

Where does quanta meet mind?

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Abstract The connection between quantum physics and the mind has been debated for almost a hundred years. There are several proposals as to how quantum effects might be relevant to understanding consciousness, including von Neumann’s Consciousness Causes Collapse interpretation (CCC), Penrose’s Orchestrated objective reduction (Orch OR), Atmanspacher quantum emergence theory, or Vitiello’s field theory. In this paper, we examine the CCC, in particular Stapp’s theory of interaction of mind and matter, and discuss how this imposes constraints to possible brain structures. We then argue that those constraints may allow us to identify a possible locus of the interaction between mind and matter, if CCC is true.

1 Introduction

In a seminal book, von Neumann formulated what became one of the main interpretational difficulties of quantum theory: the measurement problem (von Neumann, 1983). In a nutshell, the measurement problem can be seen as a difficulty of understanding how the transition from the quantum to the classical domain happens, and, more importantly, how the quantum and classical dynamics and descriptions of nature can co-exist in a consistent way. Since von Neumann’s book, there were many attempts to solve this problem, which led to diverse interpretations of the mathematical formalism, sometimes with very disturbing ontologies associated to them. Among the most well-known and discussed interpretations are the many worlds interpretation (Everett, 1957), Bohm’s pilot wave theory (Bohm, 1952a,b), Nelson’s stochastic theory (Nelson, 1985), and epistemic interpretations (such as QBism; see, e.g., Fuchs (2014)).

There is no consensus among physicists or philosophers as to which of those interpretations is most adequate. However, there is perhaps no other interpretation that leads to a stronger negative reaction and perhaps even downright disdain by many physicists than the Consciousness Causes Collapse (CCC) interpretation of quantum

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mechanics, which invokes a different dynamics for quantum systems when they interact with a mind. This connection between quantum mechanics and the mind dates back to the beginning of the 20th Century, when researchers were trying to understand the meaning of the quantum formalism. The idea was that, when looking at the difference in quantum and classical behavior of material particles, it was clear that we only observe classical behavior, but never quantum. For example, for a particle in a quantum superposition of two states, whenever we observed it (measured) for the property that was superposed, this particle would be in either one or the other state, and never in a strange non-classical superposition of properties. This led von Neumann to postulate that the quantum realm had two different dynamics, one linear and deterministic, which would happen for isolated quantum systems, and another non-linear and probabilistic, which would happen when a quantum system interacted with the observers mind (von Neumann, 1983). The CCC interpretation seems to postulate a dualist view of the world: there is matter, which satisfies an unitary and deterministic evolution, such as Schrodinger's equation, including when interacting with material objects, such as a measuring device; and there is the mind, which not only is unclear as to which dynamics it follows, but also causes matter to evolve differently, via a non-deterministic and non-unitary quantum jump, when mind interacts with matter.

Whether we believe or not on the CCC interpretation, or whether we find its dualistic ontology too difficult to swallow, it is still an interesting question to ask what are its consequences, and whether we can learn something about quantum mechanics or the philosophy of mind by studying it. For example, Henry Stapp, a student of Emilio Segré who has devoted his life to the CCC interpretation, has developed a clever way to model the control of matter by a mind using the inverse Quantum Zeno Effect (IQZE). In this paper, we will explore this idea, and try to discuss what possible structures in the brain might be candidates for the loci of interaction between mind and matter.

This paper is organized as follows. In Section 2 we briefly review the measurement problem, and briefly introduce some possible solutions, focusing more specifically in the CCC interpretation. In Section 3 we discuss Stapp's idea of using the inverse Quantum Zeno Effect to model the effects of the mind on the brain/matter. In Section 4 we discuss constraints to the behavior of matter, where the model presented in Section 3 true, and we argue that the search for the loci of interaction between mind and matter should look for certain particular aspects of brain dynamics. Section 5 ends this paper with some conclusions.

2 The CCC interpretation

As we mentioned above, the CCC interpretation was the first attempt to address the measurement problem. So, it is fit to start our discussion of this interpretation with a discussion of this problem.

In quantum theory, the state of a physical system is described by a normalized vector¹. Properties are represented by hermitian operators in the Hilbert space, called *observables*. Properties are then associated to eigenvalues of the observable, and states that are eigenvectors can be thought as having well-defined properties, since the repeated measurement of this property yields always the same outcome, i.e. the same eigenvalue and eigenvector.

¹ More precisely, a vector in a Hilbert space.

Any vector on the Hilbert space can, in principle, be physically realizable through careful preparation of the physical system. This fact leads to some problematic issues for the concept of properties attached to observables. For example, imagine a two-dimensional vector space, and in it the observable σ_z with two eigenvectors: $\sigma_z|+\rangle = |+\rangle$, and $\sigma_z|-\rangle = -|-\rangle$. The observable σ_z thus have two possible outcomes for experiments: “+” or “−.” If the system is prepared initially in the state $|+\rangle$, a measurement of σ_z will always yield the outcome “+”, even if repeated several times, and similarly for $|-\rangle$. However, what happens to the state $|\psi\rangle = c_+|+\rangle + c_-|-\rangle$, the superposition of $|+\rangle$ and $|-\rangle$, where $|c_+|^2 + |c_-|^2 = 1$, when we measure property σ_z ? We will either observe “+” or “−”, and if measured again, we will observe the same outcome. This means that when we measure σ_z the state $|\psi\rangle$ “collapses” into either $|+\rangle$ or $|-\rangle$ with probabilities $p(+)=|c_+|^2$ and $p(-)=|c_-|^2$; we never observe the property to actually be in a superposition.

So, it is natural to ask about the meaning of superpositions of vectors such as $|\psi\rangle = c_+|+\rangle + c_-|-\rangle$. Does it mean that we have either state $|+\rangle$ or $|-\rangle$ but we do not know which? Or does it mean something different? It so happens that the idea that a superposition is a state with either one property or the other is not consistent.² So, a measurement does not reveal the existing value of a property, but seems to create it.

The puzzling aspect of quantum superpositions is perhaps better exemplified by the famous cat gedankenexperiment proposed by Schroedinger. In this experiment, a system, namely a cat, consists of two possible states, $|\text{live cat}\rangle$ and $|\text{dead cat}\rangle$, corresponding to the cat being either alive in one and dead in the other (i.e., repeated measurements of the cat lead to the same conclusions). Then, through a simple mechanism that constructs quantum superpositions for these two states, Schroedinger argued that it is possible to reach a superposed state of the type $c_l|\text{live cat}\rangle + c_d|\text{dead cat}\rangle$, such that for this state we cannot say that the observation reveals that the cat was either dead or alive. Instead, before the observation the cat is neither (or both), and the observation itself causes the cat to fall into the category of either dead or alive.

At the core of the seemingly absurd example from Schroedinger’s cat seems to be the issue of observations. What are observations? What is to observe? To model observations, von Neumann (1983) proposed the following idea. Observations, he said, require something that determines which properties are being observed: call it a measurement apparatus. For example, if we want to observe if the cat is dead or alive, we can construct an apparatus that measures the cat’s heartbeat: if a heartbeat is present, the cat is alive; otherwise, the cat is dead. Measuring apparatuses are physical systems themselves, and as such can be described by quantum physics. Now, quantum physics says that a system described by a vector $|\psi\rangle$ evolves according to a unitary evolution, i.e. $|\psi(T)\rangle = U(T, T_0)|\psi(T_0)\rangle$, where $|\psi(t)\rangle$ is the state at time t and $U(T, T_0)$ is the evolution operator.

The measurement apparatus modeling done by von Neumann does not resolve the problem of the cat superposition. This is because, during a measurement, the unitary evolution of the systems results in a superposition of the cat dead and alive. So, von Neumann then argued the following. Since the measurement apparatus is in a superposition, then we can measure it with our eyes (themselves a measurement apparatus); this leads to a superposition of the dead and alive images in our retinas.

² This result is the core of the Kochen-Specker theorem, but showing it here would go beyond the scope of this paper. Interested readers are referred to the original paper of Kochen and Specker (1967).

But then we can consider the optic nerves as measuring the eyes themselves, and the optical nerves would be in a superposition. This would keep going on, until all matter in the brain/body would be in a quantum superposition of states where the cat dead or alive were imprinted. However, we never see such superposition. This led von Neumann to postulate two different dynamics for quantum processes: one, linear, unitary, and deterministic, that tells us how matter evolves in time; another, non-linear and probabilistic, which comes into play only when an observer experiences the measurement.

The idea proposed by von Neumann was later on modified, first by London and Bauer, and then by Wigner (see Bueno (2019) in this volume for details and references), to include the mind. They argued that if all matter followed unitary and deterministic dynamics, then the mind had to be something else, something that was not matter. This is the idea behind the Consciousness Causes Collapse interpretation: matter evolves differently when it interacts with the conscious mind, which itself is not matter. This idea was later on abandoned by Wigner, but Henry Stapp continued to be one of its main proponents.

We can see how the CCC interpretation solves the measurement problem, and many readers of this book can imagine the many reasons why such proposal is not widely appreciated by physicists. But what are the alternatives? What other possibilities exist for the measurement problem. It would be beyond the scope of this paper to detail all the existing interpretations, and our goal here is simply to briefly comment on some popular interpretations, and what are the problems with them.

Let us start with hidden-variable theories. The idea of hidden variables is that quantum mechanics is an incomplete theory, and it is the goal of physicists to find a more complete description of nature. Perhaps this new theory includes variables that can account for the quantum observed phenomena, and can be used to solve the measurement problem, but are themselves not observable (thus the name hidden variable).

Perhaps the best known hidden variable theory is Bohm's pilot wave interpretation. In Bohm's theory, a quantum system represented by a wave function $\psi(t, \mathbf{r})$ that can be thought as a vector in an infinite dimensional vector space together with a particle that "rides" this wave, following a modified Hamilton-Jacobi equation with an added quantum potential. In this interpretation, the wave function has a dual aspect to it: it is both epistemic, as $|\psi(t, \mathbf{r})|^2$ gives us the probability of where the particle is at time t due to our lack of knowledge about it, and it is ontic, as its presence physically guide the particle. The main issue, according to many physicists, is the blatant non-locality of this interpretation. When two particles are described by a wave function of the form $\psi(t, \mathbf{r}_1, \mathbf{r}_2)$, where the index refers to either particle 1 or 2, an action (e.g. a measurement) in one of those particles would instantly affect the wave acting on the other particle, and since the wave has this ontic character, this amounts to an action-at-a-distance, and Bohm's theory is non-local. This non-locality is seen by many as a major incompatibility with relativity theory (see Holland (1995) for a more detailed discussion of Bohm's theory and its criticisms)³.

³ Though the author of this paper does not consider himself a "Bohmian," he believes that theories such as Bohm's are extremely important to get a fuller picture of what nature is trying to tell us. For example, it can be argued that Bohm's interpretation can lead to different outcomes from other interpretations when applied to extreme conditions, such as when the universe as a whole was dictated by quantum effects (de Barros and Pinto-Neto, 1997, 1998; de Barros et al., 1998, 2000).

Another approach to the measurement problem is to deny the basic idea that a measurement yields a single outcome. For example, for Schrodinger's cat, the assumption is that when we observe the cat, we either get a dead cat or an alive cat. But a possibility is that both dead and alive cats are something that happen. To reconcile this with our experience, the many-worlds interpretation (Everett III, 1957) assumes that in the process of a measurement, its possible outcomes (i.e. dead or alive cat) all happen, but in different universes. There are many reasons why people are reluctant to accept this theory, but perhaps the main difficulty is its very high ontological cost, where an infinitely large number of co-existing universes pop up every instant. Despite this, the many-worlds (and its variant, the many-minds) interpretation is, perhaps, the most popular among physicists working on foundations (Schlosshauer et al., 2013).

A third approach to the measurement problem is to deny the universality of quantum unitary evolution. This is the approach of the CCC interpretation, as it says that, e.g., Schrodinger's equation applies to all matter, but not to mind. Furthermore, it postulates that the interaction of mind with matter yields a different type of dynamics, a non-unitary one. Since this is the main approach we are interested, we will discuss it in more detail.

Let S be a quantum system, represented by a vector that can take two states, $|+\rangle$ and $|-\rangle$. Let us assume that M is a measurement apparatus that has its own states described by $|\text{Pointer at } 0\rangle$, $|\text{Pointer at } +\rangle$, and $|\text{Pointer at } -\rangle$, where each of those states may represent a degenerate quantum state that has a pointer indicating that the system it measured has property $+$ or $-$, or that it is simply waiting for a measurement. If M measures the properties of the state, its interaction with S should satisfy the following:

$$|+\rangle|\text{Pointer at } 0\rangle \xrightarrow[\text{interaction}]{S \text{ and } M} |+\rangle|\text{Pointer at } +\rangle, \quad (1)$$

$$|-\rangle|\text{Pointer at } 0\rangle \xrightarrow[\text{interaction}]{S \text{ and } M} |-\rangle|\text{Pointer at } -\rangle. \quad (2)$$

In terms of the quantum formalism, this means that there should be a unitary operator U_{measure} that when applied to the lhs of (1) and (2) yields their rhs, i.e.

$$U_{\text{measure}}|+\rangle|\text{Pointer at } 0\rangle = |+\rangle|\text{Pointer at } +\rangle$$

and

$$U_{\text{measure}}|-\rangle|\text{Pointer at } 0\rangle = |-\rangle|\text{Pointer at } -\rangle.$$

What happens when the measuring device modeled by the quantum unitary evolution interacts with a superposition? Let S be in the state $c_+|+\rangle + c_-|-\rangle$. Then, the evolution of S and M during their interaction is determined by U_{measure} , and after a measurement the final state is

$$U_{\text{measure}}(c_+|+\rangle + c_-|-\rangle)|\text{Pointer at } 0\rangle = c_+|+\rangle|\text{Pointer at } +\rangle + c_-|-\rangle|\text{Pointer at } -\rangle. \quad (3)$$

A careful analysis of (3) reveals that, after a measurement, the final state is not either $|+\rangle|\text{Pointer at } +\rangle$ or $|-\rangle|\text{Pointer at } -\rangle$, but instead a superposition of these two states. The consequence is that the final state is not an eigenstate of either $|+\rangle\langle+|$ nor $|\text{Pointer at } +\rangle\langle\text{Pointer at } +|$, which are the projection observables associate to those

states. In other words, no collapse of the wave function happened, and therefore no measurement happened.

In his book, von Neumann (1983) argued that we could think of our eyes (call them system E) as a measurement apparatus that measures M itself. If we do that, and describe our eyes' interactions with S and M via an unitary operator, we end up with a similar superposition to (3). We could go further, and think of the optic nerve O as measuring the eyes, and the visual cortex V as measuring O , the brain B measuring V , and so on, until all matter in the body (and outside of it) is taken into account as part of the description, and we still end up with a superposition. But since we never see a superposition, the *observer* causes a different dynamics in the process that is not unitary: the collapse of the wave function.

3 Mind, Brain, and the IQZE

The above description is, briefly, the CCC interpretation. As we mentioned, this is a very controversial interpretation, and many researchers have not only argued against it in philosophical grounds, but claimed that it has been falsified. However, claims that the CCC interpretation was falsified have been greatly exaggerated. For instance, in de Barros and Oas (2017) it was argued that in order to falsify the CCC interpretation, one would need to perform an interference-type experiment with an organism candidate for having consciousness⁴. However, to prepare such an experiment, one would need to control all quantum variables that could get entangled with the measurement apparatus. This task is not solely difficult to realize from a technical point of view, but it would require keeping the organism decoupled from a thermal bath, at temperatures that are incompatible neither with life nor with behavioral responses, not to mention consciousness. But even though CCC probably will never be falsified, at least not in a way that is convincing to many of its proponents, it does not mean that it cannot raise some interesting, and falsifiable, models of interaction of mind and brain. This is what we will explore in this section.

Here we will focus on Stapp's work, in particular his proposal of how the mind affects matter in particular ways, e.g. how the non-material my mind controls my motor cortex such that my fingers type the words I wish in my keyboard (Stapp, 2009, 2014). Stapp's idea relies on the Inverse Quantum Zeno Effect (IQZE), which we describe below. The idea of the Quantum Zeno Effect is that it is possible to create systems and observables, such that the expected values of some observables change with time when the system is left to evolve regularly but remain constant when the system is being observed through this time. The IQZE is the opposite: the observation of a system whose observables would remain the same leads to changes in time for the value of those observables. To show how this works, imagine a quantum harmonic oscillator represented by a coherent state $|\alpha\rangle$, defined by

$$|\alpha\rangle = e^{-|\alpha|^2/2} \sum \frac{\alpha^n}{\sqrt{n!}} |n\rangle,$$

⁴ Here we should clarify what we mean by consciousness. von Neumann seemed to be thinking about a generic concept, that of an observer. He did not (at least explicitly) commit to a mind or consciousness that was outside of the physical realm. This connection between a nonphysical mind seem to be espoused initially by Wigner, and later on by Henry Stapp. But even for Stapp's view, it seems that what is meant by consciousness is not phenomenal consciousness, but access consciousness (see Montemayor (2019) on this volume).

where α can be interpreted as the amplitude of oscillation. Imagine that we have as our observer the projection operator

$$P_{\alpha+\epsilon} = |\alpha + \epsilon\rangle\langle\alpha + \epsilon|,$$

which corresponds to the question “is the system in a coherent state with amplitude $\alpha + \epsilon$?” If we perform such measurement for the coherent state $|\alpha\rangle$, we have two possible outcomes: the system ends in a coherent state $|\alpha + \epsilon\rangle$ with probability $p(\alpha + \epsilon|\alpha) = 1 - \epsilon^2$; the system does not have the property $\alpha + \epsilon$ with probability ϵ^2 . Now, let us assume that we make N measurements like the above one, but in the following order: $P_{\alpha+\epsilon}, P_{\alpha+2\epsilon}, P_{\alpha+3\epsilon}, \dots, P_{\alpha+N\epsilon}$. It follows, because of the collapse of the wave function for each observation, that after these N measurements, the system will be in the state $|\alpha + N\epsilon\rangle$ with probability $p(\alpha + N\epsilon) \approx 1 - N\epsilon^2$, for small values of ϵ . If we take the limit for $\epsilon \rightarrow 0$ while keeping $N\epsilon = \beta$ constant, the system ends up in the state $|\alpha + \beta\rangle$ with probability one. In other words, the continuously increasing measurement of quantum oscillator can lead to its change of amplitude.

Notice that the IQZE happens because we have a collapse of the wave function. If there were no collapse, a multitude of superpositions would be created, and the final state would not be $|\alpha + \beta\rangle$ with probability one. So, keeping this in mind, Stapp proposed to use the IQZE as a way that the mind could influence matter. According to Stapp, small neural oscillators on the cortex micropill could be measured in a similar way as the IQZE, and what was originally a small oscillation could become a very large one (in fact, as large as one wishes): if the mind chooses to observe the oscillator in a particular way, the measurement causes an increase in the amplitude of neural oscillators; if the mind does not choose to observe, there is no increase in the amplitude of neural oscillators.

4 Where mind meets matter

In previous work, we argued that the model presented by Stapp is incomplete (de Barros, 2016; de Barros and Oas, 2015). Our basic reasoning was, briefly, the following. Even in the CCC interpretation, a measurement does not constitute an interaction between a system and the mind. Instead it is the interaction of a system with a measurement apparatus and with a mind. The measurement apparatus is a crucial component of the measurement, as it defines the measurement basis (Schlosshauer, 2005). In other words, what determines whether we are measuring spin in the direction z is not the mind of the observer, but the fact that our measurement apparatus is physically placed in a way that measures spin in that direction. If we were to physically rotate this measurement apparatus to the direction y , we would obtain measurements in the direction y , regardless of whether our mind wanted or not.

So, here we seem to hit an apparent problem: for mind to affect matter, we need to have a measurement apparatus that moves in a very particular way. But this measurement apparatus needs to be moved by mind. So, this seems to lead to a circular argument, one where mind affects matter through measurements (via the IQZE) only if mind can physically affect matter (through the positioning of measurement apparatuses). Does this mean that we need to abandon the IQZE model? Not necessarily. As we showed before, it is possible to resolve this issue of circularity if we make additional assumptions to the dynamics of the brain. Furthermore, those additional assumptions

perhaps may provide us with specific types of structures that may be involved in the interaction between mind and matter, so let us examine them now.

First, the issue of a measurement and its basis is essential for a measurement. This is, after all, the main success of decoherence theory: the explanation of why a measurement yields a preferred basis. So, any theory of measurement, which CCC is, needs to include this. In other words, the first constraint on Stapp's model is that, in addition to the neural oscillators in a coherent state $|\alpha\rangle$, there needs to be a physical structure that provides a preferred basis for the successive measurements of $P_{\alpha+\epsilon}, P_{\alpha+2\epsilon}, \dots, P_{\alpha+N\epsilon}$. Let us call this the *brain-mind mediator structure* (BMMS), as it mediates the interaction between mind and matter.

In addition to interacting with the neuropill oscillators (NO) as a measurement device with increasing amplitude, BMMS has to offer some predictability, for the following reason. If the mind is to control MP, choosing freely to increase or not its amplitudes, it has two choices: observe the BMMS or not. Note that for a measurement to occur, according to the CCC theory, we need a physical system being measured (here the NO), a physical measurement apparatus (BMMS), and an observer's mind (OM). If OM observes, then a collapse occurs, and the amplitude of $|\alpha\rangle$ increases. If OM does not observe, the amplitude of $|\alpha\rangle$ remains the same. But given that the observation needs to start happening when BMMS is at the state of measuring $P_{\alpha+\epsilon}$, and not later, and then keep measuring until the desired amplitude is reached, the dynamics of the measurements need to be predictable, and it needs to be such that the mind can choose the measurement often as it wishes. This can be accomplished by assuming that BMMS's dynamics is periodic, but how this periodicity is described (i.e. what are the exact details of this oscillations) is not clear.

So, here we reach the constraints involved in the brain structures needed for Stapp's model to work.

NO. The neuropill oscillators are the basic structures that are associated with the increase of activity due to the mind's volition. Stapp assumes them to be in a quantum coherent state, $|\alpha\rangle$. Though this is a simplifying assumption, there are other quantum oscillation states that could be increased by a similar effect to the IQZE. But, effectively, what we would need to be looking for in the brain are structures that have some type of oscillation that could be directly linked to a behavioral response.

BMSS. The NO needs to be interacting with BMSS to be a candidate for where the mind meets the brain. BMMS needs to have some sort of predictability, i.e. it needs to be periodic (though its specific dynamics may be very complicated. Furthermore, BMMS interaction with NO has to provide a preferred basis of measurement that allows for the increase in activity of the NO if a mind observes it.

The neural system NO+BMMS constitute the locus on which mind interacts with matter in a CCC model consistent with Stapp's.

5 Conclusions

In this paper we examined Stapp's model of interaction of the mind with brain using the CCC interpretation of quantum mechanics. We discussed some constraints associated with Stapp's model, and argued that some very specific dynamics for brain structures need to emerge, if the mind were to affect the brain structures according to its volition.

These interaction constraints, together with the dynamics, should provide a way for us to investigate the existence of structures that allow for the interaction of the mind and brain, and would be indicative of Stapp's model.

We should emphasize that a major assumption was made in this paper, which is that the mind interacts with matter in the brain. It is quite possible that the mind actually does not interact at all in the brain, or not even in the structures that we identified as NO and BMMS. Such structures could, in principle, get entangled with other environmental components, and the interaction of the mind with those other components would lead to the same type of outcome: a control of matter from a non-physical mind. However, the interaction with other components would have to be done in a way that could keep the independence of each BMMS associated to distinct NOs and diverse behavioral outcomes. I.e., the NO associate with moving my right arm would need to be isolated, from a quantum perspective, to the oscillators associated to moving my left arm. So, this suggests that the mind observations happen at a very local level, and clearly at an unconscious way.

Another issue that is important to mention is related to Wigner's friend. If we were to identify the structures in question, and then allow them to be observed also by an external observer (the experimenter), it would be possible, in principle, that this external observer would have an effect. For example, let us say that we can pinpoint the NO+BMMS associated with rising a participant's right leg. If we were to observe this oscillator, with no physical interaction with it other than, perhaps, a weak interaction that would entangle its quantum degrees of freedom with our mind, we would be able to make the participant's legs rise. In other words, even though the participant did not want to rise their legs, the observation by an external mind caused it to do so.

Finally, the last issue that should be addressed is about the NO+BMMS systems that were not observed. How are those systems prevented from being entangled with environmental variables, such that they are always being measured by the observer, or even by an external observer? Or are there other structures that are observed, and that prevent the quantum coherence to proceed and be affected by external observers?

Though the CCC interpretation is not taken seriously by many physicists, it does solve the measurement problem. And even though one could argue that it cannot be falsified, it does provide some interesting opportunities to think about modeling the mind interacting with matter, e.g. with Stapp's model. These models may provide constraints to brain structures that could be, in principle, observed. Furthermore, as we saw, this types of model raise many important, and falsifiable, questions, the mark of an interesting scientific theory. It is the hope of this article provides some grounds for these types of discussions.

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