Does Consciousness-Collapse Quantum Mechanics Facilitate Dualistic Mental Causation?

Preprint; please cite from published version only

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Abstract

One of the most serious challenges (if not *the* most serious challenge) for interactive psycho-physical dualism (henceforth interactive dualism or ID) is the so-called 'interaction problem'. It has two facets, one of which this article focuses on, namely the apparent tension between interactions of non-physical minds in the physical world and physical laws of nature. One family of approaches to alleviate or even dissolve this tension is based on a collapse solution ('consciousness collapse/CC) of the measurement problem in quantum mechanics (QM). The idea is that the mind brings about the collapse of a superposed wave function onto one of its eigenstates. Thus, it is claimed, can the mind change the course of things without violating any law figuring in physical theory.

I will first show that this hope is premature because energy and momentum are probably not conserved in collapse processes, and that even if this can be dealt with, the violations are either severe or produce further ontological problems. Second, I point out several conceptual difficulties for interactionist CC. I will also present solutions for those problems, but it will become clear that those solutions come at a high cost. Third, I shall briefly list some empirical problems which make life even harder for interactionist CC. I conclude with remarks about why no-collapse interpretations of QM don't help either and what the present study has shown is the real issue for ID: namely to find a plausible integrative view of dualistic mental causation and laws of nature.

Manuscript received 30 April, 2020; Revised versions received 2 May 2020 and 4 June 2020; Accepted 04 June 2020
Journal of Cognitive Science ???, 2020

Keywords: *interactive dualism, mind-body-dualism, substance dualism, property dualism, mental causation, quantum mechanics, consciousness, collapse of the wave function, energy conservation, momentum conservation, laws of nature, Born rule*

1. Introduction[1]

Mind-body-dualism, or sometimes called psycho-physical dualism (hereafter just 'dualism') is the view that the mind is non-physical and as such of a different ontological nature than the physical body. Dualism is certainly the view almost all people standardly hold before coming under the sway of anti-dualistic doctrines (see for example (Bloom 2004)). In philosophy as in science, dualism has for many decades been frowned upon, but in the last 30-40 years it made a strong comeback with many sophisticated philosophical[2] as well as scientific[3] defenses.

Dualism comes in two main varieties: substance dualism (SD) and property dualism (PD). Substance dualism maintains that there are purely mental, non-physical substances (most notably human or animal minds/souls), while property dualism contents itself with claiming that some things (substances or not) have mental properties besides their physical properties, and that those mental properties are in no way reducible to physical properties; in other words, that they are part of the basic property furniture of the world. Both SD and PD can be defended as interactive or non-interactive varieties. By 'interactive' I mean the thesis that the mind has the power to causally influence the physical world in such a way that the course of things is different than it would otherwise have been, along the lines of the slogan "Had the mind not interacted, physical event *e* would (not) have happened". There are also non-interactionist versions of dualism. One is Leibniz's 'pre-established harmony', where the physical and mental worlds run parallel but do not causally affect each other; it is God who established a perfect harmony between the two in terms of a *correlation* (as opposed to *causation*). Another example is epiphenomenalism, where the mind is also causally impotent; causal activity belongs to physical structures only, and while the mind does register what is going on in the physical world (i.e. there is physical-to-mental causation), it cannot interfere with it (no mental-to-physical causation). I hope this suffices to make clear what I mean by 'interactive dualism' (ID). It is ID only that this article deals with.

There are a number of objections against both PD and SD (with the bulk against SD). The presumably most serious one, however, is directed against the interactive versions of PD and SD: the so-called interaction problem. The interaction problem has two facets. One takes issue with the mere idea that something non-physical influences the physical world (sometimes called the 'causal nexus problem'). I shall focus on the other facet, which we might call the 'laws of nature problem'. Whatever you think of laws of nature, no one denies that there are regularities in nature which we call 'laws of nature': positive and negative charges attract (and do not repel) each other, apples fall to the ground (and do not rise into

1 I am grateful to Michael Esfeld, Dustin Lazarovici, Kenneth Augustyn and Brian Pitts for fruitful exchange and consultation and to the John Templeton Foundation for enabling me to visit the summer school "Paradoxes in Quantum Mechanics" of the John Bell Institute on Hvar, Croatia.

2 See e.g. (Swinburne 1996; 2013; 2019; Loose, Menuge, and Moreland 2018; Taliaferro 1994; Goetz and Taliaferro 2011; Baker and Goetz 2011)

3 Averill and Keating 1981; Popper and Eccles 1977; Eccles 1986; Beck and Eccles 1992; Collins 2008; 2011a; 2011b; Cucu and Pitts 2019

the sky), energy and momentum are conserved. Now, by above definition of ID, the mind would make it the case that some of those laws fail in some instances (presumably in the brain, on a submicroscopic scale, but that makes no difference to the point). The concrete objection depends on the type of law that the detractor of dualism thinks is violated.

2. How QM is supposed to facilitate mental interaction

What does quantum mechanics (QM) have to do with all this? The starting point is the collapse view of measurement processes in QM. Suppose an electron in a superposition of spin +½ / -½ in a certain direction (say, x-direction) is measured. Quantum formalism as well as empirical investigations show that the outcomes of spin +½ and -½ occur with a probability of 50 % each; there is simply no predicting what the outcome in the next measurement will be, just that probability. The standard view in QM is that this happens due to a 'collapse of the wave function': prior to the measurement, the Schrödinger wave function of the electron is in a superposition of spin +½ / -½, and the measurement somehow brings about a 'collapse' to one sharp spike, i.e. one of the possible eigenstates with the corresponding value +½ or -½.

Quantum theory is not restricted to the quantity of spin. Position and momentum are other quantities (in QM jargon: observables) of which a quantum system can be in a superposition of. In fact, every definite state (eigenstate) of the position observable is a superposition of the momentum states, and vice versa. The famous Heisenberg uncertainty relation quantitatively links momentum and position in such a way that the more exact the measurement of one of them is, the more uncertain the value of the other will be, and that there is a lower bound of the product of position and momentum uncertainty[4]:

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

The idea is now that the mind, if it could influence spin, momentum or position (or some other observable) within the given constraints, then it could make a difference in the physical world without violating any regularity, simply because there is merely a *probabilistic* (as opposed to a determinate) answer to the counterfactual question "What would have happened had the mind not interacted?" (We will see later on that the probabilistic occurrence of the outcomes poses problems for QM-aided ID). For example, if a certain particle in the brain (or a brain area) were in a superposition of several position states, and if the mind could bring about a state reduction ('collapse') to one of those positions, then it could influence brain processes, provided the submicroscopic change results in a macroscopic effect. (We will see in due course that none of those antecedents is without difficulties). An important corollary

4 The ontological status of the uncertainties is unclear. Some think that it's just a lower bound on the statistical standard deviations of position and momentum measurements (making it an epistemic matter), while others hold that there is as a matter of fact no definite pre-measurement value (making it an ontological matter) (e.g. (Bricmont 2016, 42-44). Bricmont's position seems more conclusive to me, since he offers the 'no hidden variables theorem' (which he also proves) in its support. For the rest of this article, I will assume genuine indeterminacy (as opposed to mere epistemic indeterminacy) for the observable-dyad of position and momentum.

of this mind-induced state-reduction is – or so it is hoped – that conservation of energy and/or momentum is respected, again because momentum (and thereby energy) may have a range of possible values prior to state reduction.

At any rate, we can sum up the view just described as ‘sometimes-consciousness collapse’ (‘sometimes-CC’): the idea that the conscious mind *sometimes* collapses (state-reduces) quantum superpositions in the brain, namely where and when it wills a bodily action (or perhaps a purely mental action such as directing one’s attention to something).

However, the theory that’s been around for much longer is what I call ‘always-CC’. ‘Always-CC’ expands mental influence to *all* quantum objects. In fact, it is one of the earliest interpretations of QM. John von Neumann (1932) first pointed out that the strict application of the quantum formalism entails that conscious observers end up in a superposed, indeterminate state when observing a superposed quantum object; but no conscious observer ever seems to have experienced such a state of ‘superposed phenomenal experience[5]’. This dilemma is the so-called measurement problem. Eugene Wigner (1967) took up Von Neumann’s thread and claimed that it is our non-physical consciousness (note: I shall henceforth use ‘mind’ and ‘consciousness’ interchangeably) that brings about the state reduction (= collapse). Let us call this view ‘always-CC’, since it claims that whenever a state reduction takes place, it was a non-physical mind that brought it about.

It is important to note that always-CC is designed to explain phenomenal experiences, not actions. But of course, if always-CC is correct, then actions are no less caused by the state-reducing influence of mind than phenomenal experiences, on the plausible assumption that the physical structures involved in action (most notably the brain) are subject to the laws of QM. If true, always-CC would constitute a deep connection between mind and matter. In fact, defenders of always-CC claim that QM is at best a pragmatic, unsatisfactory piecemeal theory which can only be made complete by incorporating dualistic mental influence. However, there are other ways to solve the measurement problem (of which some are mentioned briefly in section 6), and that therefore dualists are not limited to always-CC for an account of an influence of mind on matter. Moreover, CC faces some difficulties which I will address in what follows.

5 I speak of ‘phenomenal experience’ rather than of ‘perceptions’, because perception is a success term and should be reserved for those instances of phenomenal experience where the experiences forms a perceptual belief.

3. No conserved quantities

Let's first deal with the hope that a CC theory deflects the objection[6] that interactive dualism violates conservation laws[7]. I will show that it is far from clear that CC can do this.

Take the position wavefunction $\Psi(\mathrm{x})$ of a spinless particle, with just one spatial dimension for simplicity. It indirectly represents (via $|\Psi^2(x)|$) the probability distribution of the particle being in places along the x-axis. This is nothing but a superposition of positions; standard QM has it that it is a genuinely ontological matter that the particle is not in one precise place, but just has a certain probability $P(x)$ of being there (see fig. 1).

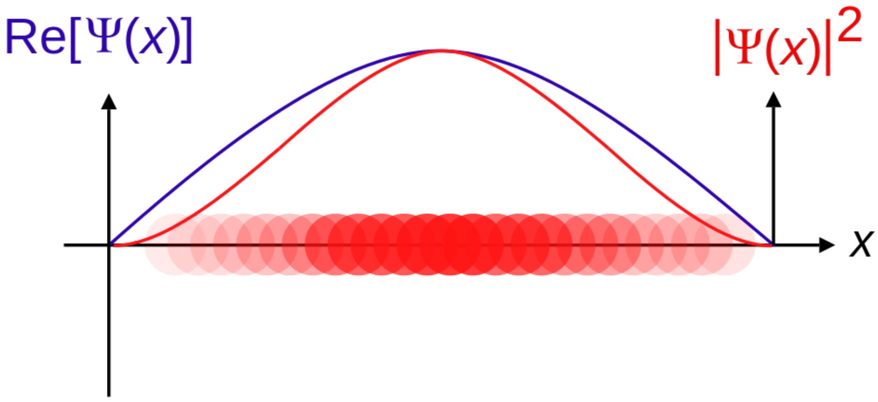

Fig. 1: Standing wave for a non-relativistic single particle in a box. The blue curve depicts the real part of the wave function, and the red curve the squared wave function, representing the probability density of particle position. This is also illustrated by the particle shades below – the more opaque, the higher the probability. (Image adapted from: Maschen / Wikimedia / Public Domain)

Now suppose a collapse of the wave function occurs. Immediately after the collapse, the $|\Psi^2(x)|$) (position probability distribution) curve looks like in fig. 2:

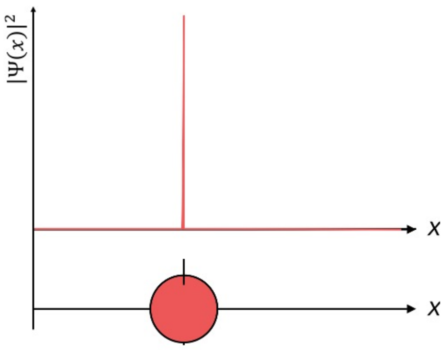

Fig. 2: Squared wave function after a position collapse. The particle is perfectly localized, represented by the spike. (Image adapted from: Maschen / Wikimedia / Public Domain)

6 The objection is that interactive dualism violates energy(-momentum) conservation and is therefore impossible (cf. (Dennett 1991; Westphal 2016; Flanagan 1991; Searle 2004). The objection is almost never stated precisely or adequately and can be fended off easily by realizing where conservation laws derive from (Cucu & Pitts 2019).
7 I comply here to the usual terminology, although it may be that energy and momentum conservation should be credited the status of 'principles' rather than 'laws' (cf. Collins 2008).

This means that the position of the particle has now become definite. But via the uncertainty relation, a decrease in position uncertainty entails an increase in momentum uncertainty (and, since momentum ($p = mv$) and (kinetic) energy ($e_{kin} = \frac{1}{2}mv^2$) share the same basic quantities, an increase in kinetic energy uncertainty).

It is not immediately clear what to make of this. All we've established so far is that a collapse increases either energy-momentum or position *uncertainty*. To understand better what a collapse does to energy-momentum conservation, let us consider a particle in a superposition of energy eigenstates, say $c_1|E_1\rangle + c_2|E_2\rangle$. The Schrödinger dynamics will conserve the modulus squares $|c_i|^2$ and thus the (pre-measurement) expectation value $\langle\Psi|H|\Psi\rangle = |c_1|^2E_1 + |c_i|^2E_2$. However, what if a collapse occurs? Then, the system will collapse onto either $|E_1\rangle$or $|E_2\rangle$, and the possible values are E_1 or E_2, and energy seems not to be conserved.

Several replies are possible. One might hold that the particle had no pre-measurement energy-momentum value at all. However, this anti-realist view looks more like 'ostrich tactics' with the purpose of eschewing any ontological commitment. If a plausible scientific realist view can be found, I submit that it should be preferred. And indeed, there are at least three. First, one might assume that the system had either E_1 or E_2 all along, and that the measurement just brought forward the true value. The problem is that such definite pre-measurement values seem to be excluded by the no-hidden-variables theorem (see fn. 3), which is why I already rejected this assumption. Second, it might be held that conservation laws apply to closed systems only, and since a measurement entails that the measured system isn't closed any longer, energy conservation need not hold for that system. But of course, open systems exchange energy with their environment, and energy conservation can be formulated via the energy density in- and outflux across the system's borders (see Pitts 2020). Hence, energy conservation does hold, and there must be a matter of fact as to where energy came from (or went) if a measurement changes the energy state of a system. A third possibility is to claim that energy is conserved on the 'ensemble' level. The idea is that if one measured a large number of identically prepared systems, one would get as a mean value (at least approximately) $|c_1|^2E_1 + |c_i|^2E_2$, which corresponds to the expectation value $\langle\Psi|H|\Psi\rangle$.

In the following, I shall work with the third understanding of energy conservation in quantum systems. Gao (2017) offers an account along those lines. According to it, energy is conserved at the 'ensemble' level, i.e. at the level of an ensemble of identically prepared systems. Such conservation obtains if "the probability distribution of energy eigenvalues [manifests] itself through the collapse results for an ensemble of identically prepared systems. This means that the diagonal density matrix elements for the ensemble should be precisely the same as the initial probability distribution at every step of the evolution" (Gao 2017, 136); in other words, if no quantum information is lost throughout evolution and collapse. However, in Gao's theory, the collapses and their frequency are explained wholly physically, without any recourse to minds. Does mind-induced collapse conserve energy at the ensemble level?

To answer this question, it is helpful to examine another mind-independent collapse theory, the GRW[8] theory. Roughly, on GRW, wave function collapses occur stochastically; also, the particle localization is 'imperfect' (the position spike still has a certain width around a collapse center) and obeys a Gaussian distribution (concerning the position of the collapse center). What is clear is that collapses in GRW do not conserve energy-momentum at the ensemble level. This is primarily because energy superpositions do not collapse to eigenstates. Now, is CC more akin to GRW or to Gao's account? This is not clear. It might be that consciousness-induced collapses conserve energy-momentum at the ensemble level, although this is would be an additional constraint to mental action besides the Born rule. It might also be that the collapses are more of a GRW type (i.e., failing to conserve energy at the ensemble level) and thus plausibly preserve complete freedom for mental interaction. Therefore, on the understanding of energy conservation endorsed here, we seemingly have reached a dilemma that can only be solved through a trade-off: either sacrifice *complete* freedom of action or energy-momentum conservation. Of course, this dilemma might not arise if one of the other understandings of quantum energy conservation are true.

At the same time, we probably need not worry about any such dilemma, or even if there indeed is one, I urge that we can solve it by going for the latter option: accept violations of conservation laws. Energy-momentum conservation is not as sacrosanct as philosophers tend to think. The physics community doesn't seem to have a problem with GRW *because of failures of conservation principles*[9] – implying that physical theory can accommodate theories which violate those principles –, so it might as well accept another conservation-violating collapse theory. Support comes from the fact that physical theory construes conservation principles as conditional statements rather than as unconditional ones, at least for Lagrangian theories in classical physics, but apparently also in quantum mechanics[10]. The conditionality is constituted by the Noether theorems (Noether 1918; Goldstein 1980, ch. 12-7): iff a system possesses continuous space (time) translational symmetry, then there is momentum (energy) conservation, and vice versa. This implies that failure of conservation can simply occur if the antecedent of the conditional statement is not satisfied – period. In fact, it is accepted that energy-momentum conservation in Noether's sense can be violated if space translation is not homogenous (as is the case in

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8 Acronym referring to its founders, the Italian physicists Ghirardi, Rimini and Weber.
9 A serious worry, though, is that the parameters of the 'spontaneous collapses' in GRW need to be within certain confines in order to not lead to too much energy gain and thus to 'global warming' (see also (Feldmann and Tumulka 2012)). At any rate, there does not seem to be an in-principle problem for physicists if energy/momentum conservation didn't hold in spontaneous collapses.
10 Quantum field theory books often start with Noether's theorem, which suggests that the relation between symmetries and conservation laws is both largely true and important in quantum field theory. Also, in Feynman diagrams, energy and momentum are exactly conserved in each diagram. (I am indebted to Brian Pitts for this hint; e-mail conversation)

concepts in General Relativity). With this 'conditionality response' (Pitts 2020; Cucu and Pitts 2019) the dualist can fend off any objection specifically targeting energy-momentum conservation).

However, this won't in general please physicists, for they will presumably be worried about a deeper point, namely the regularity of nature and the status of laws of nature. After all, if the temporal and spatial symmetry of nature – in other words, the principle that the laws 'governing' the behavior of physical objects are the same in all places and at all times – fails in some places and at some times, what of the idea of laws in general? And even if it can be made plausible that in the vast majority of times and places the laws hold (and fail only very seldom), what of the idea of 'laws of nature'? What law of nature could possibly accommodate such, even though infrequent, capricious behavior? In fact, there are answers to this question, but a treatment goes beyond the scope of this paper. At this point, it has to be acknowledged that the concept of laws of nature poses a *prima facie* problem for ID. GRW, by contrast, is in far less trouble with respect to laws of nature. Here is why: the GRW theorist has two options for integrating his theory into a regularity view of laws of nature. The first is to say that spontaneous collapses just happen, with a certain probability, and that this is simply a law of nature, primitive and not further explainable. The second option is to claim that the spontaneous collapses can be explained by a deeper, undiscovered law of nature. An interactive dualist, however, cannot make either of those moves, at least if he wishes to grant the mind independent causal powers (more on that later).

Another defense of the failure of QM-aided ID in respecting conservation principles is that although violations happen, they are too gentle to be detected. This could be the case if consciousness-collapses reduce the wave function in a 'smooth' GRW manner (in GRW the parameter of post-collapse peak width is chosen so as to not generate empirically disconfirmed 'global heating'). Thus, we may gain the impression that brains perfectly comply to the laws of nature, although, undetectable by us, non-physical minds cause irregular behavior. This may yet be the case (in fact I believe it to be so), but it completely misses the point: in dealing with failures of conservation principles/laws of nature, we deal with an ontological question, not an epistemological one. If conservation failures occur, no matter how small, the law-based argument against ID takes off, and the dualist needs to defend his position at the level of laws of nature in general, not at the level of specific conservation principles. It should also be noted that a GRW-type collapse leaves 'tails' in the wave function which create theoretical and philosophical problems (cf. (McQueen 2015)).

In summary, the interactive dualist's hope that mental interaction through CC conserves energy-momentum stands on shaky ground. A possible solution would be to construe quantum energy conservation to hold at the ensemble level (perhaps along the lines of Gao's theory), but this might entail a significant restriction of the freedom of mental interaction. Either way, ID needs to address the issue of natural laws, even though it is equally clear that the specific principles (or 'laws' if you wish) of momentum and energy conservation pose no threat to it. Thus, one important motivation for seeking a QM-aided account of ID is considerably weakened.

4. Conceptual problems for CC

In this section, I argue that sometimes-CC as well as always-CC suffer from conceptual difficulties, that is, problems concerning the internal coherence of the theory. Empirical problems will be addressed in the next section. The conceptual problems apply to sometimes-CC as well as to always-CC, though of course our interest focusses on interactive sometimes-CC.

4.1 CC is mysterious

One objection often raised by physicists is that 'consciousness' cannot be part of a physical theory, and hence contributes nothing to the elucidation of the physical processes underlying a measurement. On the one hand, if consciousness is, as proponents of CC claim, *ex hypothesi* non-physical, it cannot find a place in physical theory. On the other hand, even if consciousness is somehow linked to physical systems, for example to a supervenience basis, then it is still problematic to make it part of quantum theory, because its connection to the physical basis is at best very poorly understood. Therefore, the complaint goes, stipulating consciousness as the cause for wave function collapse verges on mysteriousness.

4.2 Problems posed by the Quantum Zeno Effect

4.2.1 Making CC accessible for physical theory

In order to fend off the mysteriousness objection, more needs to be said about how the mind 'measures' quantum objects (measurement being the process that leads to wave function collapse). In particular, one needs to link non-physical consciousness to brain structures in such a way that it becomes available for physical theory. The best way to do this I can think of is via a physical correlate of consciousness[11] (PCC). For a PCC we need assume no more than a systematic *correlation* between physical states of the brain and conscious states. In particular, no commitment to any metaphysical view about the relation of mind and brain[12] is required. However, it is important that the correlation reflects a genuine dependence of mental (conscious) states on brain states. Otherwise, it seems difficult to speak of a PCC in the sense relevant here, for then any given neural state might be instantiated without consciousness. The systematicity (which does not preclude multiple realizability!) also seems crucial to enable us to cast consciousness collapse as a rigorous theory (as it seems there can be no scientific theory without some degree of systematicity in the correlation of two parameters).

11 The bulk of the literature deals with neural correlates of consciousness (NCC). PCC include NCC and thus have the advantage of keeping the search for correlates of consciousness more open.
12 The three most important ones being supervenience, grounding, and emergence (identity is, of course, out of the question for dualists).

What exactly is a PCC? I shall use David Chalmers's (2000) definition in an adapted way[13]:

A PCC (for content) is a minimal physical representational system P such that representation of a content in P is sufficient, under conditions C, for representation of that content in consciousness.

The addition 'for content' is important, because we are not interested in a correlate for the general property of *being conscious* (as opposed to being in a coma, for example), but in a correlate for certain *contents* of consciousness (in this case, volitions). What is meant by 'representation'? If I see an apple, the content is 'apple'. Neural activities appropriately correlated with my seeing-an-apple are a physical representation of that content, and of course my experience of an apple is a conscious representation of the apple. It should also be noted that above definition suspends judgment on causal relations. It does not say that a certain representation of a content in P *causes* a representation of that content in consciousness (or the other way around), but it certainly leaves that possibility open.

What could P be? It could in principle be a certain anatomical brain area, but it might also be 40-hertz oscillations in the cerebral cortex (Crick and Koch 1990) or a field generated by the brain (Libet 1994). Of course, different proposals pertain to different aspects of consciousness, so not all of them will be equally viable for our purposes here. However, I am not concerned with those details here; all we need is a candidate for P which allows CC to be formulated more rigorously.

The next question we need to tackle is to which extent the content of P is mapped onto the content of consciousness. In particular, will a superposed P be mapped onto a superposed consciousness (*modulo* consciousness-caused collapse)? If it does, a CC theory must find an explanation why consciousness in fact never seems to be superposed. If it fails to do so, the whole project should be dropped and we are back with the 'mysteriousness' objection. I shall assume that the aforementioned correlation does hold. Without having too much space to argue for this, here is why: in order to make the role of consciousness accessible for physical theory, we need to claim a strict (though perhaps multiply realizable) correlation of P-states with consciousness states. The physical collapse will then be caused by a property of P (or P *tout court*, if P *is* the collapse-causing property, see below) which is strictly mapped onto some property of consciousness (both of which, as we will see, must at least statistically resist superposition). But then *some* P-properties (or P itself), if they can enter superposition at all (due to their being physical properties), will, when in superposition, correlate with consciousness properties (or consciousness *tout court*) in superposition, due to the strict mapping.

Thus, we can sum up the relation between states of P and states of consciousness as follows:

13 Chalmers focused on neural correlates of consciousness (NCC) in the cited article. I replaced 'NCC' by 'PCC' and 'neural' by 'physical'.

superposed P → superposed consciousness[14]

and

definite P → definite consciousness

4.2.2 CC and the m-property framework

Let me next clarify the interplay between measurements and the evolution of undisturbed quantum objects. Measurement in the language of QM is what leads to definite states (and results). In terms of a wave function diagram, a measurement turns the extended 'hill(s) and valley(s)' of a wave function into one sharp peak (at least in case of a collapse onto an eigenstate, which I shall assume here). Such a process (if it indeed takes place) is a disruption of the temporal evolution of the wave function dictated by the dynamical Schrödinger equation.

It is important to note that the Schrödinger dynamics is *deterministic* (*not* probabilistic!) and *unitary* (roughly, it preserves all the information contained in the wave function across time). The collapse, by contrast, is *non-unitary*, i.e. it 'destroys' most of the information contained in the wave function prior to the collapse, by reducing the multitude of possible values contained in the wave function (corresponding to a superposition of states) to just one. After a collapse, the Schrödinger dynamics again determines the evolution of the wave function, until the next measurement/collapse.

Spelling out a physically viable theory of CC requires an explanation of how the mind 'measures' superposed brain structures. The most elaborate approach I know of is the one by David Chalmers and Kelvin McQueen[15]. They propose the existence of 'm-(measurement-)properties'. An 'm-property' (or 'm-observable' or 'm-quantity') is characterized as follows:

- There can be no superposition of an m-property => a system's wave function is always in an eigenstate of the operator of this property
- Whenever an m-property is about to enter a superposition (via entanglement with a superposable property of another physical system), it collapses to definiteness
- The probabilities of the collapse are given by the Born rule for the associated m-operator

In the framework used here, an m-property must of course be a property of a PCC; in fact, as I understand Chalmers and McQueen, the m-property *is* a the PCC. Which properties might be m-properties? In principle, any physical or mathematical property is a candidate. There are at least two constraints, however: (1) an m-property must not be too common, so that there is room for superpositions (otherwise collapses could not occur); (2) an m-property must not be too rare, so that measurements (which always

14 The arrows signify entailment.
15 I refer to drafts available on the internet (Chalmers and McQueen 2014 - draft planned for an anthology that is due 2020); an overview of the different drafts can be found on http://consc.net/qm/ (accessed 2020/04/30)).

yield definite results) always involve m-properties. Constraint (1) rules out at least position, mass or very common atoms or molecules. Constraint (2) suggests that m-properties must be present in brains. For now, just to get an idea how m-properties work, let me briefly present an illustrative toy model. Suppose an m-property has two eigenstates, $|m_1\rangle$ and $|m_2\rangle$ with eigenvalues μ_1 and μ_2, respectively, and that the structure possessing the m-property is in state $|m_1\rangle$. Suppose further that a particle in a superposition (of observable p) of $\pi_1|p_1\rangle$ and $\pi_2|p_2\rangle$ gets entangled with our m-system. The (fictitious) superposition

$$|\Psi\rangle = \mu_1|m_1\rangle\,\pi_1|p_1\rangle + \mu_2|m_2\rangle\,\pi_2|p_2\rangle$$

results, which will in fact not occur. Rather, there will be an instantaneous collapse onto either $|m_1\rangle|p_1\rangle$ or $|m_2\rangle|p_2\rangle$.

4.2.3 CC and the Quantum Zeno effect

The main problem for the m-property theory stems from the application of the so-called Quantum Zeno Effect (QZE) to m-properties. The QZE roughly consists in quantum systems becoming 'frozen' in one state if they're being measured in very rapid succession[16]. Some have thought the QZE conducive to interactive dualism, arguing that the mind could, through a fusillade of measurements, hold certain brain structures – which would otherwise 'smear out' according to the Schrödinger dynamics – in one definite state and thus trigger actions (Henry Stapp is perhaps the most famous proponent of this theory, see a.o. his 2017).

Alas, it is not so easy. Remember that an m-property cannot enter superpositions of its values. This means that by itself it cannot evolve, at least if we take the Schrödinger evolution as a basis (which requires constant, though changing, superposition). And if consciousness is strictly correlated with an m-property, then it cannot evolve either, at least not by itself. But this seems unacceptable – surely our consciousness constantly evolves, i.e. changes. On the other hand, if we allowed (*contra* the initial hypothesis of m-properties) consciousness to go into superposition, we would get the similarly implausible result of a non-definite consciousness.

A first way out of this dilemma could be to stipulate a different physical dynamic for m-properties, one that does not entail constant superposition[17]. Perhaps this is a viable proposal, but I don't know which dynamics could be adequate. I'll leave the idea for further exploration.

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16 Rigorous definition of QZE: "If system S is in eigenstate E of some observable O, and measurements of O are made N times a second, then, the probability that S will be in E after one second tends to one as N tends to infinity."
17 I am indebted to Dustin Lazarovici for this suggestion.

Another option is to propose that consciousness can change once it interacts (gets entangled) with other physical systems. Via the QZE, the impending superposition would instantly collapse. If it could collapse to its initial state only, then we would again get a frozen consciousness. But as my above toy example shows, there is no need for the superposition to collapse to the initial eigenstate of the m-operator; it could as well (with a probability given by the Born rule) collapse onto one of the other eigenstates. Thus, we get an evolving consciousness, albeit one that evolves in discrete steps rather than continuously. Is this plausible? It depends on two things: (1) whether such a 'jumpy' evolution is compatible with our first-person conscious experiences; (2) whether the m-property can have enough eigenstates.

(2) should not be a problem. Take the position operator: it might have infinitely many eigenstates (or a continuous spectrum of eigenstates) or (if space is discrete) very many eigenstates. This could similarly be the case with the m-operator. As to (1), it needs to do justice to our conscious experiences by excluding gaps and indefiniteness in the stream of consciousness. The 'discrete evolution' theory clearly disallows indefiniteness (which is a problem for the 'approximate m-property' account, see below). Regarding gaps one might argue that, provided the quantum leaps from eigenstate to eigenstate take (very little) time, this short intermediate period constitutes a gap.

It is hard to make an informed judgment about this, since we simply lack background knowledge. Comparing the stream of consciousness to a movie is of no help here. We experience a movie as continuous (rather than as what it actually is, a rapid succession of pictures) because of limitations of our visual system, but more importantly we experience a movie *in our consciousness*, while it is nonsense to say that we experience *consciousness itself in consciousness*. While we have experiences of both continuous-appearing and discrete sequences of pictures, we have no experience of a continuous vs. a discrete consciousness. At least it is not obvious that an ontologically discrete stream of consciousness is at odds with our experience. Furthermore, there is still the option that the m-operator has infinitely many eigenstates (or a continuum thereof), which certainly supports 'gap-less' consciousness.

McQueen and David Chalmers[18] have their own way out of the quantum Zeno dilemma. They call it 'approximate m-properties'. The idea is inspired by the GRW theory. An approximate m-property is thus a property whose superpositions *stochastically* collapse (as opposed to *always collapse*, like in absolute m-properties discussed above). Chalmers and McQueen suggest that the collapse frequency depends on the size of the superposition; the more superposed the m-property is, the more probable a collapse becomes. Their favorite candidate for an m-property is integrated information as it figures in Integrated Information Theory (IIT). Simply put, their theory has it that the more integrated information (the more consciousness) accumulates in a brain, the more probable a collapse onto a definite state of the m-operator (and, by implication, of the physical substrate, and of consciousness) becomes.

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18 (K. McQueen, n.d.)

I must admit that I find the idea of discontinuous consciousness more attractive. On the approximate m-property approach, there will still be tiny periods of time during which consciousness is superposed and hence indefinite. But presumably none of us ever experiences 'superposed consciousness'. Are the superposition periods so short that we don't experience them? Perhaps, but, again, consciousness is not something *of which* we can be aware but the one thing *through which* we can become aware of things. Therefore, I take it that we could not fail to experience even short superposition periods. On SD, there is the additional question whether or how a non-physical *mental substance* can be superposed. If it cannot, this would unduly exclude SD from being a viable position.

Dualists, at least those who are committed to a sufficient ontological independence of mind from matter[19], can take a completely different route, namely posit a total independence of consciousness dynamics from brain dynamics. This ensures complete causal autonomy for the mind, but it is also highly implausible – within the framework of CC, *nota bene*. First, neuroscience has provided ample evidence for mind-brain correlations. Plausibly, the evidence so far leaves room for a partly independent mind dynamics, especially when it comes to actions. But this option is barred on always-CC, since no definite brain state can hold without consciousness. Thus, the dualist who wishes to combine independent mind dynamics with CC must take the more radical step towards a *complete* independence of mind from brain. But this is also implausible: suppose the brain goes into superposition, but the mind does not (presumably cannot). Can this state of affairs last? If yes, the combination of definite consciousness & indefinite brain suggests that having a brain is not a necessary condition for either phenomenal experiences or actions. This possibility cannot be dismissed out of hand, perhaps near-death experiences (NDE) show that this is possible. But note that in NDE, on a substance dualist reading, people leave their bodies. Maybe free-floating souls don't need brains for phenomenal experiences, but embodied souls almost certainly do. If, on the other hand, the divergent state cannot last, it will have to be ended by the mind collapsing the brain onto a definite state. But this takes us back to where we started, namely to the brute assertion that non-physical minds collapse quantum superpositions, with no further elucidation.

4.3 Free actions in danger?

Let's take stock what we have seen so far. If a dualist wishes to hold onto CC to explain mental causation and make the theory rigorous, he needs to find a way out of the quantum Zeno dilemma. The best option here is, in my view, to posit discontinuous 'measurements' of the mind via m-properties. This seems superior to the 'approximate m-properties' view which implies short periods of superposed consciousness.

19 In particular, supervenience and perhaps some grounding relations seem to be excluded, because they tie mind dynamics to closely to brain dynamics.

There are, however, two big challenges for both accounts.

The first one is the question of causal efficacy. Does the mind really play a *causal* role, such that some events happen at least partly because of a causal contribution of the mind, or is it just 'consciousness dangling from physics', where the physics does all the causal work? On PD, causal efficacy is guaranteed if the mind/consciousness is identified with the relevant m-property. Since it is (causally) *because of that property* that collapses in the brain occur, one can confidently speak of the mind being causally efficacious. On SD, however (as well as on any variant of PD that distinguishes between mind and bearer of m-property) things look different. It seems that a combination of such dualism, CC and a dependent mind-dynamics entails that the mind is causally impotent. Here's why: as pointed out, it is because of certain states of an m-property (actual or impending superposition) that a collapse occurs. On SD, the mind is distinct from the physical basis with its m-property; the mental states merely supervene on brain states. Hence, the mind just 'tracks' what is going on in the brain, but its causal contribution is exactly zero. Causal efficacy for the mind can of course be attained by positing independent mind-dynamics (and thereby dissolving supervenience), but we have already seen that this leaves us with an unsatisfactorily brute account.

The other question is that of causal independence. By 'causal independence' I mean what other authors have termed 'being the ultimate author of one's actions' (Moreland and Rae 2000), 'being the producer of one's actions' (Hasker 1999) or 'self-movement' (Gasser 2015)[20]. In effect, this is nothing but our commonsense conception of free will: I can generate actions/mental events "*ex nihilo*"[21], without being caused (deterministically or indeterministically) to do so by anything external (ultimate authorship condition), and I can choose between alternative actions/mental events without being externally tied down to one of them (alternate possibilities condition[22]). Now, is the mind, on one of the outlined CC theories, causally independent in this sense? We have already seen that this is not possible on a CC/SD combination, since on this view the mind is causally inefficacious and *a fortiori* cannot be causally independent. On PD, things are a bit more complicated. At first glance, it might seem that the mind cannot be causally independent, for it is the m-property that is doing all the work. But all the m-property framework says is that (impending or actual) superpositions collapse to one of the m-eigenstates with a probability given by the Born rule. *Prima facie* this does not prevent the mind from making some causal contribution to the *direction* of the collapses. But now we have to be careful how to spell this out. First, it seems to me that we need to distinguish between *observation* and *action*. I assume that it is wildly implausible to claim that observers somehow 'choose' whether an electron goes spin up or spin down,

20 One should think that 'agent causality' suffices, but there are many views figuring under that label which clearly assign far less causal independence to the agent than I have in mind here (e.g. (R. Clarke 2000; Chisholm 1976; Kane 2011)).

21 I chose this strong expression to delineate the view proposed here from other, weaker views of agent causality, which at first glance speak no less of the agent being the cause of her actions. For example, Clarke (2011) claims that the agent is a co-cause besides her reasons; Swinburne (2013) holds that it suffices for agent causality that the agent complete the otherwise insufficient physical causes.

22 Some philosophers have attempted to show that this principle is not a necessary condition for free will (e.g. (Frankfurt 1969). I take those attacks to be unsuccessful (cf. Swinburne 2013, ch. 7.6).

but that an agent choosing his action is exactly what we want to get at. So we could propose that in observations, the mind is causally efficacious but not causally independent, while in actions it is both efficacious (regarding the collapse direction) and independent. A possible complaint against this is that it sounds ad hoc. After all, the underlying mechanism is the same in both cases, which suggests an equal treatment: either the mind is merely causally efficacious in both cases, or it is causally independent in both cases. But this disjunction is unsatisfactory, since the first disjunct precludes genuinely free actions, and the second disjunct posits an implausible 'Jedi' power of choice over what happens in the physical world.

Let's grant for the sake of argument that the mind can have different causal roles in observation and action as outlined above. It then follows that the mind directs the collapses. But doesn't this run counter to quantum theory and physical theory in general? At least not obviously, and not in all respects. Remember that we allowed for some theoretical role of consciousness in the first place. Then suppose that consciousness is an m-property. Do we know *in what manner* this m-property brings about collapses? We don't. The collapse process is a 'black box' for us. It might as well be that the box contains the effects of conscious volitions. One could still object that the introduction of m-properties was meant to naturalize consciousness by making it accessible for physico-mathematical theory, and volitions elude the grasp of physics and mathematics. But this objection fails to acknowledge that the naturalization of consciousness does not annihilate its phenomenal nature; to the contrary, it must preserve it, on pain of ceasing to be a theory of phenomenal consciousness. In fact, naturalistic theories of consciousness try to model features of phenomenality and often center on the concept of information (see e.g. (Chalmers 1996; Tononi et al. 2016). Hence, I conclude that claiming causal independence of the mind does not violate the spirit of a naturalistic CC theory.

There is one restriction for the causal independence of the mind, however, at least if one wishes to stay on safe ground in physical theory: the Born rule. The Born rule is a mathematical postulate that fixes the probability of outcomes of measurements of a superposed quantum system, and it is experimentally very well confirmed. For example, it follows from the Born rule that an electron in a superposition of spin-up and spin-down (relative to a given axis) will with a probability of 0.5 go up or down in a magnetic field, respectively; and indeed, doing sufficiently many (say 10,000) measurements with prepared electrons yields probabilities of the two possible outcomes close to 0.5 each. If a CC version of ID is to respect the Born rule, then the relative frequency of a given type of outcome must converge to the value given by the Born rule. For example, if the m-operator has four eigenvalues, the relative frequency of each corresponding outcome will converge to 0.25 in case of a uniform superposition (with equal weights of the superposed states), or, more generally, to a number depending on its individual weight (while the relative frequencies/probabilities must add up to 1). In other words, it is simply not possible that, in the long run, a certain action/action type (corresponding to a certain eigenvalue of the m-operator) occurs in 40% of instances of willings[23], given a uniform superposition (*mutatis mutandis* for non-uniform superpositions).

How much of a restriction of freedom is this? We should halt here for a moment and realize that we've reached a crucial point. The Born rule can reasonably be called a law of nature. Thus, if mental causation does not respect Born's rule, a law of nature is violated. We should then in principle be able to detect those violations in brains. An independent issue is how to construct the notion of 'laws of nature', if such violations are possible. I will briefly gesture towards this point in section 6.

But back to the question: how mutilated will freedom come out if mental causation respects the Born rule? This will depend on the number of eigenvalues associated with the m-operator in conjunction with the possibility of multiple realizability. The more eigenvalues, the more 'destinations' there are for a collapse process. However, there must also be multiple realizability, that is, a certain action (type) needs to be realizable by different brain states (corresponding to different eigenvalues). This is because even if there are many possible target states of a collapse process, it should be ensured that a number of them (not just one) leads to a desired action; otherwise, volitions and body movements would frequently come apart. But those two conditions (multiplicity of m-eigenvalues and multiple realizability) seem to be just necessary, not sufficient conditions. After all, a multiplicity of eigenvalues distributed over redundant brain states just raises the probability of the desired action being carried out; it does not guarantee it. It might still happen, with a certain probability, that I endeavor to raise my arm, but end up with stomping my feet. I presume that such aberrations are extremely rare, and that there are good physiological (as opposed to quantum mechanical) explanations for them. Therefore, it seems that a CC theory of ID cannot afford to allow inherent action failures.

A proposal of how to reconcile free will and CC comes from Henry Stapp, one of the most prolific writers on this subject. I cannot do justice to his ample work here, especially because his theory seems to have evolved over the years. What I am going to do is draw mainly on his most recent work *Quantum Theory and Free Will* (2017), focusing on the most relevant points for ID.
Stapp divides the causation of a free action into three processes[24]. Process 2 is the Schrödinger dynamics, process 3 the probabilistic collapse process, and process 1 the mental influence. He conceives of process 1 as a Y/N question, e.g. "Am I moving my finger?". The link to the brain as a quantum object consists in every volume V of a brain's state space having a discrete observable with the values Y and N. David Bourget (Bourget 2004, 9) succinctly sums up this view as follows: "A measurement of this observable for some V yields a positive outcome if the brain is in V and negative otherwise. There should thus be

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23 By 'willing' (or volition) I mean here the mental state that either constitutes the actual carrying out of the (conscious) action or inevitably (physiological failures notwithstanding) leads to the action. In other words, a conscious raising of my arm couldn't happen if I didn't will it in the sense here under discussion. By contrast, an expression of will like in "I want to watch a movie tomorrow night" is *not* what I mean by 'willing'.
24 In his 2017, Stapp speaks of two processes (1 and 2) only. Although this is his most recent advance, it is still legitimate to depict him as assuming three processes, since he divides process 2 into two phases (2017, 8).

a measurement that can tell us if a brain is in one of the many possible states in which any decision has been made." In other words, in contrast to my suggestion concerning the m-properties account above, Stapp is multiplying observables rather than eigenvalues. It is important to note that for Stapp, the two pivotal points for free actions are processes 1 and 3. Process 1 determines the 'question'[25], and process 3 (probabilistically) determines the answer, thereby not – it seems – strictly observing the Born rule. He writes: "In the quasi-orthodox theory nature's choices are not random, hence lacking a sufficient reason to be what they are, but are assumed to have sufficient reasons that entail a biasing of nature's choices in favor of choices that advance the personal values of the subjects in these experiments who are posing the questions pertaining to matters of interest to themselves." (2017, 99-100). The (in my view) insurmountable difficulties of integrating values into a physical theory notwithstanding, it may well be that already at this point, Stapp's theory breaks the Born rule, something he emphatically excluded in earlier writings (e.g., (Stapp 2004)). Be that as it may, on Stapp's account, each 'question' the mind may ask in order to trigger an action corresponds to a 'projection operator' belonging to an observable[26]. Now, the values of those observables are subject to the Schrödinger evolution (process 2) and thus the probabilities of receiving a 'Yes' or 'No' answer, respectively, depend on the point of time of the question. Put simply, the probability for a desired answer (Y/N) to a certain question rises to its possible maximum (0.5) within a certain time limit (call it T_S), only to result in a collapse (without the mind's interference) and re-rise of the probability within the next T_S period (see fig. 3). What the mind now does, according to Stapp – not, *nota bene*, collapsing the wave function – is to 'hold in place' the collapse outcome (in case it was the desired one) via the QZE, for time period T_a.

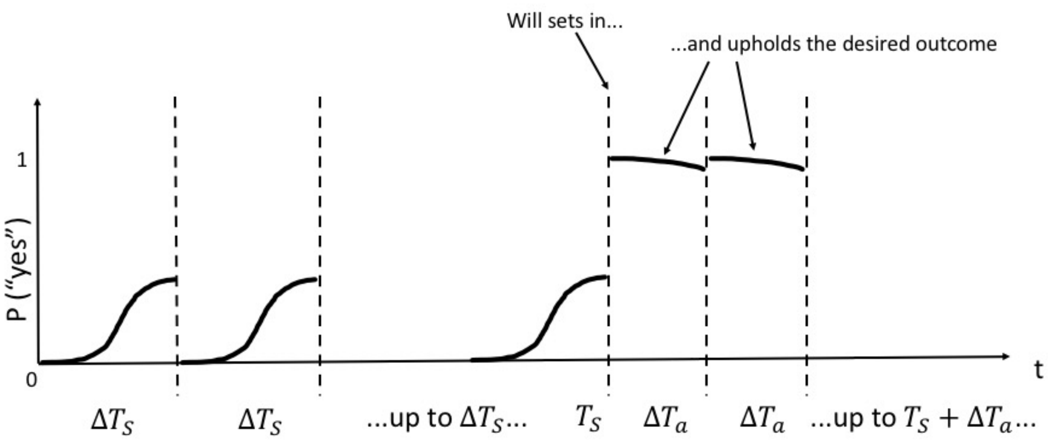

Fig. 3: Process of enforcing a free decision according to Stapp. The vertical axis represents the probability that a collapse to the 'yes' state occurs upon measurement (here it is assumed that the state is the desired one). Dashed lines mark actual events.

25 According to the most recent version in Stapp 2017. He held this already in his (1999), then intermittently retracted it.

26 „The detailed psychophysical rules that are presumed to fix or determine the projection operator P (which defines the empirical question) are not yet known, and I have made no basic commitment concerning the form of those rules." (Stapp 2004)

In the above example, the will sets in at T_S and upholds the probability of the desired outcome at ~1*. (Own creation after fig. 3 in Bourget 2004)*

Stapp's account can be criticized in several ways. First, his conception of 'mental measurements' as empirical questions is awkward and implausible. Asking a question simply does not seem to be what is going on when we will an action (perhaps a case can be made for phenomenal experiences being construed as a 'Q & A game', but I doubt that). There is no introspective evidence for this claim, and simply re-christening volitions as questions won't do, not least because we can clearly distinguish between the mental events of questions and of volitions. But admittedly, not much hinges on how one construes the mental events initiating actions; perhaps one could just claim that volitions as directed to one outcome are successful only to the extent to which the Born rule allows it. Nothing essential would be lost by dropping the 'Q & A' talk.

Another, more serious concern is that free actions may have to wait, since 'nature's answer' to an 'action request' can be negative. This stands in contradiction to our daily experiences. Stapp seeks to evade such an obvious discrepancy by making mind-matter-'communication' exceedingly rapid; for example, he holds that many 'Nos' can occur without any passage of time (2017, ch. 2) and that the mind can transmit information faster than light (2017, ch. 6 + App. A). I leave to physicists to judge whether all this is tenable and whether his rejection of 'no superluminal transmission' does not run up against the no-signaling theorem[27].

A third objection is that Stapp's account entails ubiquitous deviations of actions from will. David Bourget (2004) argues to this effect. As sketched above, the mental interactions are bound to time frames T_S. Within one instance of T_S, the mind can send a finite number of 'requests' for a wave function collapse in the desired direction. Bourget assumes that T_S should be at most 100 ms, this representing the empirically discovered lower threshold for the individuation of *complex* conscious events ((Varela 1997); coincides with Libet's 'urge' (Libet et al. 1983; Libet 1999)); and that T_a is in the order of 20 to 50 ms, this representing the lower threshold for simple conscious events to be perceived as separate in time (Kristofferson 1967; Hirsh and Sherrick Jr 1961). Under those assumptions, 2 to 5 attempts of doing an action are available per timeframe. With the *ex hypothesi* stipulation that the probability of the desired response is 0.5 at each attempt, we get a probability of between 0.03 (for 5 attempts) and 0.25 (for 2 attempts) that the desired action fails. It seems clear that even a ratio of 3 failed actions per 100 are highly implausible. Stapp has replied to this criticism in the following way: "[T]he events in a rapid sequence generated by a willful effort are not perceived as separate in time. They all run together, and their rapidity is associated with the feeling of effort. I have never found any reason why the temporal separation between the events experienced in this run-on way could not be a fraction of 1ms, if their rapidity is controlled by conscious effort." (2004, 7) Apparently, he rejects the construal of single

27 The no-signaling theorem (or no-communication theorem) is a no-go theorem from quantum information theory which states that, during measurement of an entangled quantum state, it is not possible for one observer, by making a measurement of a subsystem of the total state, to communicate information to another observer.

conscious efforts as simple conscious events falling under the 20 to 50 ms restriction. Indeed, we plausibly don't experience willful effort as a rapid sequence of events, but Stapp's analyzing conscious effort into many quantum-mechanically relevant single events is currently just a hypothesis in need of corroboration. So, the difficulty here may after all not be insurmountable.

The fourth objection is one of two problems of CC having to do with decoherence. Decoherence means the leaking of quantum information from a system to its environment, which could only be prevented by perfect isolation (including very low temperature). Brains, however, are of course open systems, heavily coupled to their environment. In any case, decoherence times in brain structures are short by the standard of time frames of our conscious lives (in the order of $10^{-12}s$ or even significantly less, depending on the exact structure in question). Whether or not decoherence times constitute a difficulty for quantum-aided mental causation will be discussed in section 5.3. Here, we will deal with a different problem arising from decoherence. As David Bourget (2004) argues, decohered states can and should be thought of as *improper mixtures*. Improper mixtures are quantum superpositions, albeit without the ability to generate interference effects. Thus, the mind could still wield its quantum influence on the brain.

There is a significant drawback, however. Decoherence construed this way entails that the brain is entangled with a host of external systems and that brain regions relevant for a given action are entangled with irrelevant ones. But this means that superposition collapses of brain structures must encompass the entangled systems beyond the brain as well. Applied to action, this implies that conscious effort directed at a bodily action would have *direct* consequences for physical structures beyond my body. Proponents of telekinesis should not rejoice prematurely, however. After all, a *directed* manipulation of one part of an entangled system via the other part is forbidden by the no-signaling theorem. Also, there doesn't seem to be good evidence for even random influence of mental volitions on physical objects outside the body.
More importantly even, the entanglement of relevant brain areas with irrelevant ones raises the question why only the relevant ones (e.g. the SMA[28]) collapse. This is clearly a problem for accounts like Stapp's that construe NCC as specific brain areas, but even if one went for a neurologically more unspecific PCC, the difficulty might persist. In the m-property framework, even if an m-property is not a neural property, its causal role will ultimately bring about the collapse of neurons that trigger actions. It seems we are again faced with an unpleasant dilemma: either (if this is physically tenable) one construes decoherence as the complete loss of superposition and thus runs into the problem of far too short decoherence times; or one preserves the superposition character, only to face the problem of undesirable entanglements. This dilemma seems to be a problem for CC accounts in general.

28 Supplementary motor area

4.4 Summary of conceptual problems for CC

We have seen that in order to evade the mysteriousness objection, CC needs to be made physically rigorous. I presented a way how this could be done, inspired by Chalmers's and McQueen's theory. The QZD seems tractable, but two other problems are more severe. First, the Born rule stands like a monolith against all attempts to make CC compatible with libertarian free will. A solution of this problem requires at minimum a theory of laws of nature that adequately accommodates the required violations. Second, there is the problem of undesired entanglements, a problem specifically created by Stapp's theory which sets out to reconcile quantum theory with free will.

At this point, one may legitimately ask why QM should be invoked at all. Note that above difficulties arise if one takes into account all aspects of QM, and not just the ones (seemingly) conducive to one's theory. Since the those problems also pertain to the 'classical' version of CC (designed to explain definite conscious *experiences*), one may well ask if one should not look for a better QM interpretation, quite independently of ID. In conjunction with the possible failure regarding conserved quantities, the list of motivations for CC grows thin. For CC in the service of ID, at any rate, there are also empirical problems beside the conceptual ones. We will look at some of them in the next section.

5. Empirical problems

5.1 Energy-time uncertainty doesn't leave enough leeway

In one of the first serious attempts to show that QM-aided ID is viable, Beck & Eccles (1992) calculated that an object as heavy as six hydrogen masses could be moved by the mind within the confines of the momentum-position uncertainty relation. As indicated in section 3, there are several positions as to what the uncertainty relation actually describes; but let us, *arguendo*, assume that it captures an actual, ontological indeterminacy.

Eccles's and Beck's calculation is based on the equations of the quantum mechanical zero-point energy E_0 and the thermal energy E_{th} of the model system. The idea is that if $E_0 \gg E_{th}$, the particle is in the 'quantal regime' (with quantum effects dominating over classical effects), while it is in the 'thermal regime' (with classical effects preponderating) if $E_{th} \gg E_0$; finding the borderline between both regimes would then be tantamount to obtaining the critical mass a particle can maximally have while falling under the quantal regime. With $T = 300K$, $\Delta q \cong 1$ Å the borderline equation $E_0 = E_{th}$ yields a critical mass of $m_c \cong 6m_H$. And indeed, if the mind could shift around a particle that heavy without violating energy conservation, this would support ID. However, as we've seen above, energy-momentum conservation is not guaranteed in this case. Furthermore, Wilson (1999) has contested Eccles' and Beck's claims. His calculations, based on the time-energy uncertainty relation, yield a time period during which the breaking of one single hydrogen bond could go undetected[29] of $\Delta t < 3.2 \times 10^{-15}s$ – much too short for any relevant neurophysiological process (like ions passing through a channel) to happen.

29 No matter what further ontological conclusions one draws from the uncertainty relation, it is clear that it denotes a limit of detectability.

(Those processes are rather in the order of milliseconds ($10^{-3}s$)). Conversely, if one picked a reasonable (though conservative) time period like $10\ ms$, one ends up with an 'energy leeway' of $5.2 * 10^{-30}J$, which is 200,000 times smaller than a Van der Waals bond and thus much too little (see (P. G. H. Clarke 2014)).
Beck (1996) has presented a slightly enhanced account, where he holds on to the 1992 result but additionally calculates a signal time for quantal processes of about $30 * 10^{-12}s$, which comes relatively close to Wilson's result, and is well in the order of recent calculations of ion decoherence times in protein channels (V. Salari et al. 2011; Summhammer, Salari, and Bernroider 2012; Salari et al. 2015; Summhammer, Sulyok, and Bernroider 2018). In fact, the just-cited 2012, 2015 and 2018 papers even argue that decoherence times in the order of picoseconds are beneficial for ion transmission through protein pores, and that the transmission dynamics could not be explained without recourse to a quantum model of ions. (The import of this for dualistic mental causation will be discussed in section 5.3). All in all, it seems that Wilson's result stands on firmer ground. Apart from the uncertainty equation, he uses only one quite conservative assumption (one hydrogen bond[30]), while Eccles and Beck work with the additional notions of thermal and quantal regime. I'll leave the final verdict to the physicists. Perhaps, one more plus on Wilson's side is that his equation directly targets the more relevant quantity of energy (momentum isn't conserved either way). At any rate, what can be said about Eccles' and Beck's proposal is that it is not watertight.

Recently, Georgiev and Glazebrook (Georgiev and Glazebrook 2014) have undertaken an attempt to salvage Eccles's and Beck's basic idea. By their time, it was already established knowledge that vesicular release of neurotransmitters into the synaptic cleft is an exocytotic, protein-mediated process (Jahn and Fasshauer 2012) - not the product of the state change of a metastable paracrystalline vesicular grid, as Eccles (Beck and Eccles 1992; Eccles 1994) assumed. The main protein complex involved in vesicular exocytosis is called the SNARE complex. Glazebrook and Georgiev hypothesize that a 'quasi-quantum particle' – a *soliton* – might propagate along the 4-alpha-helix-bundle of the SNARE complex and thus trigger exocytosis which is foundational for neuron firing. The posited soliton is assumed to have 5% hydrogen mass, which would allow it to tunnel through potential barriers of 1-2 nm width, which seems to correspond well with the conformational situation in a SNARE complex. As support for their hypothesis, they offer three arguments:

- Solitons are not a quixotic idiosyncrasy of theirs. A so-called Davydov soliton (Davydov 1973; 1977) has been posited as an explanation for the actin-myosin interactions in muscles.
- Their model is temperature-dependent, which is also true of SNARE proteins. The model thus looks more realistic than electron tunneling (apparently proposed by Beck 1996) which is temperature-independent.

30 The smaller the energy, the larger the time interval. One could replace the hydrogen bond with an even weaker bond type, the Van der Waals force, which has a bonding energy of 0,5-5 kJ/mol (H bond: 20 kJ/mol). But this would increase the time frame by 4 to 40 times, which is still by far not enough.

- Glazebrook and Georgiev claim that 'vibrationally assisted tunneling' (under which the soliton action would fall) "has been experimentally proven for the action of a number of enzymes with dehydrogenase activity" (Glazebrook & Georgiev 2014, 20).
- The hypothesis is experimentally testable: replacing hydrogen atoms in SNARE proteins with deuterium atoms[31] should have a clear effect on the probability of synaptic vesicle release.

This certainly looks like an interesting approach. Further work is needed to make the soliton hypothesis more robust; as of now, it is not much more than speculation. At any rate, even if this succeeds, the other problems with quantum theory outlined above remain. But perhaps, after all, what we need is just a locus in the brain where gentle, possibly undetectable interactions can take place, and quantum theory with its restrictions and strict formalism is more ballast than help.

5.2 Amplification of quantum effects is doubtful

As we've seen, the uncertainty relations allow (if anything) only for effects which by themselves seem much too weak to make any difference in the brain. It has been suggested, therefore, that those tiny leaps might be amplified by (deterministic!) chaos in the brain (Hobbs 1991; King 1991; Hong 2003; Kane 1996). In fact, there is little doubt that chaotic behavior actually occurs in the brain (Korn and Faure 2003; Tsuda and Fujii 2007; Battaglia and Hansel 2011). There are, however, some major problems with the combination of quantum events and chaos.

First, the very existence of 'quantum chaos' is doubtful (Bishop 2008).This has to do with the Schrödinger equation, which mathematically predicts 'quantum suppression of chaos' (Hobbs 1991; Koperski 2000). A more general problem is that (in fact irrespective of the means of amplification) one needs to be able to specify precise initial conditions. At least on some interpretations of QM (in particular, the very collapse theories under discussion here), the notion of precise pre-measurement conditions is void of meaning. Third, a chaos-amplified quantum-ID would have to translate the directed collapses (whose plausibility is debatable, see above) at the quantum level into macroscopic effects – whether this is plausible is at least unclear. Fourth, the noise-resistance of the brain constitutes a further difficulty. Brain cells, like cells in general, are quite resistant to thermal fluctuations, which are about one billion times stronger than quantum fluctuations (Clarke 2014, 115). Hence, *a fortiori* brain cells should be resistant to quantum fluctuations. If, by contrast, they're not, it then seems that thermal fluctuations will be amplified as well, something we do not observe. The solution is of course to posit low-energy quantum events in rapid succession (like (Beck 1996; 2001; 2008)), a proposal whose problems we have already seen.

31 Deuterium ($^{2}_{1}H$) is a heavy isotope of hydrogen ($^{1}_{1}H$).

5.3 Do we have empirical evidence for relevant quantum effects in the brain?

Of course, all conceptual investigations of CC-ID are fruitless if there *empirically* are no relevant quantum events in the brain which the mind could make use of. In many fields of biology, the existence of a host of quantum effects, ranging from bacteria through the animal kingdom to the human retina (see (Jedlicka 2017; Al-Khalili and McFadden 2015; Gehlert 2019)), has been proven. This raises the prior probability of their occurrence in human brains. But do we have evidence for them?

One central issue in this context are decoherence times. If they are too short for a given biological structure in the brain, quantum effects seem be drowned in thermal noise and doomed to irrelevance. For about ten years, Max Tegmark's (2000) calculations concerning ion transmission through the cell membrane and microtubules were taken to be decisive. He arrived at decoherence times of $10^{-20}\ s$ to $10^{-13}\ s$, which is thought to be far too short to make any difference to neuronal function. However, in the past decade, some new simulation studies (esp. Summhammer, Salari, and Bernroider 2012; Salari et al. 2015; Summhammer, Sulyok, and Bernroider 2018) suggest that (1) decoherence times for ions in protein channels are shorter (in the order of $10^{-12}\ s$), that (2) a quantum-mechanical behavior as well as quick decoherence are even beneficial for ion conduction through channels, to the extent that conduction dynamics could hardly be explained without those factors, and that (3) the quantum model even explains the selectivity (at high throughput!) of the channel.

Remains the question what to make of this. First and foremost, the model speaks of decoherence, not of collapse; these are different things. Perhaps, in so far as collapse entails decoherence, mind-induced wave function collapse is what accounts for decoherence. Second, the model is about a K^+ pore in bacterial cells, not in human neurons, so applicability to human Na^+/K^+ pumps would have to be shown. Third, even if the model could be transferred to human neurons, it is not clear where mental action should set in. At the level of the ion wave packet? This seems unnecessary, since according to the model, the ion 'sneaks' through the channel (Summhammer, Sulyok, and Bernroider 2018, 9) and 'needs no further help'. At the level of ion velocity, thereby increasing the portion of ions with sufficient kinetic energy? This is not only completely independent from the channeling model, but also re-imports the issue of energy conservation. At the level of the protein (constituents)? On the one hand, the ion quantum dynamics seem sufficient to explain their passage through the tunnel, and on the other hand, the plausibility of mental manipulation decreases with the size of the objects. Perhaps influencing single oxygen atoms (as in Summhammer et al.'s model) will suffice, but that is presently just speculation.

All in all, the recent advances in quantum biochemistry have raised the plausibility of quantum effects in the brain, but likewise left dualists will little to make of it: in an 'in-out' superposition setting (as in Tegmark 2000 and Beck and Eccles 1992), the mind can influence the outcome probability in one direction (problems with the Born rule notwithstanding). In the recent 'quantum tunneling' model, the ions basically help themselves, and no mental influence seems possible without betraying the very motivation of CC-ID.

6. Why no-collapse interpretations of QM don't help, and what the real issue is

I think by now it should be clear that CC does not give the interactive dualist a 'free lunch', but, to the contrary, creates more problems than it solves. One might ask whether other no-collapse interpretations of QM are of any help. It should be noted from the outset that they lack the collapse process interactive dualists have put their hopes in, since it appeared to leave some 'gaps' in nature the mind could fill. However, as we've seen, on closer inspection, CC-ID faces the issues of non-conserved quantities and the Born rule, issues that no-collapse interpretations do not even pretend to avoid. In fact, an important no-collapse theory (Bohmian mechanics/BM) makes quantum dynamics wholly deterministic[32] and thus offers no more help to ID than classical mechanics. And that is not all: two other important no-collapse interpretations – the Many Minds Theory (Albert and Loewer 1988) and the Many Worlds Theory (Everett 1957) – require quite extravagant ontologies. I have no space here to treat those approaches adequately, but it is to be expected that they make life for the dualist harder, if anything.

I conclude that the real problem an interactive dualist needs to solve is how to reconcile his view of mental causation with laws of nature. For example, does it make sense to claim that the Born rule holds in all physical systems except those that undergo mental influence? If physical dynamics should turn out to be wholly deterministic, how do construe mental interaction be construed at all, without violating laws of nature? And even if dynamics were (partly) probabilistic, it seems that one needs to 'choose one's poison': either make ID laws-complying and bite the bullet of giving up on libertarian freedom or accept that probabilistic laws fail where minds intervene. So, the real question is how we should construe laws of nature in a way that gives both physics and mental causation their due. This is where interactive dualists should put their efforts.

32 There is a probabilistic element in BM, but it is located in the initial conditions of particles. The dynamics of particle movement is completely deterministic (see (Bricmont 2016, ch. 5; Oldofredi et al. 2016)).

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