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

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ABSTRACT
Starting with 2003 some authors performed a number of experiments with the finality to ascertain if quantum mechanics has a role during the perception and cognition in Humans. The arising quantum cognitive model was repeatedly confirmed. In the present paper we perform for the first time a similar experiment but executed this time on the single subject. The finality is to establish if also in these conditions we are able to estimate the quantum interference effects. Since the results of the experimentation are positive we conclude that we may start using the quantum cognitive model not only as basic theoretical framework for understanding cognition in humans but also to apply the new methodology in clinical cases of interest as in investigation of psychological disorders and psychiatric diseases.

Keywords: *Quantum cognitive model, Perception, Cognition, Single subject, Quantum interference.*

1. INTRODUCTION

It is well known that in 1935 J.R Stroop published an article entitled "Studies of verbal interference in serial verbal reactions" [1] following previous studies conducted in Germany about 1929 [2] In psychology, the Stroop effect is a demonstration of interference in the reaction time of a task. If the name of a colour (e.g., "blue," "green," or "red") is printed by a colour not denoted by the name (e.g., the word "green " is printed in red ink instead of green ink), the subject takes longer time in naming the colour of the word and is more prone to errors than when the colour of the ink matches the name of the colour. The original paper has received and continues to take consideration with great interest. The paper results to be been one of the most cited papers in the history of experimental psychology, and the analysis of the effect has collected more than 700 replications. The effect has been used to create a psychological test (Stroop Test) that is widely used in clinical practice and investigation. In substance it evaluates variations of reaction times when the task consists in an interactions word-colour. Stroop effect is of interest in various fields covering clinical studies to evaluate the basic psychological features of the subject, his selective attitude, his cognitive flexibility, his speed in elaboration of the information. Increasing interference has been observed in some psychological conditions of brain damage, cognitive deficit, deficit of the attention and still covers a large spectrum of investigation ranging from depression as far as schizophrenia.
The experimental studies on a possible quantum cognitive model of the mind started in 2003 [3].
We will not enter in the details of the theoretical elaboration suggesting the reader to link directly the basic literature [3].
Essentially, when we introduce quantum mechanical foundations as having a role during perceptive-cognitive performance in humans we introduce some basic new concepts.
We consider two basic elements. Let us consider the case in which a subject is submitted to a task A that may admit as final decision two possible alternatives or yes (say +1) or not (say -1). According to the model when the task is posed , the subject poses himself in a condition of potentiality , that is to say that he realizes a potential superposition of the two alternatives.
Let us indicate the mental state by a symbol, select for it the ψ and let us acknowledge that the two potential states of the subject are indicated respectively by φ_1 corresponding to the alternative that the subject answers Yes to the posed question and φ_2 corresponding to the alternative that the subject answers Not.
The principle of the superposition of the states in quantum mechanics may be written as it follows

$$\psi = a|\varphi_1\rangle + b|\varphi_2\rangle$$

In substance, $\psi, \varphi_1, \varphi_2$ are the mental states of the subject following the posed task.
The formula indicates that the subject poses himself in such simultaneous superposition of mental states, and ontological status of potentiality in which both the alternatives (φ_1 corresponding to Yes and φ_2 corresponding to Not) coexist. The following decision of the subject (yes or not) is context dependent and the whole process is intrinsically marked from irreducible indetermination. This is to say that the complex number, a and b, represent probability amplitudes and the square modulus of such number are the probabilities that the subject will answer Yes or Not following his final decision.
In substance $|a|^2$ will represent the probability that the subject will select the answer Yes and $|b|^2$ will represent the probability that the subject will select the answer Not.
Obviously
$|a|^2 + |b|^2 = 1$.
In substance a process of transition is realized. The mental status of the subject performs a transition from a condition of ontological potentiality to a condition of actualization in which, depending from the context in which the task is posed, with probability $|a|^2$ the subject will select (and thus will actualize) to answer Yes and with probability $|b|^2$ will select (and thus will actualize) to answer Not.
The central question is that by this way we arrive to a violation of the basic and well known Bayes theorem.
Let us admit that we pose to the subject two task, A and B, with first B and soon after A.
We have two experimental conditions.
The first time we pose to a group of subjects the task A and thus finally we will obtain a probability p(A=+1) and a probability p(A=-1). The second phase of the experiment is that to another group of subjects we pose first the Task B immediately followed from the Task A . In this case we will obtain the following probabilities:
p(B=+1), p(B=-1), p(A=+1/B=+1), p(A=-1/B=+1), p(A=-1/B=+1), p(A=-1/B=-1).
Bayes theorem states that

p(A=+1)=p(B=+1)p(A=+1/B=+1)+p(B=+1)p(A=+1/B=-1)

and a similar relation for p(A=-1)
The crucial step is that formula is violated if instead quantum mechanics has a role during the cognitive process and it is modified in the following manner
p(A=+1)=p(B=+1)p(A=+1/B=+1)+p(B=+1)p(A=+1/B=-1)
$+2\sqrt{p(B=+1)\,p(B=-1)\,p(A=+1/B=+1)\,p(A=+1/B=-1)}\ \cos\vartheta$
In other terms, if quantum mechanics has a role in such mind process we find a further term that is
$2\sqrt{p(B=+1)\,p(B=-1)\,p(A=+1/B=+1)\,p(A=+1/B=-1)}\ \cos\vartheta$
and it is called quantum interference term.
Following this approach we have thus an important method to experience if quantum mechanics has a fundamental role or not in our dynamics.
As previously said Conte and co-workers, starting with 2003, have conducted a large number of experiments [3-25] and all they have repeatedly confirmed that Bayes standard version is violated and the quantum interference effect exists.
We suggest the reader to carefully take vision of the previous contributions where it is also reported a detailed and rigorous exposition of the basic foundations of all the theory [3].
As previously stated, all the previous experiments were executed of group of subjects. It should be of valuable interest to identify an experimental method that could be applied to the single subject. In this manner it should be of valuable interest since we may estimate the quantum interference effect for the single subject and thus to open the perspective to apply it in cases of clinical interest. The aim of the present paper is to illustrate such method indicating the corresponding obtained results.

2. THE METHOD

The method was elaborated from Conte and one author of the present method (V.L.). Just to identify it we will then call it the CL method.
According to the Stroop effect we use the table given in Figure 1

Figure 1 . Basic Stroop effect Table used in the CL method.

As previously described, we have to submit the subject the first time to only the task A and the second time to the Task B followed soon after from the Task A.
For the Task A only we give to the subject the coloured words of the Figure 1, one for time and each one posed with a satisfactory time interval respect to the subsequent posed task, providing in the time interval that the subject remains at rest, with calm and providing the psychologist to distract the attention of the subject from the Figure 1and from the previous posed task. In this manner we have a prefixed number of posed independent questions posed to the same subject. We may count the number of errors that the subjects realizes and finally we have the final probabilities p(A=+1), as example related to correct answers, and p(A=-1), related to mistaken answers.
The second section of the experiment consists in the preparation of a table as in Figure 1 where this time we have pairs of coloured words so that we have the possibility, for each pair, to ask the subject the first colour (Task B), immediately followed from asking about the second colour (Task A). Also in this case we will follow the procedure to separate by some prefixed time interval each pair of posed question inducing the subject to be at rest, with clam, and providing the psychologist to distract the attention of the subject from the Figure and from the previous posed task as pair of coloured words. All the times of the experiment were calibrated and standardized by using an appropriate software. By this second task we may estimate p(B=+1) and p(B=-1) and p(A=+1/B=+1) and p(A=+1/B=-1) as well as all the remaining probabilities of interest.
At this stage of the experimentation we may admit the consideration of the quantum cognitive model previously discussed and, in particular, we may verify if the standard Bayesan formula
p(A=+1)=p(B=+1)p(A=+1/B=+1)+p(B=+1)p(A=+1/B=-1)
and its corresponding for p(A=-1) are maintained or if instead they are violated by the presence of the quantum interference terms that , as said, is given by

$$2\sqrt{p(B=+1)\,p(B=-1)\,p(A=+1/B=+1)\,p(A=+1/B=-1)}\quad \cos\vartheta$$

3. RESULTS

We examined fifty normal subjects (50% male and 50% female) with age distribution between 25 and 35 years old.
We give here the obtained results

Task A :
p(A=+1)=0.875, p(A=-1)=0.125.
Task B soon after followed from Task A:
p(B=+1)=0.750, p(B=-1)=0.250, p(A=+1/B=+1)=0.833, p(A=+1(B=-1)=0.500,
p(A=-1/B=+1)=0.166, p(A=-1/B=-1)=0.500

For the case of Task B/A with A=+1 we obtained a calculated probability of 0.749 against 0.875 obtained with the Task A only.
For the case of Task B/A with A=-1 we obtained a calculated probability of 0.249 against 0.125 obtained with the Task A only.
Therefore the experiment confirmed that Bayes formula was violated as due to the presence of the quantum interference term.
We calculated also the angle of interference that resulted to be

$$\cos \vartheta = 0.223$$

We estimated also the coefficient of intrinsic doubt, indetermination, and uncertainty that aimed the subject in the case of the Task A and Task B/A and we had respectively
D=0.250.
In the case of the Task B/A we obtained instead
D=0.500.
The estimation of the D-coefficient is due to Conte [3], and it may be performed by using the detailed indications that are reported in the quoted reference. The result confirms that the condition of intrinsic doubt, indetermination and uncertainty of the subject in the case of the Task B/A was exactly twice the value relating the Task A only.

4. CONCLUSIONS

By using the Stroop effect we were able to evidence the presence of quantum interference effects in single subjects when submitted to two different tasks A and B/A respectively. The results evidence some interest since we realized and standardized a method of analysis that we called CL. Since it may be applied to a single subject we are know in the condition to apply it to single subjects, normal as well as in pathological conditions giving also detailed parameters to quantify the mental condition of the investigated subject. Consequently we have delineated a new methodology that seems promising at the level of clinical application.

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