Some Brief Comments on Recent Studies on Quantum Cognition

Elio Conte and Rich Norman

ABSTRACT

The emerging discipline of Quantum Cognitive Studies is filled with promise and pitfalls. The rich and detailed formalism of quantum theory must be closely considered in crafting an approach to the field. This essay strikes a cautionary note in assessment of trends which reduce the theory to instrumentalism. A brief accounting of the proper formalism, will correct the problem of "quantum-like" adaptations. The quantum principles which govern the complexities of dynamic object representation may be analogously and fruitfully captured in a schematic adaptation of the Mach-Zehnder interferometer. The appropriate brain areas and functions are briefly discussed, and a justification for utilization of quantum features in describing macro-scale biological systems is presented. The problem of maintaining quantum superpositions is delineated inviting people to study and evaluate human experience through analysis of the well-known Leggett-Garg relation which then implies the quantum statistical model of quantum cognition that we have delineated in this paper.

Key Words: quantum cognition, quantum interference, quantum mechanics, Leggett-Garg relation, Mach-Zehnder interferometer and neurological correlates, Conte perceptive -cognitive quantum model

DOI Number: 10.14704/nq.2016.14.3.945 **NeuroQuantology 2016; 3:514-523**

Introduction

It has become a general tendency in recent years to maintain that a new field is emerging. It is often denoted as "quantum cognition" and, in some cases more adventurously, quantum-like models in cognition. Scholars in quantum mechanics well know that quantum mechanics arose within the evident result that it has a fundamental role in explaining the mechanisms and the dynamics of our mental entities, particularly at the perceptive and cognitive levels of our mind. For brevity we do not mention the long list of founding fathers who as Bohr, Heisenberg, Schrodinger, von Neumann, just to remember a few authors, espoused that the scheme of reality outlined within quantum mechanics had profoundly changed the older traditional classical approach, which was based incorrectly on an ingenuous vision of realism in which resultant external reality does not depend upon observation and thus also not upon logic and cognition and, in addition, this older scheme of reality rejects the suspension of judgment. We find experiments and basic theoretical elaborations on quantum cognition, published in valuable journals of unquestionable scientific value in 1980, well thirty-six years ago and well documented in our results (for a comprehensive review of our results we suggest Conte, 1983; Conte *et al.,* 2004; Conte *et al.,* 2007; Conte *et al.,* 2008b; Conte *et al.,*

Corresponding author: Elio Conte
Address: School of Advanced International Studies on Applied Theoretical and non Linear Methodologies of Physics, Bari, Italy.
e-mail ✉ elio.conte@fastwebnet.it, stmp@saistmp.com
Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
Received: 25 March 2016; **Accepted:** 26 June 2016
***e*ISSN** 1303-5150

2009a; Conte *et al.,* 2009b; Conte, 2010a; Conte*,* 2010b; Conte *et al.,* 2010; Conte, 2011a; Conte, 2011b; Conte, 2011c; Conte *et al.,* 2011b; Conte, 20012; Conte *et al.,* 2012b; Conte *et al.,* 2012d; Conte, 2013; Conte, 2014a; Conte, 2015a; Conte, 2015b; Conte, 2015c; Conte, 2015d; Conte *et al.,* 2015; Laterza *et al.,* 2013). A turning point was obtained in 2003-2009 when we started to publish new experimental results that added to our basic theoretical formulations (Conte *et al.,* 2004; Conte *et al.,* 2007; Conte *et al.,* 2008b; Conte *et al.,* 2009a; Conte *et al.,* 2009b; Conte, 20010a; Conte*,* 2010b; Conte *et al.,* 2010) initiating the present investigating perspective. As a consequence of these studies, authors responded with renewed interest currently involving researchers with an interdisciplinary attitude and competencies. Some authors often forget that this new field was built from the outset on solid theoretical foundations and hence, propose these new applications as the instrumental method used at present, because it seems to provide better results than those based on the classical calculus of probability. The term "quantum-like" cognitive models is often used as a superficial garment to support these studies while instead the true reason for obtaining satisfactory results does not reside in the use of an instrumental method, empirically used for a calculus that proceeds as quantum-like, since it gives better results but because at the basis there are solid conceptual foundations. Of course, science is never a purely instrumental method. To avoid further confusion one has to evidence that in studies on quantum cognition, as well as in all studies that consider quantum mechanics, one cannot use the basic formalism of quantum mechanics as an instrumental method, right there, as a quantum-like adventure just because at first glance the use of this formalism seems to give better results than the classic one. To be more specific: The formalism of quantum mechanics involves the theory of the linear operators in Hilbert space and the Schrodinger equation or, equivalently, the Heisenberg representation and still more. However, these formulations do not constitute quantum mechanics. This last is obtained by establishing appropriate links between the mathematical formalism, interpretation of the formalism and experiment. Only the formalism supplemented by robust interpretational explanation, constitutes quantum mechanics. The apparently beneficial use of only a formalism, used as instrumental method and protected from any possible criticism from a term coined specifically as ad hoc such as "quantum-like," *cannot be admitted* since the formalism and its interpretation form a natural whole: physical theory applied to cognition. The consequences of such assumed behaviour are relevant since they induce confusion in a promising field. We have demonstrated several times the possible way in which the current studies on quantum cognition should be addressed (Conte, 2011a; Conte, 2011b; Conte, 2011c; Conte *et al.,* 2011b; Conte, 2012; Conte *et al.,* 2012b; Conte *et al.,* 2012d; Conte, 2013; Conte, 2014a; Conte, 2015a; Conte, 2015b; Conte, 2015c; Conte, 2015d; Conte *et al.,* 2015; Laterza *et al.,* 2013). Therefore, we will not enter into such features also in the present paper but we will limit ourselves to elaborate only upon specific questions. One example is given by the so called question of the order-effect that also recently has been represented in this journal by us (see as example, Wang *et al*., 2016). The question is posed in the following terms. If x_i and y_i are the answers a subject give to two posed subsequent tasks A and B, in one order or in the other, the probabilities, predicted by the quantum mechanical formalism, $p(x_i / y_i)$ and $p(y_i / x_i)$, satisfy the general rule $p(x_i / y_i)$ = $p(y_i / x_i)$ under the condition that the eigenvalues are not degenerate. $p(A/B)$ = $p(B/A)$ is the general rule in quantum mechanics. This quantum mechanical result has given the opportunity to introduce tests (Wang *et al.,* 2016) of verification to study the obtained experimental results. This is a clear example of so much confounding which may result in the use of an instrumental method disengaged from the basic conceptual foundations and interpretations of the formalism of a theory. The basic general rule $p(x_i / y_i) = p(y_i / x_i)$, $(p(A/B) = p(B/A))$ of quantum mechanics derives from the basic relation $< y_i / x_i >=< x_i / y_i >*$

It implies directly the mathematical operation of the complex conjugate of a complex number. One cannot use this simple relation for instrumental purposes. Behind this obvious mathematical relationship, quantum mechanics really delineates, as a conceptual and formal counterpart, one of its greatest pillars, represented from the intrinsic and irreducible feature that is the time symmetry in this theory. This symmetry enters in the fundamental construction of quantum mechanics and is basically linked to the CPT theorem that is another pillar of the theory. As everyone may immediately acknowledge, the feature of time symmetry is of basic importance just in the analysis of the question of the order effect that the previously mentioned authors considered.

Generally, scholars of quantum mechanics are aware of the basic role of time symmetry of quantum mechanics and correctly they often manipulate expressions of this kind: given the state ψ_0 at the initial time t_0, and $\psi(t)$ at time $t > t_0$, and $U(t)$ the time evolution operator with $U(t)U^{+}(t) = 1$,

it is

$$a_{t,j} = \left\langle \psi(t) \middle| \omega_j \right\rangle = \left\langle \psi(0) \middle| U^{\div}(t)\omega_j \right\rangle$$

since a complete orthonormal basis $\{\omega_j\}$, $(j = 1,2,....)$ has been identified.

According to the foundations of quantum physics, the intrinsic time symmetry of this theory is the cause by which we obtain $p(x_i / y_i) = p(y_i / x_i)$, $p(A/B) = p(B/A)$). Owing to the importance of such a foundation we add still some further considerations. The traditional wave function in use in quantum mechanics is represented by retarded and advanced waves, the retarded wave passing from an initial event, i, to a future event, a, and the advanced wave, the complex conjugate of the retarded wave, passing backward in time toward i.

These features relating time symmetry in quantum mechanics are a well-established matter of this theory from the early days of its advent. The founding fathers of quantum mechanics as Wheeler (1978), Wheeler and Feynman (1945), Wigner (1959), Costa de Beauregard (2006), Cramer (1988), and also the present author (Conte, 1981; Conte, 1981a; Conte, 2010a; Conte, 2010b; Conte, 2015a; Conte, 2015b; Conte, 2015c), just to quote only the smallest list of authors, have spent years of their activity to explain this foundation of quantum mechanics in the framework of retarded and advanced actions. Costa de Beauregard considers a standard quantum measurement that always consists in a quantum measurement operation of a preparation of the system and a final performed operation of actual measurement performed in the laboratory. In the so called collapse of the state that is considered as basic process of quantum mechanics characterizing the measurement, one must account for the collapse and for the retro-collapse that is to say a time symmetric phenomenon that goes back in time until the preparation is reached by the universal known mechanism of the retarded and advanced actions. The first induces information as knowledge in the observer performing the measurement and the second instead realizes time reversed information as order at the preparation of the system. Cramer has produced in his celebrated papers and, in order to illustrate the matter, has repeatedly represented the situation by using the terminology of an emitter and an absorber. The emitter sends the signal ψ forward in time and the complex conjugate ψ^* backward in time. Receiving the absorber, the ψ, it must respond with a time symmetric process sending forward in time $-\psi$, and back in time $-\psi^*$. The result is that only two components remain active: ψ, retarded action, and - ψ^*, advanced action, in a complete time symmetry. The matter is to be understood in detail in the following statement: realizing time symmetry, both ψ and $-\psi^*$ really act, *but an observer remains aware only of ψ, that is to say, of the retarded action*. According to the rules of quantum mechanics, the probability distribution (probability per unit volume) for an event to occur, is given by $\psi^*\psi$ whose meaning has been previously illustrated. The advanced wave modulates the retarded wave thus producing the required $\psi^*\psi$ probability pattern. The probability, $\psi^*\psi$, which then results in a probability for a kind of transaction (Cramer, 1988), a correlation between the two events, arises as a probability field at the initial event. The notion that reversibility is mixed to irreversibility is crucial and, on the other hand, is well known in quantum mechanics for years. It is the crucial point that we should keep in mind and may also be expressed in a lightly modified manner by using different terminology. Time symmetry holds rigorously in quantum mechanics as *law-like* and it is fixed rigorously in the body of the theory. Instead *irreversibility* follows as FACT-like. As consequence, time symmetry is the basic law that we find at each step in the basic mathematical and conceptual framework of quantum mechanics, and instead, as FACT-Like we observe irreversibility. Owing to irreversibility functioning as fact-like, if we expect to find in an experimental situation the result $p(x_i / y_i) = p(y_i / x_i)$, $p(A / B) = p(B / A)$, this means that we hope in pure expectation of a matter of the case. It could be observed and not. Note that we have elaborated this question of irreversibility considering the pure physical plane. If we add instead that in our experiments we used *human beings* having their individual and subjective mental functions, the attempt to carry out a discriminative test on experimental data in these conditions of experimentation, becomes even more serious owing to the subjectivity of each person. Consequently, the posed question of the order effect in quantum cognitive studies becomes only a trivial question that does not deserve consideration since it is the fact-like irreversibility that, depending in a contextualized manner on the experimental conditions acting during the experiment, can mask or not, the effects of time symmetry and let us derive that $p(A / B)$ gives results different or equal to $p(B / A)$.

These are basic theoretical considerations that elucidate the existing problems if one attempts to introduce tests to study experimental data obtained in quantum cognition studies performed on human subjects. However, we have also further reservations linked properly to the general methodological profile. Let us examine those.

a) Preparation - Measurement in Quantum Mechanics

We have previously delineated a question relating the foundations of the theory. However, also attempting to overlook these obviously not negligible aspects, other basic limitations remain also under the methodological profile. The notion of quantum measurement runs about two basic concepts. One is that of the final measurement that actually is performed in a laboratory from the operator. The other, the most important, is the notion of preparation for the measurement. When one performs an experiment with the aim to give to a subject only a Task A, one realizes a given preparation. When one decides to give to the subject first the task A and subsequently the task B the experimenter performs another preparation. When the experimenter decides to give to the subject first the task B and subsequently a task A, this realizes still another kind of preparation. When one performs the demonstration that $p(x_i / y_i) = p(y_i / x_i)$ and uses the standard derivation that is found of course in all textbooks of quantum mechanics, obviously this is admitting that the notion of preparation and of final measurement are those robustly established in the theory of quantum mechanics. In this case the notion of preparation is related to an ensemble of systems that are admitted to have been all rigorously prepared in the same identical manner. The notion of preparation of the system to be submitted to a measurement is crucial. The preparation has been conceived to consist in the application called/conceived usually as a filter, admitting, as example in the physical case, only particles (or, generally speaking, systems) with some rigorously fixed and specific characteristic, and rejecting all others. One has to take care that the foundation here maintains that the desired characteristic must prevail immediately after having finished the preparation of the state so as to be able to use it for predictions of results of future measurements. In the case of the final measurement, one has to take care not to spoil or to change or to influence the properties which are going to be measured before the act of measurement has been accomplished. The complex application of such a notion seems to still be possible for physical objects where we may also admit a priori that there are not substantial differences, as example in an ensemble of identically prepared particles such as electrons. When the demonstration of $p(x_i / y_i) = p(y_i / x_i)$ is performed, and subsequent tests are realized in order to analyze experimental data, one should be sure that all the previously mentioned requirements are respected. Obviously, in the case of quantum cognition studies, not one of the required statements on the preparation of the measurement is really respected. In this case human subjects are submitted to tasks and the subjects have their marked subjectivity and their mental functions that are subjective and differentiated, subject by subject and time by time. The hope of considering systems that are all equally prepared is practically nothing and then, since it is instead a basic requirement for the subsequent demonstration, one can never, even remotely, dream of applying it as a test of the experimentally observed data.

b) Conte Model in the Experimental Case

We have now to consider what really happens by application of the Conte model in the experimental case in the previously mentioned experiments. As is known, tasks are given to groups of subjects. Consider the experimental case conducted on a large number of respondents as it was in the different experimental studies that were conducted. Having given the task to a group of subjects, each of them will bring into it the uniqueness of his/her mind, each one with a specific conceptual network forming his/her inner memory structure. This means that participants in the experiment will have different ways of choosing his/her answers among those that are available to them to be selected. There is still more. The timed answers of each subject cannot be accurately defined as in an ordinary experiment of physics depending instead upon his/her Reaction Time that is a psychological and subjective variable that literature has shown to be linked to a great many psychological and neurological factors. The conceptual consequence of such a situation at an experimental level is that we have what P.T. Landsberg (1964) called an incompletely specified system at the experimental level. In quantum mechanical terms, this is to say that, given a complete orthonormal basis $\{\omega_j\}$, the probability that arises experimentally can no longer be considered as

$$p(t) = \sum_{j=1}^{n} \left| a_{t,j} \right|^2$$

but, as it is due to the profound uncertainties for each subject and across the subjects in their mental conditions and time, owing to the presence of an incompletely specified system, we observe probabilities that are due to profound fluctuations so that finally a mean value is given as a result of the observation. This is to say

$$< p(t) >= \sum_{j=1}^{n} < \left| a_{t,j} \right|^2 >$$

In order to illustrate the situation, let us provide an example. Consider the case of our experiments relating a dichotomic task. We have a two-dimensional space where ω_1 and

ω_2 are the basis vectors. Let us assume for example that the amplitudes are real, and this is to say that $a_1 = \cos\alpha$ and $a_2 = sen\alpha$. The condition that specifies our question is then the angle α. In the usual quantum mechanical case a value of α is given. To be clear we have $a_1 = \cos\alpha_1$ and $a_2 = sen\alpha_1$ where α_1 is a precise value in the possible range $0 \le \alpha \le 2\pi$. In our case when instead we have the condition of an incompletely specified experiment that is due to the different mental features of the subjects participating in the experiment and to the subjective contextual variability of the mental state of each individual and his/her response time, we may not conclude that each subject will perform the task giving one and only one value of α. On the contrary, each subject will perform the task on the basis of his/her mental and neurological attitudes and thus with a particular value of α. In conclusion α will fluctuate in each subject and from subject to subject in the range $0 \le \alpha \le 2\pi$. These values of α will remain obviously all strongly correlated but it will be impossible to express a complete specification in the initial condition and regarding the time of response for the experimental group of subjects. The only remaining feature is that one of expressing a probability for α to be between α and $\alpha + d\alpha$. For example, for a probability of a subject of giving a value of alpha between α and $\alpha + d\alpha$ we could in principle assume a function of distribution $f(\alpha) = Asen^b(2\alpha)d\alpha$ with $\int f(\alpha)d\alpha = 1$ and A constant of normalization and b parameter ($b > -1$) ($b = 0$ responding as an example in the case of a strictly uniform distribution and $b = 2$ responding as an example in the case of a weakly uniform distribution), and arriving to estimate $< \cos^2\alpha >$ and $< sen^2\alpha >$ in order to approach what we observe experimentally and that, we repeat, is given by

$$< p(t) >= \sum_{j=1}^{n} < \left| a_{t,j} \right|^2 >$$

The conclusion is that, owing to the presence of fluctuations in the mental conditions of the subject submitted to experimental tasks, we really may arrive to observe mean values of probabilities. As a consequence, it is evident that we cannot apply any tests of the kind suggested by the authors. The only suitable test is the estimation of the spread of the individual mental status of the subject relating the mental values exhibited in his/her intrinsic, contextual and irreducible individual fluctuation and indetermination and those exhibited from the other subjects, by using the second moment

$$Z = \frac{< (p(t) - < p(t) >)^2 >}{(< p(t) >)^2} = \frac{< p(t)^2 >}{< p(t) >^2} - 1$$

The use of this test immediately enables us to determine if we are or are not in the presence of a dispersion free ensemble as of course was discussed by von Neumann in his celebrated theorem (Conte *et al.*, 2012b).

This last statement concludes our comments including also those under the methodological profile. We have to add still a final consideration. When we started our experimental studies on quantum cognition in 2003 (Conte *et al.,* 2004; Conte *et al.,* 2007; Conte *et al.,* 2008b; Conte *et al.,* 2009a; Conte *et al.,* 2009b; Conte*,* 2010b; Conte *et al.,* 2010) we focused our attention on the mechanism of perception-cognition using particular tasks such as ambiguous figures or the so called Stroop effect that is able to induce a semantic conflict in the subject by figures or colors, and we considered also some cognitive anomalies such as the so called conjunction fallacy. In the following studies we have also studied a number of other experimental arrangements, for example the priming effect, and the conflict between emotion and cognition (Conte *et al.,* 2012d; Conte *et al.,* 2015; Laterza*et al.,* 2013). The objective of the studies was to analyze the presence of the peculiar features of quantum mechanics that are the quantum interference effect, intrinsic irreducible indeterminism and quantum non local entanglement. Always we reached theoretical and experimental evidence on the role of quantum mechanics in mental processes (Conte*,* 2010a; Conte*,* 2010b; Conte *et al.,* 2011b; Conte, 2012; Conte *et al.,* 2012b;

Conte, 2013; Conte, 2014a; Conte, 2015a; Conte, 2015b) here including the behavior of our consciousness. Always we have outlined that quantum theory is logic and thus semantic, interfaced with matter. As a consequence, our studies always have attempted to connect also the neurological profile since the brain as neurological matter is primarily involved in studies of mental processes. In a recent paper (Conte *et al.,* 2015) one of the present authors (E.C), Licata I. and Alelù-Paz R. have delineated a quantum mechanical neurological model of perception and cognition of the ambiguous figures (here including also the particular case of the so called Dalmatian dog).

We have demonstrated evidence that at the neurological level the following brain structures are involved: The V1(the striate cortex), V2 (secondary visual/pre-striate cortex), V3 (ventral and dorsal complexes), V4 ("color center" in extra-striate visual cortex/the prelunate gyrus), and BA20 (Inferior temporal, Fusiform and parahippocampal gyri). The model was formulated by using the Mach-Zehnder interferometer that is a standard quantum mechanical device used in quantum mechanics to demonstrate the peculiar features of quantum interference. The reason to introduce this quantum mechanical model was to demonstrate that not only experiments executed but tasks given to subjects give results confirming existing quantum interference at the levels of human perception and cognition and that also the basic neurological structures of the brain confirm that this is exactly what really happens. All the details of the model are formulated in (Conte *et al.,* 2015) and therefore we will not insist more on it. Previously, by using a Clifford algebraic formulation, one of us (E.C.) discussed the Mach-Zehnder interferometer (Conte, 2011b) on the basis of a pure logic viewpoint outlining the logical origins of quantum mechanics. In brief, we have provided several examples in order to demonstrate that the current quantum perceptive and cognitive studies should not be intended only as a use of the quantum formalism as an instrumental method but as a discipline that has basic and robust foundations. The Mach-Zehnder interferometer is a pillar of quantum mechanics and in our use in studies on quantum perceptive - cognitive properties, gives strong confirmation of the existence and fundamental role of quantum mechanics at the level of mental processes as well as at the neurological level. In order to move forward, we intend to take the opportunity of this present paper to make further progress, by explaining our more recent studies that confirm the validity of the analogous use of the Mach-Zehnder interferometer at the perceptive, cognitive and neurological levels. The scheme of the interferometer is given in (Conte, 2011b) and, as previously said, we used the V1, V2-4, A20 brain structures. On the other hand, a Mach-Zehnder interferometer is realized by two BS (beam splitters), BS1 and BS2 and two Mirrors. We analogously interpret BS1 to brain structure V1, and BS2 to the A20 while mirrors are represented through V2-V4.

We are in the condition to justify now the reasons for such couplings in the following manner. The reason to connect V1 to BS1: V1 is the striate cortex: Visual information derived from thalamic output pathways (via lateral geniculate nucleus) enters V1, and represents a superposition, a probability distribution, raw data which is not yet measured or defined. We may consider V1's dynamic perceptive signal processing as an unresolved matter of probability, also constrained by previous experience and activity, which delineates two coexisting alternatives just as in a quantum superposition of states: *"Where is it, and, what is it?"* (Mishkin-Ungerleider, 1982). This superposition, is a wave function which must be further measured and defined in collapse, to create the perceived object. This will take place as quantum self-interference, and measurement.

Now let us examine V2-V4: V2 is the secondary visual/pre-striate cortex: in neurological terms V2 receives feed-forward input from V1, and also, sends feed-back (self-interference) to V1, while robust feed-forward connectivity into areas V3, V4, and V5 are evident. Spatial frequency, orientation and color tuning of neurons is as V1, but, greater detail is added, measurement detail increased to include tunings for textures and contours (Anzai*et al.*, 2007) and figure/ground distinctions (Fangtu*et al.*, 2005). We may consider V2 as a (ventral/dorsal) focusing mirror.

V3 and the ventral and dorsal complexes: V3 and the attendant associated ventral and dorsal anatomical complexes may be considered as focusing mirrors with complete visual field representation. These brain areas are sensitive to coherent visual motion and also, further detail such as color related to object identification, are elaborated here.

V4, (the "color center," in extra-striate visual cortex/the prelunate gyrus): Powerful attentional modification in the ventral stream is the hallmark of this area. Orientation, spatial aspects and increased complexity to account for basic geometric identifications are evidenced in neuronal tuning of this area. Salience of input, color processing, alterations in spatial processing due to attentional influence are added here, as the stimulus is further measured and defined. Consequently, V4 may be considered as a detailed focusing mirror as in the Mach-Zehnder interferometer.

BA20 (Inferior temporal, Fusiform and Parahippocampal gyri): This area acts as Beam Splitter Two (BS2) in the Mach-Zehnder Interferometer. Here, the two unequal streams, as the split photon, recombine and self-interfere to create via collapse the contextualized, defined, final dynamic object in space.

In conclusion the link between the neurological model and the Mach-Zehnder interferometer seems to be appropriate and well founded. Please do note how the factor of (macro)-superposition in the mental system is a clear violation of the Leggett-Garg inequalities. It is still necessary to add a final observation. Followers of quantum cognition based on an instrumental use of the quantum formalism claim that the brain is definitely a macroscopic physical system operating within scales of time, and space which differ crucially from the corresponding quantum scales. As a consequence, a quantum neurological model could not represent quantum superposition of states and quantum interference. This claim may be deeply questioned. It is reduced to the following statement: "Is quantum superposition a valid conceptual entity at macro-scales?" A positive answer has been given recently in the journal *Nature* (Kovaschy*et al.*, 2015). These authors have demonstrated that the quantum superposition principle allows massive particles to be delocalized over distant positions and for large time intervals**.** There is more. Entanglement is a property at the roots of quantum physics which leads to non-local correlations between distant particles that cannot be explained by classical physics. Entangled particles behave as if they were a single object, non-separable into its constituents. Now, concerning quantum information, entanglement itself can be teleported, if the state to be teleported is part of an entangled state. This process, called entanglement swapping (De Riedmatten *et al.*, 2004) allows one thus to concatenate quantum teleportation channels as reported in the figure of the quoted paper. Desbranches and Van Gent have demonstrated that swapping entanglement may be realized in ion traps of crystals (Desbranches *et al.*, 2006).

Therefore, our conclusion is that we cannot escape, and must admit the role of quantum mechanics. We see that in quantum information processing we are in a position as if we hunt the thief from the door but he re-enters by the window.

References

Anzai A, Peng X, Van Essen DC. Neurons in monkey visual area V2 encode combinations of orientations. Nature Neuroscience 2007; 10 (10): 1313–1321. doi:10.1038/nn1975. PMID 17873872.

Conte E, Exploration of biological function by quantum mechanics using biquaternions. In: Le Concept d'organisation en Cybernétique. Namur, 22-27 Agosto 1983, p. 16-23, Namur: Association Internationale de Cybernètique.

Conte E, Todarello O, Federici A, Vitiello F, Lopane M, and Khrennikov AY. A preliminary evidence of quantum like behaviour in measurements of mental states. In: Quantum Theory: Reconsideration of Foundations 2, 2004 Vaxjo University Press, Vaxjo, 679-702.

Conte E, Todarello O, Federici A, Vitiello F, Lopane M, and Khrennikov AY, Zbilut JP. Some remarks on an experiment suggesting quantum-like behaviour of cognitive entities and formulation of an abstract quantum mechanical formalism to describe cognitive entity and its dynamics. Chaos, Solitons and Fractals 2007; 31: 1076-1088. doi:10.1016/j.chaos.2005.09.061.

Conte E, Khrennikov AY, Todarello O, Federici A, Zbilut JP. A Preliminary Experimental Verification on the Possibility of Bell Inequality Violation in Mental States. NeuroQuantology 2008b; 6: 214-221.

Conte E, Khrennikov AY, Todarello O, Federici A, Mendolicchio L, Zbilut JP. Mental states follow quantum mechanics during perception and cognition of ambiguous figures. Open Systems and Information Dynamics 2009a; 16: 85–100. doi:10.1142/S1230161209000074.

Conte E, Khrennikov AY, Todarello O, Federici A, Zbilut JP. On the Existence of Quantum Wave Function and Quantum Interference Effects in Mental States: An Experimental Confirmation during Perception and Cognition in Humans. NeuroQuantology2009b; 7: 204-212.

Conte E. A proof of Von Neumann's postulate in quantum mechanics. In: Quantum Theory Reconsideration of Foundations 5. American Institute of Physics, New York, 201-205, 2010a.

Conte E. On the Possibility That We Think in a Quantum Probabilistic Manner. NeuroQuantology 2010b; 8: 3-47.

Conte E. Todarello O, Laterza V, Khrennikov AY, Mendolicchio L, Federici A, A Preliminary Experimental Verification of Violation of Bell inequality in a Quantum Model of Jung Theory of Personality Formulated with Clifford Algebra. Journal of Consciousness Exploration & Research 2010; 1: 831-849.

Conte E. An investigation on the basic conceptual foundations of quantum mechanics by using the Clifford algebra. Advanced Studies in Theoretical Physics 2011a; 5(11): 485-544.

Conte E. On the logical origins of quantum mechanics demonstrated by using Clifford Algebra: A proof that quantum interference arises in a Clifford algebraic formulation of quantum mechanics. Electronic Journal of Theoretical Physics 2011b; 8: 109-126.

Conte E. On the Logical Origins of Quantum Mechanics Demonstrated by Using Clifford Algebra. NeuroQuantology2011c; 9: 231-242.

Conte E, Khrennikov AY, Todarello O, De Robertis R, Federici A, Zbilut JP. On the Possibility That We Think in a Quantum Mechanical Manner: An Experimental Verification of Existing Quantum Interference Effects in Cognitive Anomaly of Conjunction Fallacy. Chaos and Complexity Letters 2011b; 4: 123-136.

Conte E. Advances in application of quantum mechanics in neuroscience and psychology: A Clifford algebraic approach. Nova Science Publishers, New York, 2012.

Conte E, Todarello O, Federici A, Santacroce N, Laterza V, Khrennikov AY. May we verify non-existing dispersion free ensembles by application of quantum mechanics in experiments at perceptive and cognitive level? Neuroquantology 2012b; 10, 14-19.

Conte E, Santacroce N, Laterza V, Conte S, Federici A, Todarello O. The Brain Knows More than It Admits: a Quantum Model and its Experimental Confirmation Electronic Journal of Theoretical Physics 2012d; 9 (27): 72-110.

Conte E. A Clifford algebraic analysis gives mathematical explanation of quantization of quantum theory and delineates a model of quantum reality in which information, primitive cognition entities and a principle of existence are intrinsically represented ab initio. World Journal of Neuroscience2013;3(3): 157-170.

Conte E. Can Current Quantum Cognition Studies Give Indication on the Manner in Which Human Cognition Arose ab Initio? Psychology2014a; 5(8): 798-800.

Conte E. Answer to Giancarlo Ghirardi: Quantum Superpositions and Definite Perceptions: Envisaging New Feasible Experimental Tests. A Novel Proposal for Quantum Mechanics, Perception and Cognitive Science? International Journal of Theoretical Physics 2014b; 54:672-679.

Conte E. Additional Comments Added to Our Recent Answer to G. Ghirardi. Journal of Modern Physics2015a; 6 (1): 12-15.

Conte E. What Path Monitor: A Brief Note on Quantum Cognition and Quantum Interference, the Role of the Knowledge Factor. Psychology2015b; 6(3): 291-296.

Conte E. A Brief Comment on Some Recent Evaluations by Basieva and Khrennikov, Wang *et al.,* Boyer-Kassem*et al.,* on Order Effects in Quantum Cognition. NeuroQuantology 2015c; 13(2): 250-252. DOI: 10.14704/nq.2015.13.2.821

Conte E. On Some Explanations and Analysis of the Basic Foundations of Quantum Cognition: Comments on a paper by Pothos, Busemeyer and Trueblood. Neuroquantology2015d; 13(3): 371-383.

Conte E, Lucas RF. First Time Demonstration of the Quantum Interference Effect during Integration of Cognition and Emotion in Children. World Journal of Neuroscience 2015; 5 (2), doi:10.4236/wjns.2015.52011.

Conte E. On psi Retrocollapse in Quantum Mechanics. LettereNuovoCimento 1981; 31(11): 380-382

Conte E. A Predictive Model of psi Collapse Retrocollapse of Quantum Mechanics. LettereNuovoCimento 1981a; 32(9): 286-288.

Conte E. On the Possibility That We Think in a Quantum Probabilistic Manner. Neuroquantology 2010a; 8(4): 53-542

Conte E. A Reformulation of von Neumann's postulates On Quantum Measurement by Using the Clifford Algebra. International Journal of Theoretical Physics 2010b; 49(3): 587-614

Conte E. Additional Comments to a Recent Answer to G. Ghirardi. Journal of Modern Physics 2015a; 6(1): 12-15.

Conte E. On Some Explanations and Analysis of the Basic Foundations of Quantum Cognition: Comments on a Paper by Pothos, Busemeyer and Trueblood. NeuroQuantology2015b; 13(13): 371-383.

Conte E. A Brief Comment on Some Recent Evaluations by Basieva and Khrennikov, Wang et al., Boyer-Kassem et al., on Order Effects in Quantum Cognition. NeuroQuantology 2015c; 13(2): 250-252

Conte E, Licata I, and Alelú-Paz R, A Quantum Neurological Model of Perception-Cognition and Awareness in Ambiguous Figures and the Case of the Dalmatian Dog. Journal of Behavioral and Brain Science 2015; 5: 533-549. doi: 10.4236/jbbs.2015.512051

Costa de Beauregard O. Two Principles of the Science of Time. Annals of the New York Academy of Sciences 2006; 138: 407-421.

Cramer JG. An Overview of the Transactional Interpretation. International Journal of Theoretical Physics 1988; 27: 227-231.

De Riedmatten H, Marcikic I, Van Houwelingen JAW, Tittel W, Zbinden H, and Gisin N. Long distance entanglement swapping with photons from separated sources. arXiv: quant-ph 0409093/15sep.2004

Desbranches R, Van Gent D. Intercontinental quantum liaisons between entangled electrons in ion traps of thermoluminescent crystals, https://www.research gate.net/publication/2199898, 2006

Fangtu TQ, and Rüdiger von der Heydt. Figure and Ground in the Visual Cortex: V2 Combines Stereoscopic Cues with Gestalt Rules. Neuron 2005; 47: 155–166 DOI 10.1016/j.neuron.2005.05.028

Kovachy T, Asenbaum P, Overstreet C, Donnelly CA, Dickerson SM, Sugarbaker A, Hogan JM, &Kasevich MA. Quantum superposition at the half-metre scale, Nature 2015; 528: 530–533DOI: 10.1038/nature16155

Landsberg PT. Does Quantum Mechanics Exclude life? Nature 1964; 203: 928-930.

Laterza V, Todarello O, Conte E. On the Possibility to Identify Quantum Interference Effects on the Single Human Subject During Cognitive Performance by Using Stroop Effect: the Perspective of Clinical Application of the Quantum Cognitive Model. IJRRAS 2013; 16 (4): 1-5

Mishkin M. Ungerleider LG, Contribution of striate inputs to the visuo-spatial functions of parieto-preoccipital cortex in monkeys. Behav Brain Res 1982; 6 (1): 57–77.

Wang B, Zhang P, Li J, Song D, Hou Y, and Shang Z. Exploration of Quantum Interference in Document Relevance Judgement Discrepancy. Entropy 2016; 18, 144; doi:10.3390/e18040144 pages 2-24

Wheeler JA. The 'Past' and the 'Delayed-Choice Double-Slit Experiment. A.R. Marlow, editor, Mathematical Foundations of Quantum Theory, Academic Press, 9–48, 1978.

Wheeler JA, Feynman R. Interaction with the Absorber as the Mechanism of Radiation. Reviews of Modern Physics1945; 17 (2–3): 157–161.

Wigner EP. Group Theory and its Application to the Quantum Mechanics of Atomic Spectra, translated from the German by J. J. Griffin, Expanded and Improved Edition Academic Press, New York, 1959.