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A proposed mechanism for mind-brain interaction using extended Bohmian quantum mechanics in Avicenna's monotheistic perspective

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ABSTRACT

In quantum approaches to consciousness, the authors try to propose a model and mechanism for the mind-brain interaction using modern physics and some quantum concepts which do not exist in the classical physics. The independent effect of mind on the brain has been one of the challenging issues in the history of science and philosophy. In some recent mind-brain interaction models, the direct influence of mind on matter is either not accepted (as in Stapp's model) or not clear, and there have not been any clear mechanism for it (as in Penrose-Hameroff's model or in Eccles's model). In this manuscript we propose a model and mechanism for mind's effect on the matter using an extended Bohmian quantum mechanics and Avicenna's ideas. We show that mind and mental states can affect brain's activity without any violation of physical laws. This is a mathematical and descriptive model which shows the possibility of providing a causal model for mind's effect on matter. It is shown that this model guarantees the realistic philosophical constraints and respects the laws of nature. In addition, it is shown that it is in agreement with the Libet style experimental results and parapsychological data.

To propose this model, we obtained a modified (non-unitary) Schrödinger equation via second quantization method which affects the particle through a modified quantum potential and a new term in the continuity equation. At the second quantized level, which is equivalent to quantum field theory level (QFT), we can use the path integral formalism of Feynman. We show that there are three methods to extend Bohmian QM via path integral formalism, which has different interpretations. By numerical simulation of trajectories in the two-slits experiment, we show their differences and choose one of these methods for our mind-brain model which can be the basis for explaining some phenomena which are not possible to explain in the standard Bohmian QM.

1. Introduction

Mind and brain issues are one of the most challenging issues in the history of science and philosophy [1]. Mind is very different from the matter due to its specific properties, such as unity, integrity and irreducibility to components, and the presence of some special laws and concepts such as perception, specific quality of mental states, thinking, creativity, self-awareness, consciousness, etc. In contrast, matter, especially in classical physics, is known to have properties such as locality in time and space, reducibility to components, atomistic individuality, etc. In this perspective, these two concepts (mind and brain) are so far apart, that it is very difficult to connect them and to explain the modality of their interaction [2, 3]. The developments in physics in the last century, especially in gravity and fundamental particle physics, have led to a new understanding of natural concepts and laws via theories of quantum mechanics and relativity. Relativity changed our understanding of time and the relation between space-time and matter. Quantum mechanics introduced some concepts such as non-reductionism to components, integrity, and wholeness of quantum systems, nonlocality due to quantum entanglement of a system's components, etc. These concepts are very close to the mind concept which is considered to be a nonphysical concept or an illusion concept. Therefore, because of this similarity and our more advanced understanding of nature, the research on the mind-brain interaction and consciousness has begun in physics, by using our modern physical theories. In addition, some attitudes such as top-down causality developed by physicists like Ellis [4, 5, 6, 7], some

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empirical neuroscience results about consciousness and brain activity pattern[1], relation between a subject's report and brain activity record, as in Libet's experiment [9, 10, 11, 12], and the mathematical and philosophical argumentsabout non-computational aspects of mind as in Penrose argument [13, 14], has strengthened the quantum approach to mind-brain interaction and consciousness.

Quantum approach to consciousness has a wide-spread scope [15], but only some researches have tried to connect the concepts of mind and brain through quantum aspects, and can explain part of mind's features through quantum properties. This has specially occurred in the models of Penrose-Hameroff [16, 17, 18], Stapp [3], Eccles-Beck [19, 20], and Bohm [21]. However, there is no complete and consistent model of mind-brain interaction in which mind is considered as an effective and independent identity. The Orch-OR theory describes some features of mental states in terms of the properties of quantum computing which are claimed to occur in the microtubules of neurons, and it tries to explain some of the experiments in neuroscience and time non-locality of mind effects, in terms of the objective reduction of wave function via quantum gravity effects [16, 18]. But the mechanism and modality of mind-brain interaction is obscure in this theory. In Stapp's model, mental states are recognized as aspects of the wave function reduction process- This process has two aspects; one is the actualization of a pattern of the neural activity at the brain; the other is the creation of a mental state [3]. In this model, the freedom and free will have no place and have no causal effect on the actualization of reality. The free will is not an illusion[2], but it only affects the state representation before the nature's choice of actualization (wave reduction)and the direct mind-agency on the brain activity is denied [22]. In Eccles's model, mind has an important role in the determination of brain activity, but there is no mechanism for its effect on the neurons' connection and the brain pattern [23]. In all of these models, a realistic physical theory and a philosophical or psychological theory of mind define a model of mind-brain interaction. In this manuscript, we try to show the possibility of the presence of a causal description of mind's effect on the brain through a mathematical mechanism for the causal effect of mind, as an incorporeal essence on the brain activity. At first, we chose a consistent and appropriate philosophical and psychological framework, which is in coordination with the viewpoint of the famous Muslim philosopher and physician “Avicenna”, and try to describe his model in terms of our modern understanding [24]. To preserve human's free will, we need both causality, (which related to self-agency and refers to “will”), and mind's freedom of choice (which refers to “free”). In physics, we chose the Bohmian quantum mechanics [25, 26], due to its causal description of events. But to achieve our aims, we extended it to quantum field theory and used the path integral formalism to describe it. In the following, after a review on the Avicenna's model and modified Bohmian quantum mechanics, we describe our model of mind-matter relation, using the laws of modern physics.

Recent empirical development in the foundations of quantum mechanics, especially delayed choice style experiments [27, 28, 29, 30, 31, 32], appear to indicate the non-local feature of nature in time, in addition to its non-locality in space. This intrinsic property of nature is consistent with incorporeity of mind, which leads to its non-temporality. In addition, psychology and parapsychology evidences, especially precognition experiments (e.g. see [33, 34]) and neuroscience experiments, such as Libet style experiments, show the complicated nature of mind-brain interaction, and are in agreement with time non-locality in physics. Therefore, in Bohmian approach we try to explain the mechanism of the non-locality by the use of a modified Bohmian quantum mechanics, obtained via the quantization of Schrödinger wave function and using the path integral formalism of QFT. Then, we try to present a causal model for the mind-brain interaction.

A quantum delayed choice eraser experiment apparently says that the design of the experimental setup at the final point affects a particle's evolution in the past. More precisely, the choice and design of the experimental setup leads to getting some information about the wave or particle nature of a quantum system. Therefore, due to the entanglement of the system's components, this information, that causes the appearance of particle or wave behavior, affects the determination of the particles' dynamics, occurred in the past at the other side of system. To get more explanation, one can refer to [35]. Specifically, in the delayed choice experiment proposed by Dopfer [36] or in Scully's version [28], there are two path entangled particles, in which the destruction of interference pattern due to the special design of mirror and lens location on one side, leads to getting information about the path of the other particle, due to the nature of entanglement. Because of the quantum nature of system, this information ensures that there is no interference pattern on the other side (second screen) at any time for the partner particles. In fact, two partner particles have the same behavioral. Therefore, since the detection of second particle has occurred in the past, there is an effect of the future setup on the past result. This can be interpreted as a kind of complicated coordination between the future and the past, which is not like the classical deterministic case. This is due to the nature of quantum mechanics. Although there is no signaling from future to past, but it can be interpreted as a nonlocal influence in time between entangled components, which is the same as space nonlocality in Bell-style experiments. There is the coordination between the future and the past that creates a whole unity. It is a kind of ultimate goal, a kind of novel force, due to the evolution of the whole system that affects the system components in the space-time. It is our Bohmian description, after its extension to QFT via path integral method, which leads to a non-unitary effect on the pilot wave.

2. Theory

2.1. Avicenna's model of mind-brain interaction

As we mentioned in our recent article [24], Avicenna, based on his proficiency in physics, medicine, and brain anatomy, proposed an interesting model of mind-brain interaction. In his model, mind as an incorporeal substance which affects the matter through an intermediate substance, is called the form of matter. Here are some possibilities because of the complexity level and properties of matter. The choice of one of these possibilities and its actualization needs a cause. The mind can be considered as the efficient cause of this actualization. In fact, the mind by imagining what he wants, affects the choice of actuality of matter by determining its form. The matter can potentially accept many different actualities and forms. In Avicenna's model, mind can have independent effects on the brain dynamics. The possibility of this interaction is based on the proximity of the quality of mind to the formal substance which both are produced by the same origins and basics. The mental properties are very close to the formal properties; for example, non-reducibility to parts, integrity, informational aspects of it, etc.

In physics, the quantum possibilities in matter states, either in quantum mechanics or in quantum field theory, are similar to the formal level (form of matter) in Avicenna's model. We showed how the mental state of imagination can have an influence on the matter via the quantum level of possibilities.

Additionally, due to the incorporeity of mind, mind doesn't have space-time properties, such as material properties. In Avicenna's perspective, mind has an important property which is its non-

[1] Such as [8] W.J. Freeman, B. Baird, Relation of olfactory EEG to behavior: spatial analysis, Behavioral neuroscience, 101 (1987) 393.

[2] The person who considers that the free will is an illusion phenomenon must be answer about how we perceive the freedom of choice between some possibilities and how we perceive the agency of our soul in choosing between various possibilities, if our free will is an illusion? In fact, where is the source of the relation between the self and an action we which perceive in voluntary action, i.e. where did it come from? In fact, the deniers of free-will suppose that there is no actual relation between mind-agency and action and there has not been any previous phenomenon concerning mind brain relation. Therefore, this illusion has no prior history that leads to this illusion!.

temporality and space-time independency. Therefore, the effects of mind on matter cannot be at a special space-time point, as the mental states are at a higher level beyond that of the matter, and its effects are on the whole space-time pack of motion and evolution. This demand is accomplished, for example, in the Penrose-Hameroff model of consciousness [17, 18]. But in our investigation, we took a different approach, which has been discussed in the following. It must be noticed that in the Islamic philosophy we do not see any violation in natural laws, and if a higher level affects a system, it occurs according to some specific laws of nature [37].

Not only the recent advances in physics and computer science have affected philosophical and logical developments, but the reverse is also true. For example, we can refer to the development of quantum logic [38] or bipolar dynamic logic [39]. To make a modeling of how mind affects body, we need a logical definition of it. However, there has been some criticisms of the logical definability of causality. But this is related to a definite understanding of causality, as it can be defined in a more comprehensive framework, like [40]. For example, some of the criticisms of the definability of causality are not valid in the Islamic philosophy, especially in Mulla Sadra's substantial motion [41]. It is possible to develop a useful formal logic in the framework of Islamic philosophy, as we have shown in the article [24] through which we can have both causality and free will together.

2.2. Extended Bohmian quantum mechanics

As Stapp noticed [3], the presentation of any quantum consciousness model needs a realistic quantum theory and its interpretation. He chose Heisenberg's model of QM. Penrose chose a realistic reduction of wave function due to gravitation [16], which is expected by some scholars to be explained by quantum-gravity, etc. Our model of mind-brain interaction needs a causal quantum mechanics theory because our aim is to explain the causal effect of mind on the brain. Presently, there is a realistic causal model of quantum mechanics, due to Bohm. In this model, the wave function acts as a pilot wave on the particle trajectory, via an extra quantum potential in the equation of motion [26]. Both particle and wave exist in nature. The wave as a real object represents the multiple possibilities of the quantum state and guides the particle in its path. This standard Bohmian QM cannot guarantee our request for mind influence on the brain, such as non temporality of mind effect on the matter and non-unitary effect of free-will. Although the properties of this pilot wave are similar to the properties of philosophical form, but it is not known abauthow the mind affects this wave function. In physics, the change in the wave function can occur in the following ways: change in Hamiltonian (particle potential), and change in the boundary conditions or system constraints. There is no method and mechanism for mind to act via these ways in physics. Philosophically, these methods are at the level of matter for the change of wave function. Therefore, by considering the mind to affect through these levels, we are considering the mind as a cause acting at the level of material causes, whereas we are considering mind to be an efficient cause, at a higher level beyond matter.

There is another method to create a change in the pilot wave. It is the change in the dynamic equation. In the standard physics, this can be accomplished at the quantum field level. The extension of Bohmian quantum mechanics to the quantum field theory leads to a modified dynamic equation, where it has an extra term [42, 43]. This additional term contains all QFT effects on the dynamics of the wave function. As we have shown in the Supplementary. A, the extension of Bohmian QM via second quantization leads to an extra term in the Schrödinger equation, which affects the pilot wave dynamics and leads to a new quantum potential in the particle dynamics, in addition to the standard Bohmian quantum potential. The modified Schrödinger equation is equal to:

$$i\hbar\frac{\partial}{\partial t}\psi(x,t)=\left[-\frac{\hbar^2}{2m}\nabla^2+U(x,t)\right]\psi(x,t)+\frac{\delta}{\delta\psi^*}Q\Big|_{\psi(x,t)} \tag{1}$$

where:

$$Q=U\frac{\left[\frac{\delta}{\delta\psi}\frac{\delta}{\delta\psi^*}\mathscr{R}(\psi,t)\right]}{\mathscr{R}} \tag{2}$$

And ψ is the wave function, and$\mathscr{R}$ satisfies the following functional equation in which Ψ is a functional of "ψ" and time. The "Ψ" is a functional which is obtained through quantization of Schrödinger equation (Supplementary.A):

$$\Psi(\psi,t)=R(\psi,t)e^{i\mathscr{S}(\psi,t)} \tag{3}$$

$$i\hbar\frac{\partial}{\partial t}\Psi(\psi,t)=\int d^3x\Big[-\hbar^2\frac{\delta}{\delta\psi}U\frac{\delta}{\delta\psi^*}-\nabla\psi^*\nabla\psi\Big]\Psi(\psi,t) \tag{4}$$

The quantum force on the matter in this extension is equal to:

$$F=m\ddot{x}=-\nabla(U+\mathbb{Q}) \tag{5}$$

$$\mathbb{Q}=-\frac{\hbar^2}{2m}\frac{\nabla^2R}{R}+\frac{1}{R}\frac{\delta}{\delta R}Q\,;\;Q=\frac{\frac{\delta}{\delta\psi}U\frac{\delta}{\delta\psi^*}\mathscr{R}}{\mathscr{R}} \tag{6}$$

where "R" is the amplitude of the wave function:

$$\psi(x,t)=R(x,t)e^{\frac{i}{\hbar}S(x,t)} \tag{7}$$

If we continue this quantization to third and further quantization by following the idea of Bohm in his mind-matter model [21], we obtain some time-nonlocal properties, as is explained in the following. In the Lagrangian of a system (particle, wave function, functional, etc.), if there is a square of time derivative of a dynamic quantity, the Euler-Lagrange equation leads to a second derivative of time in the equation of motion[3]. Then, the quantization of related Hamiltonian, in the Bohmian approach leads to the guidance equation, in which the time derivative of the quantity is proportional to the gradient of the phase of the wave in quantized level with respect to that quantity. For example, in standard Bohmian, the guidance equation is equal to:

$$m\frac{\partial}{\partial t}\vec{x}=\vec{\nabla}S(x,t) \tag{8}$$

where "S" is the phase part of the wave function (Eq.7). Then to have the second time derivative of the particle position (accelerate) we need to have the time derivative of the wave function (its phase). This can be found in the guidance equation of the second quantization. By quantization of Klein-Gordon equation, the guidance equation is equal to [42, 43]:

$$\frac{\partial}{\partial t}\varphi=\frac{\delta}{\delta\varphi}S(\varphi,t) \tag{9}$$

where "$\mathscr{S}$" is the phase part of the functional at the quantized level in the Schrödinger picture [42].

Therefore, if we can write the Lagrangian, which contains the square of time derivative of the system state, we have the nth time derivative of the particle position at any level of quantization (n-quantization). Then, if the position function (x(t)) is assumed to be an analytical function, by knowing its position at a specific time according to the Taylor expansion,

[3] To grantee this condition in the equation of motion at each level of the quantized field, we can use the equation "$-\frac{\partial^2}{\partial t^2}\Psi=\widehat{H}^2\Psi$", instead of the Schrödinger equation "$i\frac{\partial}{\partial t}\Psi=H\Psi$", because its solutions are more general than Schrödinger's equation, so, some solutions are not physical.

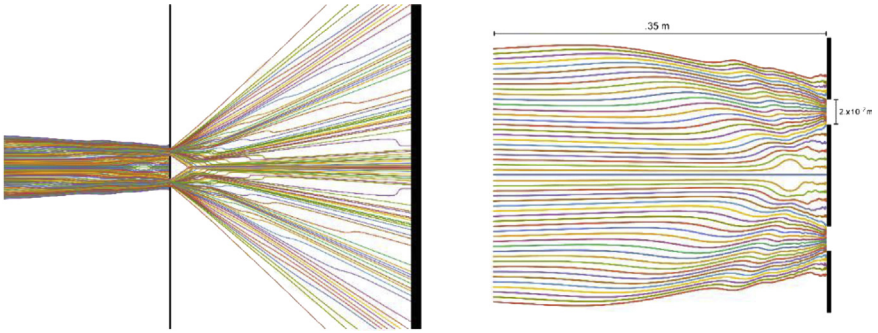

Fig. 1. The trajectories of electron in two slits experiment before and after the slits (Supplementary.B).

we can determine the function for all times. In fact, in the above picture we have infinite number of quantizations. We use the first quantization to get particle's velocity from the time derivative of its position (standard Bohmian). In the second quantization, we get acceleration from the second time derivative of the position (QFT Bohmian in Schrödinger picture). The third quantization gives us jerk from the third time derivative of the position, etc. Therefore, we have the position function at all times. This can be interpreted as a kind of non-locality in time. To reach this non-locality, we assume that the path integral method can be used alternatively.

2.3. Feynman picture

We can use the path integral formalism of quantum field theory to obtain the functional "Ψ" [44]. It can be seen that the path integral approach is more suitable for our purpose in this paper. In this approach, the probability of finding the system in the stateψ_f, if it were in the stateψ_i, is equal to the squares of the propagator between these two states [45, 46]:

$$\langle \psi_f | \psi_i \rangle = K(\psi_i, t_i; \psi_f, t_f) = \int_{b.c:\psi_i}^{\psi_f} D\psi e^{\frac{i}{\hbar}\int_{t_i}^{t_f} d^4x \mathscr{L}(\psi, \partial_\mu \psi; t)} \tag{10}$$

where "b.c" refers to the boundary condition, which contains the initial state (condition) "ψ_i" at the initial time "t_i" and the final state "ψ_f" at the final time "t_f". This integral is the summation of all possible paths from the initial state to the final state.

Due to the equivalence of the Schrödinger and Feynman's picture, we can obtain the wave functional in the form:

$$\Psi(\psi, t) = Re^{i\mathscr{S}} = \int_{-\infty}^{\infty} d\psi_i \Psi_0(\psi_i, t_i) \langle \psi | \psi_i \rangle = \int_{-\infty}^{\infty} d\psi_i \Psi_0(\psi_i, t_i) \int_{b.c:\psi_i}^{\psi} D\psi e^{\frac{i}{\hbar}\int_{t_i}^{t} d^4x \mathscr{L}(\psi, \partial_\mu \psi; t)} \tag{11}$$

According to the Supplementary. B, we can rewrite this as:

$$\Psi(\psi, t) = Re^{i\mathscr{S}} = \int_{-\infty}^{\infty} d\psi_i \Psi_0(\psi_i, t_i) \int d\psi_f K(\psi_i, t_i; \psi_f, t_f) \langle \psi | \psi_f \rangle \tag{12}$$

In fact, a realistic interpretation of path integral formalism and its use in Bohmian QM has some difficulties. As we showed in Supplementary. B, there are three mathematical methods to obtain Bohmian version of Feynman path integral QM. One of them is irrational. Another one is the same as the standard Bohmian QM. For Eq. (12) we used the third extension. We simulated the electron trajectories in the double slits experiment by the use of these extensions, in Supplementary.B. Our simulation for third one in addition to the description of experimental interference results shows that the final state can affect the trajectory details, especially before than the electron reaches to the slits (Fig. 1).

Similarly, this choice of path integral extension (Eq.12), according to Eq. (2), leads to an extra term in the Schrödinger equation which forces the wave function to reach one of the possible final states "ψ_f". This picture of Bohmian QM provides a background which can explain phenomena such as delayed choice experiment. In fact, the experimental setup preparing the final condition affects the final distribution of the wave functions, i.e. it permits some of them and bans others. For example, in the delayed choice experiment, the design of the location of mirrors and lenses leads to specific external observable states, among the possible states. This choice of experimental setup can be due to an observer's free will, i.e. because of its volition. Therefore, the change in the final experimental setup causes the change of the distribution of wave functions (Ψ_f). According to Eq. (12), the effect of changing the final distribution at the functional level, leads to an extra term in Schrödinger equation, which is interpreted as a Bohmian force at the QM level and guides the wave function to reach the final state in the domain of possibilities[4]. Although the final setup is related to the final time, but its result at the quantum level affects the evolution path of the wave function from the initial point to final one. In addition, it leads to a new Bohmian potential which guides the particle to the possible final location (Eq.6). It contains all of the QFT effects on the particle dynamics. This force is not relevant to a specific time. It exists throughout the path and is not determined only by the past. According to Eq. (12), it is also a function of future and final constraints and setup.

Although in the delayed choice experiment, it is shown that the nature of quantum world does not allow sending a signal to the past, but experimental data in the delayed choice experiments and in our modified Bohmian QM show the harmony and coordination between future and the past. In our model this is due to the aforementioned space-time nonlocal effects in the extra term in Eq. (1). It should be noticed that there is no real

[4] This is a non-unitary evolution of pilot wave. In this approach the induced extra term in the Schrödinger equation, leads to an effective non-unitary Hamiltonian, which guarantees the possibility of the effect of soul agency on the material dynamics.

retrocausation or erasing due to the delayed choice of experimental setup in the standard QM [47, 48]. In other words, in the Copenhagen QM it isn't necessary to assume such temporal nonlocality to explain quantum eraser delayed choice experiments, although there is a misunderstanding and confusion about it in literature[5]. But in the Bohmian QM, with a realistic interpretation that the particle has definite position and momentum (trajectory) at all times and we have no wave reduction, explanation of such delayed choice experiment has some ambiguities. In all Bohmian explanation of such experiments [49], the authors are considering a specific pure state of the initial quantum preparation[6]. The question of why we should take a mixture state and why this specific preparation is made, is unanswered in the Bohmian context. In other words, in some delayed choice experiments, such as [28, 50], there are no defined trajectories before determining the experimental setup. For example, in Scully version [28]. The selection of the particle behavior (D1&D2 detectors) or the wave behavior (D3&D4 detectors) for idler photon, can affects the preparation of the state function and then the signal photon dynamics. In our modified Bohmian QM, which is intrinsically 'temporally nonlocal', there is a context in which such delayed choice experiments can be explained by the Bohmian approach.

In summary, the extension of Bohmian QM to the quantum field theory and its representation in the path integral formalism leads to a quantum force which has two main properties: 1. Its effect is due to the possibilities level of wave functions (QFT level), and 2. It is a space-time nonlocal effect.

3. Model

3.1. Avicenna-Bohm theory of mind-brain interaction: Mechanism of causal effects of mind on the matter

In the hierarchical structure of nature, one of the effects of higher levels on the lower levels is the insertion of some higher level constraints on the lower level, which have some causal effects on a lower level [51]. For example, although the movement of a piston in a cylindrical chamber of gas is a phenomenon at the thermodynamic level, but it can be considered as a constraint/condition which affects the dynamics of gas molecules at the microscopic level. Another example is the movement of the walls in the case of a quantum particle in a box which is a macroscopic constraint but has causal effects on the particle dynamics in the box. Similarly, in the mind-brain case, a mind can affect the brain via the creation of constraints which are not necessarily present at the material level.

In Avicenna's model, the mind by imagination affects the form of the matter. For example, the imagination of raising one's hand, activates the neural pattern which is related to this function. In our proposed model, the mind by the imagination of a possible state[7] that wants to reach, prohibits an ensemble of possibilities. This prohibition affects the distribution function in the possibilities world. This constraint, according Eq.12 and Eq.4, leads to a space-time nonlocal effect on the physical system (Eq.6). In fact, this constraint on the possibilities distribution which is caused by mind imagination causes to the creation of a quantum force that guides the physical system to the intended state. This mechanism needs a special design in a matter where this quantum force, in addition to guiding the system to a special state, causes the production of some constraints in the final condition that corresponds to the mind intended possibilities. In fact, this causal force, thanks to the intelligent design in the brain and life, leads to some physical constraints at the right time, which are in correspondence with the mind intended state. In this proposed mechanism, mind without direct involvement, at the matter level and through the mentioned intermediate force, creates some constraints at the brain's matter level. These constraints lead to the selection of especial patterns at the neurons level, and finally lead to the occurrence of some special act or state.

Here we have assumed a space of possibilities that contains the constraints on Eq. (11). This space is, in a space-time independent way, a function of Mind's imaginations (equivalent to imagination in Avicenna's psychology), and is a time-dependent function of material constraints of the problem (equivalent to the constraints in the path integral formalism). Logically speaking, this space of possibilities is similar to the potential world in Stapp's mind-brain model (Heisenberg's quantum model) [3].

We try to illustrate this mechanism with a simple symbolic setup. Consider the following picture (Fig. 2).

According to what we have mentioned, mind due to the lateral information at time t ($t_1 < t < t_2$), by requesting the state 'a' (or 'b') related to time t_2, activating (or not activating) of neural set, creates a causal force throughout the system (neural) path, via effectiveness on the final probability distribution at the possibilities space. This causal force causes a special dynamics (behavior) of neural set before t_1, which leads to a special initial preparation for beginning of neural activating (firing). This change in the initial condition causes a deterministic effect on the creation of neural activation processing which leads to the neural activation at t_2. This is what the mind wants due the lateral activity (information) that can be received to mind among the whole process (between t_1 and t_2). This example shows how mind, through a coordinated design and without any philosophical contradiction, can affect the whole system by using quantum mechanical laws, to reach its aim.

Both aforementioned states are consistent and possible. Observation of one of them in the laboratory does not have any contradiction with physical laws, and are completely consistent. Observing one of them raises a question: "why didn't the other possible state occur and why was this state selected to actualize? In the above situation, if an observer records the state 'a' (or 'b') for the brain activity, and we ask him "why this state has occurred?" He says because of the special initial condition which occurred in past before t_1. And if we ask him "why this special initial condition has occurred?" He answers that it was for reaching to the special final state that brain wants! In fact, all are consistent at the material level, but one needs to select one of the states at the philosophical level. Indeed, it needs a cause to actualize one of the possibilities. In our proposed model, this cause is a mind which, through the mentioned mechanism, affects the appearance of states.

A more detailed explanation is that due to Avicenna's suggestion, in

[5] Part of referee comment: "The original misportrayal of such ('QE') experiments as 'erasing the interference pattern' when the idler photon is measured in a 'which slit' basis. But this never happens. No pattern of detections is ever 'erased.' If the photon measurements are timelike separated, with the signal photon being detected at t1<t2, the signal photon is in an improper mixed state when it hits the screen at some horizontal location d. Thus, all the signal detections yield noise; no pattern whatsoever, because the screen measures neither 'which slit' nor both slits' states. There are two orthogonal 'both slits' states, and thus two orthogonal interference patterns; this is usually overlooked as part of the confusion. The screen exhibits no pattern of any kind for the t1 signal photon detections; it is just noise. A pattern exhibiting any correlations (whether which-slit or both-slits) can only be retrieved after all the counts, from both photons, are recorded and sub-ensembles of the signal photon detections are assembled corresponding to specific idler outcome. Then the correct signal photon outcome distributions are seen corresponding to their partner idler outcomes. There is no necessary 'temporal nonlocality' obtained in the QE experiment. There is never any interference pattern on the screen at t1 to be 'erased' at t2. None of the detections at t1 are 'erased'. The usual conclusion of 'erasure' is a fallacy, resulting from overlooking the requirement for coincidence counting and statistical analysis of the data to sort the x detections into the correct sub-ensembles, and/or from overlooking the fact that the signal photon detections project their idler partners into pure states whose statistical properties will correctly reflect the x value of their partner signal photon's detection."

[6] This result is adopted from our discussion with Prof. Ruth E. Kastner.

[7] This imagination has two features. The first one is related to the limitations that is generated in mind upon the effect of matter/brain on mind and the mind capability. Secondly, this imagination has to be in the acting domain of the brain and the corresponding features which might happen at the level of matter.

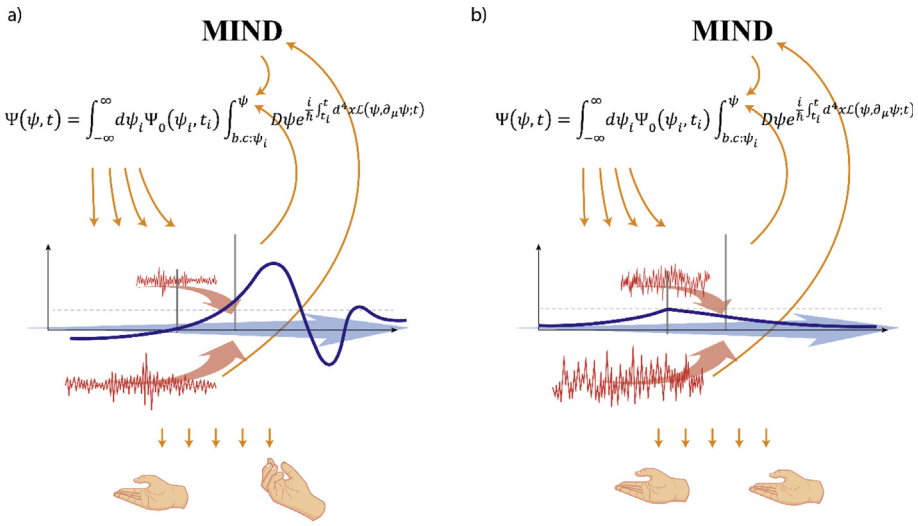

Fig. 2. Schematic of mind effect on the matter. The states a and b are classically different states. The mind with notice to lataral information which are received between t_1 and t_2, by imagination of an intended state causes the change of possibilities distribution of final state (the first top-down arrow). This leads to a nonlocal effect on the wave function (pilot wave) via determining the functional (Eq.12). This pilot wave affects the dynamics of neural set, via the quantum potential (Eq.6). a. This causal force causes a special dynamics (behavior) of neural set before t1, which leads to a special initial preparation for beginning of neural activating (firing). Now the experimental setup, which determines the final mind intended possibilities, is actualized in t_2. This is a material cause (down-top) which guarantee the final possible states to determine the functional (Eq.12). b. the choice of the situation and state (b) causes the quantum force which guides the system to lead to the inactivation of neural set and the actualization of state b.

which one considers a possibilities space which is in agreement with the functional space of the quantum field theory (analogous to possibilities space in Heisenberg quantum interpretation in the Stapp's mind-brain model). mind can be effective on the particle/matter dynamics through an effect on the final possibility distribution. The material necessity to cause a change in the possible states is the existence of special constraints and special experimental setup. Therefore, there must be a perfect design in the brain so that mind, having an effect on possibilities distribution (according to the modified Bohmian quantum mechanics), leads to a causal quantum force on the whole space-time of the particle evolution. and causes it to create some constraints and an appropriate material setup which are necessary for the desired distribution (this setup prohibits occurrence of other possible states).

The special properties of the proposed model include the following.

1. The effect of mind is a type of creation of material and physical possible states, which have causal influence on the brain matter, caused by free will and volition.
2. This model contains a definite physical mechanism which describes the mind effect on the brain in accordance with modern physics. It introduces neither self as a physical or material identity, nor disrespects the laws of physics at the material level.
3. The effect of mind is the influence on the whole of space-time of a system evolution (due to the modified Bohmian quantum potential) and does not refer to a specific point in space-time. This feature is consistent with philosophical argument, and with the incorporeity of mind, which leads to the non-temporality of mind.
4. Although the imagination and the will of mind correspond to time t_2, its effect via quantum force to create correspondence material setup is at time t_1, and it is consistent with empirical data in Libet-like experiments. Some other models which describe this data, accept illusion of free will (i.e. they consider the free will as an illusion phenomenon).
5. As we mentioned, for the effectiveness of mind on the matter, there is a need for a perfect design which provides necessary material basics. Therefore, any manipulation on the matter of the brain may lead to some constraints on the mental states and mind choices by a change in this design or in possible states.

The purpose of our proposal is to prove the possibility of presenting a causal model of mind's effect on the matter (brain), but it needs further research to provide a neural structure appropriate to it. However, generally speaking, the existence of a large number of inhibitory neurons and their important role in the brain activity to create the possible patterns, are in agreement with our model. Activating these neurons at t causes the inactivation of some of the next neurons. In addition, due to Stapp's model and according to the quantum connection between neurons in Eccles' and Beck's formalism, the possible patterns of neural activity are the quantum states. Therefore, we can introduce a guiding wave corresponding to these patterns. By noticing the role of inhibitory neurons in the formation of these patterns, it seems that our model of mind-brain is not far from reality, although it needs further investigation.

3.2. *Agreement with natural laws: Libet experiment, parapsychological data, and quantum delayed choice experiments*

The best support for our model is the results of Libet-type experiments. The experiment conducted in 1983 by Libet and his colleagues at the University of California at San Francisco, describes why there is a delay between the time of specific neural activity in motor cortex (i.e. the readiness potential), which leads to the voluntary muscle movement, and the time of conscious will [10, 52]. In fact, this experiment shows that the rise in readiness potential is visible about 350 ms before the subject became consciously aware of his decision (Fig. 3) [53]. Apparently, the Libet's experiment is contrary to free-will. Some scholars think that based on the Libet's results, the conscious will and free-will are illusion phenomena [53, 54, 55, 56, 57], but some others interpreted this experiment through other ways [58, 59]. Libet himself suggests a kind of mind ability to consciously veto before this unconscious process is led to action and muscle movement [9], which was recently confirmed experimentally [60]. The illusion interpretation of Libet's results is a hasty conclusion.

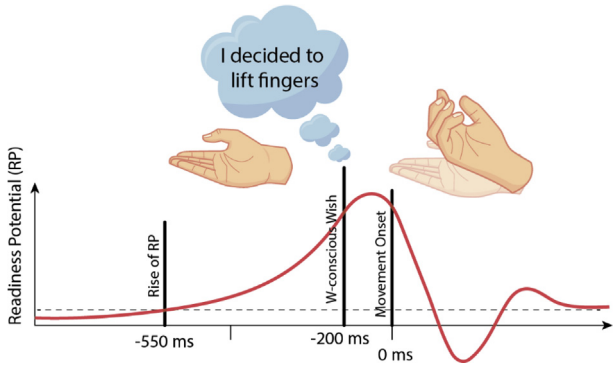

Fig. 3. Schematic of readiness potential in terms of time in the Libet's experiment about the time of free-will, and time of deferent events on the Libet's experiment. The rise of readiness potential occurs 350 ms before the conscious intention (feeling of free-will).

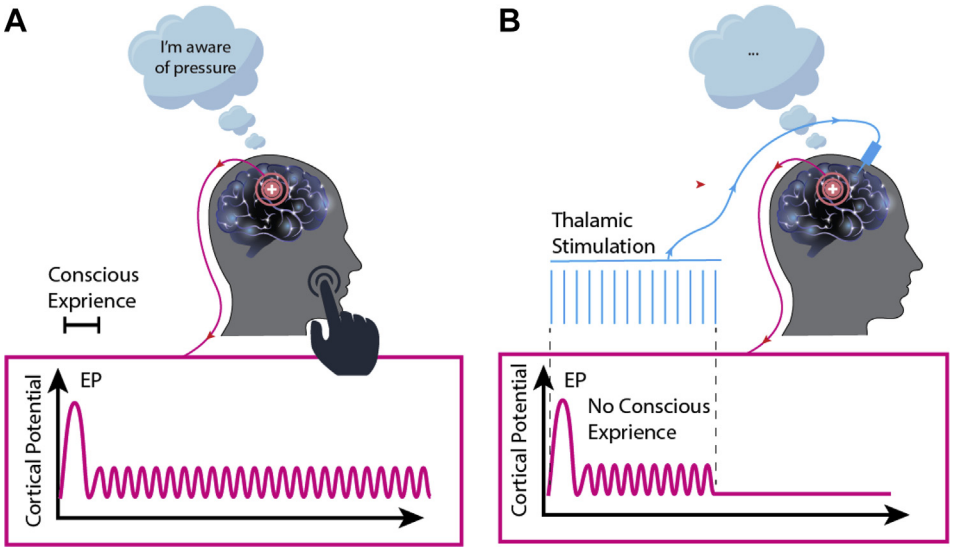

Fig. 4. Schematic of cortical potential at the somatosensory area in terms of time in the second type of LIbet's experiment. A. In sensing experiment after the occurrence of an EP with ongoing cortical activity up to 500 ms, the patient reports a conscious experience at the same time of the EP (30 ms). B. If via thalamic stimulation, an EP be created but the ongoing activity doesn't continue until 500 ms, there is no conscious experimental report.

Especially, the result of Libet's experiment on the perception and relation between neural activity and sensing awareness shows the complexity of mind-brain interaction [9, 62], which is an evidence for the presence of complex physical laws at its background. Another type of Libet's experiment shows that the awareness sensing for which time is related to the evoked potential (EP) spike in the somatosensory cortex, depends on the ongoing cortical activity up to 500 ms. In the usual sensing, the conscious awareness of it occurs in 30 ms, concurrent with (at the same time of) the EP, but ongoing weak cortical activity continues about 500 ms after EP. Although the stimulation of medial lemniscuses of the thalamus in the sensory pathway, with the period less than 500 ms, causes an EP and a brief ongoing cortical activity, it does not lead to any conscious sensing. If it continues until 500 ms, the subject reports sensing it about 30 ms after the beginning of the stimulation (Fig. 4).

The first kind of Libet's experiment has two assumptions: 1. a kind of free will and 2. time ordering (chronological ordering) and classical determinism. If the results of Libet's experiment are correct, then at least one of these assumptions has to be false. Some scholars abandon the idea of free will, but according to recent results of the delayed choice experiments, which can be represented in our approach as the space-time nonlocal nature of the quantum world, rational judgment leads to a revision of classical determinism and time ordering. Our model, by preserving causality and free will, clarifies and explains Libet's results. In fact, according to the nature of the modified Bohmian quantum mechanics and due to its QFT extension, the nonlocal quantum force transfers the mind effect to the brain as a top down causation which does not need to take free will in the time ordering, at the brain-activity level.

The second kind of Libet's experiment is consistent with the nature of the quantum nonlocality in time. This is confirmed by the delayed choice experiments and is explained by our model of modified Bohmian quantum mechanics. In addition, for a realistic interpretation of QM, there are two models which explain such phenomena: the transactional QM which was developed by Cramer and Kastner [35, 61, 62], and the realistic wave reduction due to quantum gravity, proposed in Penros-Hameroff "Orch OR" theory [16]. According to our model, the whole evolution and neural activity affects the mind perception [24]. In fact, according to the nature of path integral formalism of QFT, and due to the extended Bohmian QM, the constraints and the structure of neural connection and their activity on the whole of the process determines the possible states in the possibilities space, of which the mind can be informed. A certain perception of a sensory detection occurs when one possible state is determined. But, due to the modified Bohmian QM, it is determined when all constraints, from the beginning to the final state, are determined. Therefore, a certain mind perception needs the determination of the whole neural process. In addition, according to our model, there can be some feedback effects of the possibilities space on the neural activity, via the quantum force. The actualized activity is due to both effects of the top level (possibilities space) and the down level (sensory input).

The time related to mind perception is associated with the ongoing mind effects on the brain due to this perception, which can even be a kind of feedback on the neural activity in the somatosensory cortex. Therefore, its time can be between 0 to 500 ms of neural activity. In addition to these neuroscience experiments, there are some experiments in psychology and parapsychology which confirm the nature of time-nonlocality in the mind-brain interaction. These experiments that are called precognition or premonition of a future event shows a person's awareness of the event or phenomenon in the future [33, 63]. For example, as Hameroff mentioned in [18], the results of Ben in [33] shows the kind of picture, which appears in the future time and have effects on a person's guesses and his decision to predict the location of the image appearance among some possibilities.

4. Conclusion

In this article, we proposed a causal model and a mechanism for the mind's influence on the brain (matter). It is consistent with the free-will. In this model, freedom is not an illusion but is due to an upper level, and the mind is the cause of the effect via this higher level. This model is in agreement with the view of some philosophical schools, which believe in the incorporeity of mind, which leads to non-temporal properties of mind, i.e. it cannot affect a special space-time point of mater. In fact, in our model, mind affects the whole activity of the brain from the beginning to end, as a space-time nonlocal effect. These effects apply to the brain through a quantum force which is a function of all constraints and matter setup (complexity, design) in the future and the past of its motion (evolution); the past is its history and the future is its possibilities. This functionality is derived from a modified Bohmian quantum mechanics due to its extension to quantum field theory, via a path integral method. In fact, mind affects the possibilities' distribution (in the final state through its dependency of space-time) and leads to the creation of the quantum forces that guide the brain activity to what mind wants. At the final point, the matter constraints and neural setup of connections must

guarantee the possibilities distribution which mind has imagined. Therefore, the created quantum force due to the special design of brain must lead to these necessary constraints at the final state. Every matter has a quantum behavior in its nature, but the mentioned special matter design is a special complexity which explains the difference between spiritual matter[8] and normal matter.

In fact, we have proved the possibility of the presence of a causal description of the incorporeal mind's influence on the brain. We assumed the presence of the top-down causality and showed it in the mind-brain interaction through considering the quantum filed theory as a high level of possibilities. We assumed that this higher level has two aspects: one is affected by mind's imagination and other is affected by matter's constraints. In the free-will phenomenon, the mind affects these possibilities at first, and due to proposed mathematical formalism, the created force on the matter causes some constraints which are in agreement with these possibilities in the final state. In fact, everything is consistent at the matter level. However, the occurrence of a certain state among multiple possibilities needs an efficient cause, and this is mind.

In our modeling, we took advantage of Avicenna's philosophy and his model of mind-brain interaction. In addition, we used modern physical laws to obtain a mechanism to describe the mind's effect on the brain. Because of our belief in causality and the presence of free-will, we chose extended Bohmian quantum mechanics. The introduction of special neural connection setup can be appropriate for our description, and thisneeds some more investigation.

The comparison and application of the recent developments in logic, which are the results of the recent developments in sciences, to the conclusions of this paper is necessary. For example, important problems like two-way causality, motion from what is potentially present towards actuality, compatibility of causality and free will can be compared with the recent advances in fuzzy logic or bipolar logic. But, this needs a separate investigation.

Declarations

Author contribution statement

Mohammad Jamali, Mehdi Golshani, Yousef Jamali: Conceived and designed the analysis; Analyzed and interpreted the data; Contributed analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

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[8] The matter which is capable of accepting soul; a specific biological matter.

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