Turning the Tables on Physicalism: the Energy Conservation Objection to Substance Dualism as a Two-Edged Sword

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Introduction

The aim of this paper is threefold:

(1) to show that the objection from energy conservation is a 'non-starter'

(2) to show that energy is probably *not* conserved in the brain during volitional actions

(3) to show that physicalism faces a formidable challenge, given (2).

1. The EC objection: a proper formulation

It is widely believed that the principle of energy conservation[1] (PEC) poses at least serious difficulties to substance dualism. Interestingly, though, it is difficult to get a proper formulation of that 'objection from energy conservation' (OEC)[2]. I will here directly proceed to what I believe to be an adequate formulation of OEC:

1) Substance dualism implies that during at least some brain events, the brain's energy changes without there having been a physical cause for that change.
2) It is impossible that the total amount of energy in the physical universe change. (PEC)

C Therefore, dualism is false. (by *modus tollens*)

I deliberately formulated PEC as a strong modal claim because, as has been argued elsewhere[3], a *factual* claim à la "The amount of energy in the universe *is* constant"[4] seems to be too weak for a physicalist case against dualism.

Applying modus tollens, one could also conclude:

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1 Though less prominent, momentum conservation is often employed in a breath with energy conservation. In fact, the earliest science-based objection against substance dualism appealed to momentum conservation (Garber 1983). Given their close physical relatedness, I will treat energy and momentum conservation together, where applicable.

2 For example, what is presented under the label of OEC is often a version of the 'causal nexus problem'. See e.g. Dennett 1991, 34-35; Mcginn 2000, 92; Westphal 2016, 41-44.

3 For example (Larmer 2009, Larmer 2014; Plantinga 2007; all pertaining to divine interactions); see also (Von Wachter forthcoming) for a parallel and closely related reasoning with respect to the causal closure of the physical world.

4 Searle 2004, 42

C' Therefore, 2) is false (i.e. energy conservation does not hold categorically).

C'' Therefore, 1) is false (i.e. substance dualism does not imply that any brain event occurs under violation of PEC[5]).

I will in turn argue that C' is the conclusion to be drawn, because modern physics supports *factual* energy conservation, not the *modal* claim that energy is *necessarily* conserved[6]. This opens up to dualists the 'conditionality answer'[7]: energy is conserved in a brain on the *condition* that no mind is acting on that brain.

2. Energy conservation in modern physics

Energy conservation derives in the first place from the first Noether theorem[8], which can be rendered informally as:

> If a system has a continuous symmetry property, then there are corresponding quantities whose values are conserved in time.

And its converse:

> If in a system there are quantities whose values are conserved in time, then there is in the system a corresponding continuous symmetry property.

Logically speaking, the Noether theorem entails a biconditionality between continuous symmetry and conserved quantities:

Continuous symmetry ↔ conserved quantity(ies)

Another way of checking energy (and momentum) conservation is by using the Lagrangian[9] and the Euler-Lagrange equations[10]. Fortunately, though, we do not need to do those calculations here, because energy and momentum conservation can be read off the Lagrangian: Energy is conserved if the variable t (time) does not figure in the Lagrangian[11]; momentum is conserved if

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[5] See e.g. Ducasse 1960, Broad 1937, Lowe 1992, Collins 2008; Collins 2011.

[6] With respect to the closely related question of the causal completeness of the physical world, Sophie Gibb (2010, 366) writes: "[I]f Completeness is a working hypothesis of current physics, then it is one that is left wholly implicit – the principle is not referred to in any physics textbook." (See also Papineau 2000, 184-185).

[7] Pitts 2018

[8] Noether 1918; Goldstein 1980, ch. 12-7

[9] The Lagrangian is a functional that satisfies the principle of least action. In physics, it is used to reformulate classical mechanics problems with generalized coordinates.

[10] The Euler-Lagrange equations are second-order partial differential equations whose solutions are the functions for which a given functional is stationary. The Euler-Lagrange equations are used to calculate the solutions at which a given Lagrangian is 'stationary', i.e. the system's action is 'most' or 'least'.

[11] i.e. if the Lagrangian does not explicitly depend on time.

none of the variables x, y or z (place)[12] figure in the Lagrangian[13]. Consider the following simple example[14]; it consists of a particle with mass m moving one-dimensionally (z-axis) in the gravitational field of the earth[15].

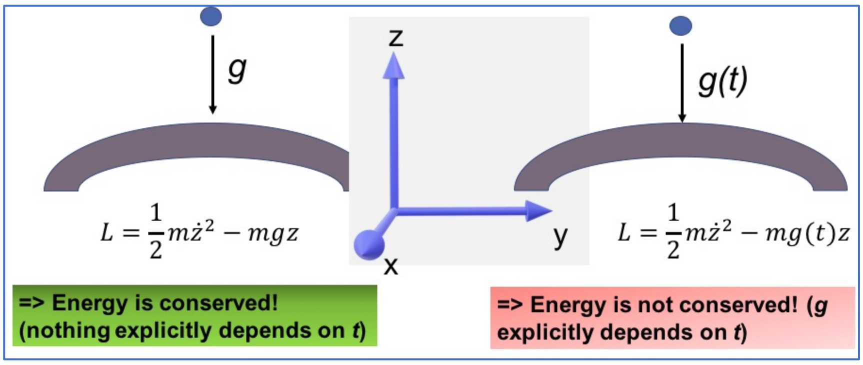

Figure 1: Particle in one-dimensional gravitational field

Since g is indeed a constant, i.e. time-independent, the Lagrangian of the system is

$$L = \frac{1}{2}m\dot{z}^2 - mgz$$

Nothing in this equation explicitly depends on t, so energy is conserved[16]. However, if g were a function of time, the Lagrangian would change into

$$L = \frac{1}{2}m\dot{z}^2 - mg(t)z$$

Now, something in the Lagrangian, namely g, explicitly depends on time; thus, as can be verified by calculation[17], energy is not conserved.

We can see the connection between continuous symmetry and Lagrangian mechanics by way of another simple example. Suppose two spheres with finite mass collide:

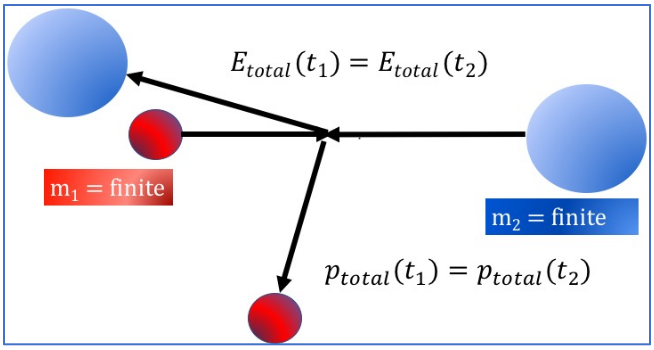

Figure 2: Collision of two spheres with finite mass

[12] There may be one, two or three spatial variables in the equation, depending on the n-dimensionality of the system in question.
[13] i.e. if the Lagrangian does not explicitly depend on place.
[14] cf. Pitts 2018
[15] Whose 'acceleration constant' is the familiar $g = 9.81\frac{m}{s^2}$.
[16] In fact, momentum is not conserved, because this Lagrangian explicitly depends on place (z); if one integrates the momenta of the earth and the gravitational field, it turns out to be conserved.
[17] cf. Pitts 2018

As can be calculated with simple classical equations, momentum[18] and energy[19] are conserved in this system.

We can also understand the conservation of momentum and energy by applying the Noether theorem:

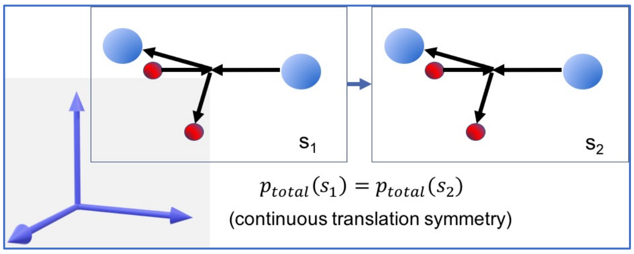

Figure 3: Space translation symmetry of the two-spheres system

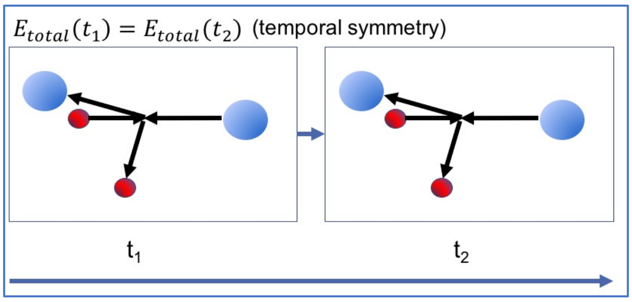

Figure 4: Time translation symmetry of the two-spheres system

Roughly speaking, since the system can be continuously moved[20] in space without any change in the Lagrangian description[21] of its elements, momentum is conserved (figure 3). Likewise, since the system can be continuously 'moved' in time without change, energy is conserved[22] (figure 4).

How the mind could make energy conservation fail: a simple model

Dualistic mental interactions are said to violate energy (and/or momentum) conservation. We can reconstruct such interactions again with a 'toy model':

[18] $m_1\,\vec{v}_1(t_1) + m_2\,\vec{v}_2(t_1) = m_1\,\vec{v}_1(t_2) + m_2\,\vec{v}_2(t_2) => p_{total}(t_1) = p_{total}(t_2)$

[19] $\frac{1}{2}m_1\,{v_1}^2(t_1) + \frac{1}{2}m_2\,{v_2}^2(t_1) = \frac{1}{2}m_1\,{v_1}^2(t_2) + \frac{1}{2}m_2\,{v_2}^2(t_2) => E_{total}(t_1) = E_{total}(t_2)$

[20] Which is a symmetry operation.

[21] Of course, the spatial coordinates change; but the main advantage of a Lagrangian is precisely to give a coordinate-independent description of a physical system.

[22] In more technical terms, momentum conservation depends on space-translational invariance (= symmetry) and energy conservation depends on time-translational invariance.

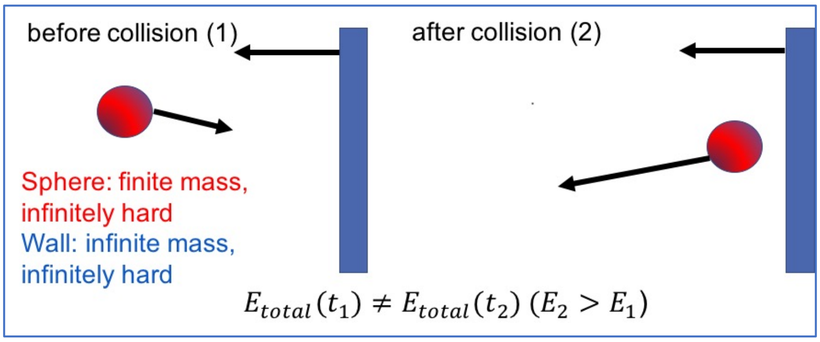

Figure 5: 'Toy model' of mental interaction with a massive object

Of course, the sphere's kinetic energy increases over time; the kinetic energy of the wall, however, is at all times *infinite* (due to its infinite mass[23]), which means that there cannot be a sensible Lagrangian description of the sphere-plus-wall-system. In other words, the wall is really *no part of the system*. Thus, the overall energy of the system increases in time. Put differently, the system (i.e. the sphere alone) is neither continuously symmetrical with respect to space nor with respect to time[24]; thus, in accordance with the Noether theorem, neither energy nor momentum are conserved.

This simple model seems to be a close analogy for mental interactions, because just like the infinitely heavy wall, the mind cannot be described physically/mathematically in any sensible way. It could be construed as a non-physical 'out-of-system' agent which acts on the system (i.e., the brain), thereby breaking spatial and temporal symmetries and changing energy and momentum.

In summary, I take it to have shown that conservation principles, being rooted in the Noether theorem, are conditional: they hold in a system *on the condition that* no non-physically-describable entity (e.g. a mental entity) interacts with the system. Therefore, premise 1) needs to be modified to

> 1)' The amount of energy in the physical universe remains constant[25] if no non-physically-describable entity interacts with any part of the universe. (cPEC)

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[23] One obtains non-relativistic kinetic energy by calculating $E_{kin} = \frac{1}{2}mv^2$. With infinite mass, one obtains $E_{kin} = \frac{1}{2}\infty v^2 = \infty$.

[24] Spatial asymmetry can be seen by moving the light sphere horizontally; its spatial relation to the out-of-system-wall (even if it stood still) then changes. As regards, temporal asymmetry, consider the movement of the wall: even if the light sphere stood still, the "sphere alone" system would be different at t_2 from what it was at t_1.

[25] Global energy conservation, i.e. conservation in the whole universe, can be obtained if and only if the surface integral (obtained as the volume integral of all energy fluxes $\frac{dJ_x}{dx} + \frac{dJ_y}{dy} + \frac{dJ_z}{dz}$) of the whole universe becomes zero; but there are ways in which global energy conservation can fail (Pitts 2004a, 2004b, 2009). At any rate, since global conservation derives from local conservation, it does no harm to my conclusion.

with cPEC being the 'conditionality principle of energy conservation'. But of course nothing like the refutation of dualism follows from such a weak premise. Hence, I take it that OEC fails – in fact, that no interesting version of OEC is even possible. The physicalist might grant this and yet insist that dualism is implausible, because energy just *is* conserved in brains. But to my knowledge this is not an empirically established fact. Therefore, I would like to make a tentative rough estimate using current neuroscientific knowledge.

3. Is energy conserved in brains? An experimental outline

Recall the main aim of this paper. It goes beyond defending dualism: it is to "turn the tables" on physicalism. By physicalism, I mean the thesis that "every physical effect which has a cause has a physical cause"[26]. Therefore, brains in which energy is *not* conserved constitute a severe problem for physicalist metaphysics, in case the energy change cannot be accounted for by a physical cause.

The specific question I pursue here is

"Is energy conserved in brains during volitional actions[27]?"

By volitional actions I mean those body movements that the subject reports to have 'willed' and which occur independently of external stimuli[28]. Thus, the brain processes involved in those actions come as close as possible to being caused by a putative immaterial mind[29].

To make the check, I suggest the following test:

Energy is conserved in the brain iff either (i) there is an uninterrupted chain of physical causes a part of which lies in the brain and leads to volitional action; or (ii) the uninterrupted chain of physical causes leading to volitional action begins in the brain, but this beginning occurs without expenditure of energy.

Criterion (i) assures that if energy increases locally in the brain, there is a larger physical system which contains a physical cause for the brain's energy increase (such that that larger system's Lagrangian will not explicitly depend on t). Criterion (ii) covers the case in which no preceding physical cause can be found for the energy change. The causal chain then begins with a physical

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26 This is a 'weaker', less demanding of physicalism than the stronger one which claims that every physical effect has a physical cause, thereby precluding some interpretations of quantum mechanics and the possibility of generic 'ontic chance', i.e. effects without cause.

27 Volitional actions are undoubtedly the best context to study energy conservation of brain processes, because volitional actions are particularly suspect of dualistic influence (see Flanagan 1991, 21; Hallett 2007; Swinburne 2013, 136)

28 Haggard 2008

29 Reflexes mostly do not involve the brain and thus, *a fortiori*, they do not seem to involve the (conscious) mind either. Perceptually triggered actions seem to be good candidates for identifying an uninterrupted physical causal chain and thus conservation of energy.

process in the brain which occurs without energy expenditure[30]. In both cases, there is a locus where the causal chain begins *in the brain;* I call this the 'neuro-causal origin' (NCO).

Energy conservation in accord with criterion (i) would be exactly what physicalism predicts; dualism would then seem superfluous as an explanation. However, if energy conservation holds according to criterion (ii), the adjudication between physicalism and dualism must occur on other grounds.

The purpose of the next section is to find possible macro- and microlocations for the NCO.

4. The neurophysiology of volitional action

I take Haggard's (2008) [31] overview to reflect current knowledge of the neuro-causal picture of volitional action. It depicts the causal history of volitional actions roughly as follows:

Basal ganglia (BG)[32] ***→ prefrontal/frontopolar cortex (FPC)***[33] ***→ preSMA → SMA → primary motor cortex → spinal cord → muscles***

Actions triggered by external stimuli take a different path[34].

The study of brain processes is basically carried out by measuring *activity*[35]. No matter which method is used, the regional activity is taken to reflect activity of the neurons in that region[36], which in turn entails a change in energy. Thus, even if the NCO of volitional actions were located in a different brain region than the BG or the FPC, there would always be an energy increase in that region. It is also important to emphasize that "activity increase of neurons" means an *increase in firing rate,* not a transition from a state of complete rest to a state of firing; in other words, neurons have a ground-state (or 'baseline'[37]) of (low-frequency) firing[38].

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[30] Dualists can use and have been using this hypothesis to undergird dualism (see footnote 5).

[31] Haggard considers 'cue-free' studies, i.e. in which the participants were not told when to act. To be sure, some of those studies (e.g. Libet et al. 1983); Libet, Wright, and Gleason 1983) have been criticized for subtly 'nudging' people to act (see replies in Libet 1985), but, following Haggard, I take the results of the formally cue-free papers to be valid, not least because they widely concur regarding the big picture.

[32] See e.g. Picard and Strick 1996; Akkal, Dum, and Strick 2007.

[33] Soon et al. 2008

[34] Haggard 2008., 937; Brinkman and Porter 1979, 703-04

[35] The activity measuring methods include electric potentials (e.g. Libet, Wright, and Gleason 1983; Libet et al. 1983; Deecke and Kornhuber 1978), regional cerebral blood flow (rCBF) (e.g. Roland et al. 1980; Roland 1981; Jahanshahi et al. 1995, 1995), firing rates of neurons ((Fried, Mukamel, and Kreiman 2011) (Brinkman and Porter 1979; J. Tanji and Kurata 1982)(Jun Tanji and Keisetsu 1994) and functional magnetic resonance imaging (fMRI) (e.g. Soon et al. 2008).

[36] For single neuron measurement, this is obvious.

[37] Fried, Mukamel, and Kreiman 2011

[38] See e.g. Stevens 1993

All in all, it seems that the NCO is in the BG and that it involves local energy increase. Whether or not this increase meets either criterion (i) or (ii) depends on what makes the relevant neurons change their firing rate. Let's find possible answers by considering a model chain of neurons.

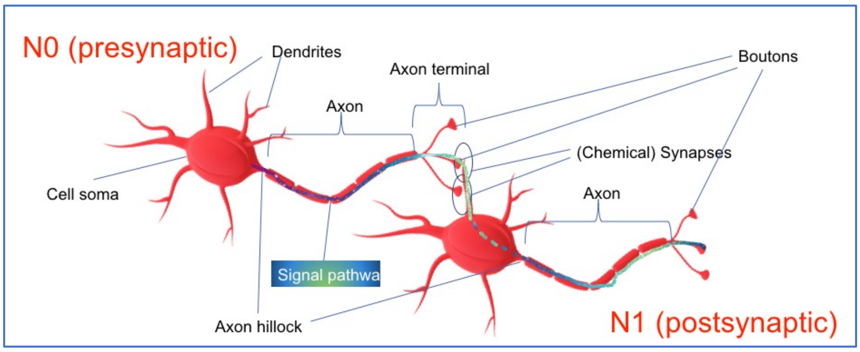

Figure 6: Two consecutive neurons

"N1 fires" means that it issues an action potential (AP)[39], caused by the opening of sodium and potassium (Na^+/K^+) channels. An AP leads to the release of neurotransmitter molecules at the boutons (into the synapse). N1 usually fires when the signals received at the axon hillock cross a certain threshold. This happens when enough excitatory neurotransmitter molecules have bound at the corresponding receptors of N1's dendrites[40]. These neurotransmitters come from the boutons of a presynaptic neuron ("N0").

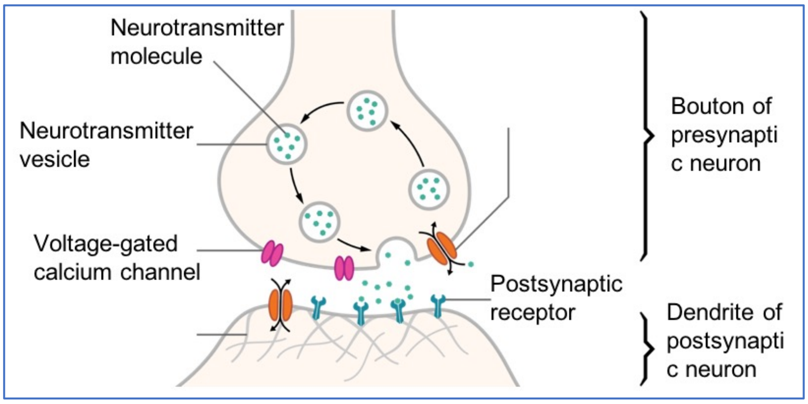

Figure 7: Synaptic communication (Thomas Splettstoesser – CC BY-SA 4.0; altered)

Thus, synaptic transmission works roughly as follows: N0 fires, releases neurotransmitters (NT) which bind to N1's dendritic receptors; N1 fires, releases NT and triggers N2 to fire; and so forth[41]. At any rate, the sequence of synaptic transmission cannot go back indefinitely; it must have a beginning, which, as indicated above, cannot lie in the sensory cells of a sense organ[42].

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[39] A current rapidly traveling down the axon.
[40] There are also *inhibitory* neurotransmitters whose binding leads to an inhibitory postsynaptic potential/IPSP which can 'neutralize' the EPSPs caused by the binding of excitatory neurotransmitters at other dendritic sites.
[41] Of course, neurons do not just form such simple *chains*, but rather complex *networks*. But the sequentiality of synaptic transmission remains the same.
[42] By definition, stimulus-driven actions are not considered; also, the sensory pathway is distinct (cf. Haggard 2008) and, on top of that, mere *intentions* (without any prior sensory input and even without movement) seem to cause activity increase in the brain (Roland et al. 1980).

Therefore, it seems that a number of neurons in the BG or FPC change their firing rate without having been triggered by preceding neurons. What are the possibilities for such a non-neuronally induced NCO, (how) do they conform to energy conservation, and (how) do they square with a physicalist metaphysics?

5. Physicalism's difficulties in accounting for the NCO

The 'pacemaker' hypothesis

One obvious possibility for an NCO meeting physicalist demands are so-called pacemaker cells. These are neurons which regularly self-generate APs due to a cyclic mechanism of ion in- and outflux[43]. However, it is doubtful that such neurons can be found in the brain[44]; also, their activity is one of strict (though perhaps modifiable) regularity, which contradicts the idea of 'irregularly willed' voluntary actions.

Endocrinal hypothesis: regular physiological causation

Some molecules of *endocrinal* origin might bind to the dendritic receptors. This well-known mechanism[45] meets criterion (i): The bonding of such molecules to dendritic receptors does entail an energetic shift (because the protein receptors change their conformation), which in this case is accounted for by a physical cause from outside the brain. However, I am not aware of any brain areas which fit the endocrinal approach. The dopaminergic influence of the substantia nigra (SN) on the basal ganglia[46] unfortunately does not come into question as a candidate for NCO. The SN is not an endocrinal gland, but consists itself of neurons; also, the SN has afferences from the motor and premotor cortices, which means that while it (regulatorily[47]) influences cortical processes, it is itself influenced by the cortex. All this makes it a poor candidate for an NCO.
Of course, further research might find an endocrinal or similar candidate for an NCO. However, it must be noted that endocrinal influences, being modulatory in nature, generally seem to be too slow for volitional actions[48].

Protein conformational change approaches

The remaining proposals all have in common that the conformation of some kind of protein belonging to a neuron is modified. Please note that basically, conformational changes imply energy expenditure[49].

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43 Hille 2001, 147-49
44 In the human body they are known to exist in the heart.
45 Examples of such molecules include hormones (e.g. adrenaline) and neurotransmitters issuing from endocrinal glands (e.g. dopamine). For the generic mechanism of ligand-gated channel opening, see e.g. Unwin 1993.
46 cf. Haggard 2008, 936.
47 Pessiglione et al. 2006
48 Wilson 1999, 191-92; Hille 2001, ch. 20
49 cf. Wilson 1999

One option is that sodium or potassium channels might open spontaneously or be caused to open in a deviating way by the binding of molecules, thereby triggering an AP[50].

By the same token, voltage-dependent Ca^{2+}(calcium) channels in the boutons might open without there having been a prior voltage change (i.e. AP) [51]. It is the calcium influx upon the opening of those channels that causes the release of the NT vesicles from the bouton.

Third, Ca^{2+} might be released from intracellular protein stores[52]. It would then have the same effect as extracellular calcium flowing in.

Fourth, neurotransmitter vesicles might spontaneously be released from the axon terminal by exocytosis, which also requires the conformational change of some proteins[53].

Now, how can a physicalist account the protein conformational changes, preferably such that energy is conserved?

1. **Deviant ligand molecules bind to the endocytotic apparatus of vesicular release (meeting criterion (i)).**

There are indeed substances which activate sodium, potassium, and calcium channels[54], but all of them are pharmacologically active chemicals supplied from outside. As regards vesicular release, there do not seem to be any endogenous substances coming into question to trigger it[55]. The same holds true for calcium release from intracellular buffers.

2. **'Outlier' molecules with kinetic energy far above average hit the triggering structure (criterion (i)).**

Statistical thermodynamics tells us that temperature is a measure for the *mean* kinetic energy of particles and that at any temperature, there are very few molecules far above/below that mean energy. Could not such 'outlier' particles, e.g. water molecules, be responsible for channel opening/vesicular release? They could in principle, but there are problems. First, the frequency of such events, given their low probability, seems to be insufficient to account for volitional

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[50] To be sure, there are so-called ligand-gated sodium channels whose occurrence is, however, restricted to the neuromuscular junction (cf. Hammond 2015, ch. 6)

[51] Normally those channels respond only to *large* membrane depolarizations (Hammond 2015, 151).

[52] The intracellular stores are proteins located in the endoplasmatic reticulum, the calciosome, the mitochondria and the cytosol (the cytosolic stores are lightweight proteins like parvalbumin and calbindin) (ibd., 155). A release of calcium from there occurs normally upon an appropriate signal (e.g. the formation of inositol triphosphate) through Ca-permeable channels. the proteins primarily serve as calcium-*binders* to reduce cytosolic Ca^{2+} (which is toxic in too high concentrations) (ibd., 51).

[53] Südhof 1995

[54] Examples include: Alkaloid-based toxins such as aconitine, batrachotoxin or brevetoxin for sodium channels (Hammond 2015, 68); diazoxide and minoxidil for potassium channels; and Bay K8644 and Ambroxol for calcium channels (Rang 2003, 60).

[55] As an example of a vesicle-release-activating neurotoxin, latrotoxins present in black widow spiders cause *all* of the neuron's vesicles to release their neurotransmitters (Ushkaryov, Rohou, and Sugita 2008). This causes extreme pain and often death.

action. Second, the approach seems much better suited for explaining the baseline firing rate, (which is clearly too low[56]); but if it explains the baseline, it cannot also explain the *increase* in firing rate.

3. **The spontaneous opening of ion channels/vesicular release is to be explained quantum-mechanically (criterion (ii)).**

Beck and Eccles (1992) calculated that the range of the Heisenberg uncertainty suffices for a spontaneous vesicle release to occur without energy expenditure. However, the validity of those calculations has been impugned[57]. But apart from that, the frequency of such quantum events seems too low; they, too, might rather explain the baseline[58]. To fix the account, one might suggest a combination of 'outlier molecules' and quantum events: either outliers explain the baseline and quantum events the increase, or vice versa. The former version is implausible: how can a quantum cause have a greater and more frequent effect in the macroworld than a classical cause? The latter is *prima facie* more plausible, but faces the intrinsic problems of the outlier hypothesis pointed out above.

If in fact energy conservation should turn out to be unavailable, a last option remains.

4. **The spontaneous opening of ion channels/vesicular release is to be explained by ontic chance (no criterion met).**

The above definition of physicalism allows for ontic chance, by which I mean phenomena which are *entirely uncaused* and do not follow any probability distributions. Ontic chance brings the physicalist into even deeper trouble, for an *uncaused* increase in energy/change of direction certainly entails that neither energy nor momentum are conserved. I doubt that any physicalist wishes to go that route, even if he believed in ontic chance in the first place.

There is a last possibility for the physicalist not mentioned so far. It is the idea that energy is somehow *redistributed* within the brain at the time of the initiation of volitional actions. But we need not look too far to see a fatal problem with this proposal: such redistribution violates (linear) momentum conservation, because clearly some particles would have to change their direction 'spontaneously', without there being a physical cause for that change.

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[56] For example, in the absence of an AP, a spontaneous vesicle release in the frog neuromuscular junction is estimated to have a rate of 10^{-2}-10^{-3} times per second and release site, which means it occurs once every 100 to 1000 seconds. (Stevens 1993, 56)

[57] Wilson (1999). In summary, Wilson's own calculations come to the result that within the confines of the Heisenberg uncertainty, the time for ion channels to stay open is far too short to account for sufficient ion influx (ibd., 196-199).

[58] As Eccles (1994, ch. 4, 5) seems to suggest.

Summary

According to modern physics, OEC does not even get off the ground, because energy and momentum conservation hold only *conditionally*.

Empirically, volitional actions begin with a local energy increase. It seems difficult to find a suitable physicalist NCO for that initiation; among the classical causes, a sensory-input-based causal chain seems unavailable, as well as candidates for the endocrinal and pacemaker account. Alternatively, the NCO might be quantum-mechanical and hence entail no energy change. However, the scope of quantum events with respect to local effectiveness and frequency of occurrence is contentious.

Dualism, by contrast, explains the putative local energy increase perfectly well and is in full accord with modern physics.

Physicalists have long wielded the 'sword' of energy conservation against dualism. But surprisingly, while it does no harm to dualism, it might severely wound physicalism. Maybe the tables are turning on physicalism.

Acknowledgements

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