of experimenters.

With a single observer, there is no significant change of the probability of concordant pairs; for each sample that is observed by a "neutral" experimenter, the probabilities to be associated with concordant or discordant pairs are equal and each reduced state is obtained randomly (Figure 4). Indeed, with a single experimenter, the intersubjective agreement has no consequence (the experimenter is always in agreement with him/herself).
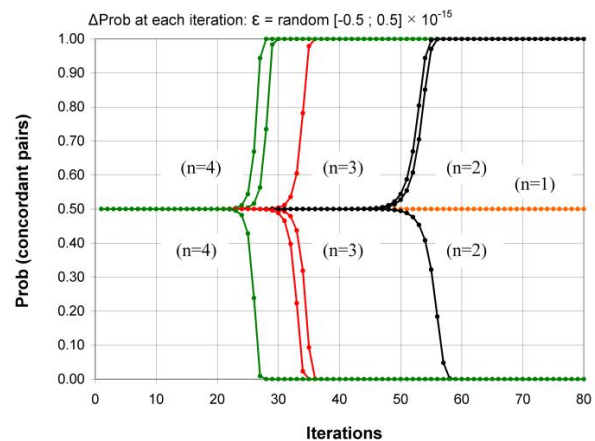

Figure 4. Divergence from "neutral" to "absorbent" states with a number of experimenters ≥ 2. Small changes in the probability of concordant pairs (related to microscopic random fluctuations) have crucial consequences if the number of experimenters who do the same experiment is ≥ 2. The elementary change of probability of concordant pairs is very small in this simulation: from −0.5 to +0.5 × 10^{-15} (the smallest change allowed in Excel sheet). In this computer simulation, probabilities diverge after several iterations toward one of the two "absorbent" states: either "all pairs are concordant" or "all pairs are discordant". Of importance, for a single experimenter, the probability of concordant pairs remains close to 0.5.

Note that even if we take into account random microscopic fluctuations, the means of

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the probabilities for concordant pairs do not change in the experimental situation described in Section 4 (two experimenters doing experiments in two separated places). Therefore, the intersubjective agreement appears to be necessary for the appearance of concordant outcomes.

How asymmetry was introduced in Benveniste's experiments?

We have now a hypothesis on the origin of the relationship between labels of samples and concordance of pairs. A strong constraint emerges as clearly depicted in Figure 4 if we take into account both the intersubjective agreement and random microscopic fluctuations. Nevertheless, for symmetry reasons, nothing in the formalism favors one relationship over the other one ("all concordant" vs. "all discordant"). Therefore, asymmetry must be added from outside into the formalism.

In Section 1, we have briefly summarized the successive Benveniste's experiments and we reported that mainly three biological models were routinely used that led to a bulk of coherent results (basophil leukocytes, isolated rodent heart and *in vitro* coagulation). In fact, these models have been progressively selected among many others that were at disposal of Benveniste's team in laboratory, either already in routine or specially developed for the purposes of this research. All these potential models were systematically assessed and abandoned if no clear "effect" of high dilutions or "digital biology" could be evidenced. Only the models that evidenced not only signal, but also correct link of signal with "active" samples were selected. To put it simply, only experimental models with results that fitted the upper part of Figure 4 were selected.

The preservation of asymmetry among the experimenters/observers is suggested by the formalism. We have seen that there are two "absorbent" elements. Therefore, there is a possibility of "contagion" from one "absorbent" experimenter (with high rates of "success") to any experimenter, for example a "neutral experimenter". Such a "mechanism" could maintain high rates of successful experiments in a circle of collaborating experimenters (this is exactly the definition of a scientific team).

In summary, biological models with their dedicated experimenter(s) that concur to achieve "expected" results have a selective advantage and they are more willingly reproduced; these experimental correlations ("successful experiments") are maintained through "absorbent" states in the circle of the collaborating experimenters.

Blind experiments with a type-2 controller

When a type-2 controller participates to blind experiments, he/she assesses the concordance of pairs in conditions strictly comparable with the experimental situation described above (Section 5) with two experimenters (see details on type-2 controller in legend of Figure 1). Therefore, a type-2 controller is equivalent to a "neutral" experimenter with cognitive state B:

$$\left| \psi_B \right\rangle = \frac{1}{\sqrt{2}} \left| B_{CP} \right\rangle + \frac{1}{\sqrt{2}} \left| B_{DP} \right\rangle$$

With or without blinding by type-2 controller, the probability of concordant pairs associated with A does not change. By definition, a type-2 controller is "neutral".

Blind experiments with a type-1 controller
First demonstration

When a blind experiment is performed with the participation of a type-1 controller, the rate of concordant pairs is assessed by this observer (see details on type-1 controller in the legend of Figure 1). This change in conditions of blinding has important consequences in the context of a quantum-like model.

This experimental situation is formally comparable to a "*which-path*" *measurement* in the two-slit experiment and *classical probabilities apply*. Indeed, the type-1 controller assesses the rate of concordant pairs *with knowledge of the label of each pair*. It could be argued that a type-2 controller has also knowledge of the labels, but he/she is on the same "branch" than the experimenter (they both observe the same "reduced" states of experimental device and labels). In contrast, a type-1 controller – who is "outside" – breaks the superposition of the states of A because *the information on the label must be taken into account* to calculate the rate of concordant pairs associated with A:

$$P_{class}(A_{CP}) = P(A_{IN}) \times P(A_{CP}|A_{IN}) + P(A_{AC}) \times P(A_{CP}|A_{AC})$$

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We define $p = P(A_{IN})$ as the proportion of inactive labels and $q = P(A_{AC})$ as the proportion of active labels:

$$P_{class}(A_{CP}) = p \times P(A_{CP}|A_{IN}) + q \times P(A_{CP}|A_{AC})$$

At the end of the experiments and before unblinding, the rate of samples with no effect is equal to p and the rate of samples associated with a signal is equal to q (the information on the values of p and q are available to all participants, including the experimenter). Therefore, the probability for an inactive sample to be associated with a concordant pair is $P(A_{CP}|A_{IN}) = p$ and the probability for an active sample to be associated with a concordant pair is $P(A_{CP}|A_{AC}) = q$. Consequently, the overall probability to observe concordant pairs is:

$$P_{class}(A_{CP}) = p^2 + q^2.$$

Second demonstration

There is another possible description of the experimental situation with a type-1 controller. For each sample, the "success" or "failure" (concordant or discordant pairs) is known with *certainty* by the type-1 controller; there is *no superposition but a mixture of two states*: $|B_{CP}\rangle$ or $|B_{DP}\rangle$. The cognitive states A and B associated with each sample (inactive label with a probability equal to p and active labels with a probability equal to q), are described by *taking into account the intersubjective agreement*:

$$|\psi_{AB}\rangle = (a|A_{CP}\rangle + b|A_{DP}\rangle) \otimes |B_{CP}\rangle \rightarrow |A_{CP}\rangle|B_{CP}\rangle$$

or

$$|\psi_{AB}\rangle = (a|A_{CP}\rangle + b|A_{DP}\rangle) \otimes |B_{DP}\rangle \rightarrow |A_{DP}\rangle|B_{DP}\rangle$$

The state $|A_{CP}\rangle|B_{CP}\rangle$ is observed with a probability equal to p for inactive labels and with a probability equal to q for active labels. Overall, the probability to observe concordant pairs is p^2 for inactive labels and q^2 for active labels:

$$P_{class}(A_{CP}) = p^2 + q^2.$$

Comparison of P_{class} and P_{quant} for concordant pairs

We can now compare $P_{quant}(A_{PC})$ and $P_{class}(A_{PC})$. If all pairs are concordant in the superposed state, then $P_{quant}(A_{PC}) = 1$ and $P_{class}(A_{PC}) = p^2 + q^2$.

$$P_{quant}(A_{CP}) - P_{class}(A_{CP}) = 1 - p^2 - q^2 = 2pq$$

The term $2pq$ is typical of quantum or quantum-like interferences; it disappears when a Type-1 controller breaks the superposition of the possible states of A:

$$P_{quant}(A_{PC}) = (p + q)^2$$

$$\downarrow \quad \textit{Type-2 controller}$$

$$P_{quant}(A_{PC}) = (p + q)^2$$

$$\downarrow \quad \textit{Type-1 controller}$$

$$P_{class}(A_{PC}) = p^2 + q^2$$

"Jumps" of "biological activities" between samples

It is important to note that even in an experiment checked by a type-1 controller, a signal is observed with some samples. Suppose, for example, that – in the absence of type-1 controller – an experimenter routinely observes a signal with 100% of "active" samples and with 0% of "inactive" samples (with $p = q = 0.5$). If the experiments are checked by a type-1 controller, the rates of signal associated with "active" samples decrease from 100% to 50% (because $(p + q)^2 = 1$ and $p^2 + q^2 = 0.5$); consequently, the rates of signal associated with "inactive" samples increase from 0% to 50%. Therefore, in the context of classical logic, these results could be interpreted as "jumps" of the alleged biological activity from "active" to "inactive" samples.

Conclusions

The apparent "jumps" of biological activity between samples were a disconcerting phenomenon, which was most probably the main reason why Benveniste failed to convince his peers at demonstrating the concepts of "memory of water" or digital biology. In our model, this phenomenon is a logical consequence of the formalism and no *ad hoc* hypotheses are introduced. Only quantum logic allows building a simple model taking into account both the emergence of a signal from background noise and the differences in outcomes for blinding with type-1 vs. type-2 controllers. This formalism does not predict the outcomes of individual events, but describes how these events are connected. Therefore, these experiments cannot be used to send useful information and there is no causal relationship between events observed together.

In the present article, we consider the interaction of the cognitive states of several experimenters using the same quantum-like logic. We see that a strong constraint emerges from the formalism due to the intersubjective agreement. The observables are then engaged in quantum-like correlations.

Some questions remain however unanswered. One of the most important issues is to define the limits of the phenomena observed by Benveniste's team and described by the equations of the quantum-like formalism. Could comparable results be seen by replacing the biological systems used in Benveniste's experiments by any classic or quantum random generator? Could anybody play the role of a "Benveniste's experimenter"?

In conclusion, we proposed in previous articles that Benveniste's experiments could be described as the consequence of quantum-like interferences of the possible cognitive states of the experimenters. However, the source of the concordant outcomes remained unknown. In the present article, we propose that the quantum-like concordance of outcomes is the consequence of the intersubjective agreement of the experimenters.

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