http://www.diva-portal.org

Postprint

This is the accepted version of a chapter published in *Consciousness: Integrating Eastern and Western Perspectives*.

Citation for the original published chapter:

Pylkkänen, P. (2016)
Consciousness in the light of quantum theory.
In: Prem Saran Satsangi, Stuart Hameroff, Vishal Sani, Pami Dua (ed.), *Consciousness: Integrating Eastern and Western Perspectives* (pp. 23-34). New Delhi: New Age Books

N.B. When citing this work, cite the original published chapter.

Permanent link to this version:
http://urn.kb.se/resolve?urn=urn:nbn:se:his:diva-13114

Chapter 2

Consciousness in the light of quantum theory

PAAVO PYLKKÄNEN
Department of Philosophy, History, Culture and Art Studies, Finland & Academy of Finland Center of Excellence in the Philosophy of the Social Sciences (TINT), P.O. Box 24 (Unioninkatu 40 A), FI-00014 University of Helsinki, E-Mail: ***paavo.pylkkanen@helsinki.fi***
Web: ***https://tuhat.halvi.helsinki.fi/portal/en/person/pylkkane***
and
Department of Cognitive Neuroscience and Philosophy, School of Biosciences, University of Skövde, P.O. Box 408, SE-541 28 Skövde, Sweden, E-Mail: ***paavo.pylkkanen@his.se***

1. INTRODUCTION

This paper explores the theme "quantum approaches to consciousness" by considering the work of one of the pioneers in the field. The physicist David Bohm (1917-1992) not only made important contributions to quantum physics, but also had a long-term interest in interpreting the results of quantum physics and relativity in order to develop a general world view. His idea was further that living and mental processes could be understood in a new, scientifically and philosophically more coherent way in the context of such a new world view. This paper gives a brief overview of different – and sometimes contradictory - aspects of Bohm's research programme, and evaluates how they can be used to give an account of topics of interest in contemporary consciousness studies, such as analogies between thought and quantum processes, the problem of mental causation, the mind-body problem and the problem of time consciousness.

2. BOHM ON THE ANALOGIES BETWEEN THOUGHT AND QUANTUM PROCESSES

In 1951 Bohm published a textbook *Quantum theory*, where he presented quantum theory in its standard "Copenhagen" interpretation (Bohm's presentation is quite similar to the physicist Wolfgang Pauli's version of the Copenhagen intepretation). Bohm also had a philosophical aim, namely to outline a "physical picture of the quantum nature of matter". In this context he was led to consider *analogies between quantum processes and thought processes*. We will here briefly present these analogies and assess their contemporary relevance. What is particularly important is Bohm's claim that if neural processes underlying mental processes were quantum physical in relevant ways, this would explain some important features of our process of thought.

In *Quantum theory* Bohm pointed to three analogies between human thought process and quantum processes which can be denoted as follows:

- Effects of observation
- Unanalyzability
- Both have a ”classical limit”

Let us consider these briefly in turn (for a more detailed discussion see Pylkkänen 2014; see also Pylkkänen 2015b).

Effects of observation. In his discussion Bohm first draws attention to the fact that introspective observation of thought typically introduces unpredictable and uncontrollable changes in the way thought proceeds thereafter. Analogously, the observation of the position of a particle introduces unpredictable and uncontrollable changes in the particle's momentum.

Unanalyzability. Bohm suggests that a part of the significance of each element of thought process originates in its indivisible and incompletely controllable connections with other elements. Analogously, some of the essential properties of a quantum system (e.g. whether it is a wave or a particle) depend on indivisible and incompletely controllable connections with surrounding objects.

Both thought and quantum processes have a ”classical limit”. Bohm suggests that the logical process corresponds to the most general type of thought process as the classical limit corresponds to the most general quantum process. His idea is that the rules of logic are analogous to the causal laws of classical physics. Similarly, he suggests that concepts and objects are analogous. The suggestion is that logically definable concepts play the same fundamental role in abstract and precise thinking as do separable objects and phenomena in our customary description of the world. At the same time, he points to an analogy between pre-logical thinking and quantum process. He says that the basic thinking process probably cannot be described as logical. For example, he thinks that a sudden emergence of a new idea is analogous to a quantum jump.

He then raises the question of whether these analogies are just a co-incidence or whether they might be a sign of a deeper connection. He acknowledges that they could be a mere co-incidence, but goes on to consider an alternative, namely the possibility that the physical aspect of thought might involve quantum processes in some important way. This, he suggests, would explain in a qualitative way the analogies. Let us briefly consider how, starting with the ”observation analogy”.

Now, if the physical aspect of thought involved quantum processes in a non-negligible way, this would enable us to develop a qualitative account of why the direction (“momentum”) of thought is disturbed by an attempt to define its content (“position”). How about the ”unanalyzability analogy”? If the physical aspect of thought and language involved quantum processes (e.g. indivisible links), it might be possible to develop a qualitative naturalistic explanation of some holistic features of language and meaning. Finally, how might we explain the ”classical limit analogy”? This might be explainable if the physical aspect of the alogical, aconceptual thought process involved quantum processes (with inseparability, discontinuity etc.), while the physical aspect of the logical and conceptual thought process involved classical processes (e.g. classically describable, separable neural “activation patterns” governed by the classical laws of physics).

In order to get a better view of the relevance of these analogies, let us consider further the ”classical limit” analogy. In the picture we are sketching it seems that we have ”two physical worlds” - i.e., the general quantum world which contains as its part the special case of a classical world. But we also have ”two minds”, i.e. the mind in the sense of a general alogical and aconceptual thinking process, which in some conditions gives rise to the special case of the mind as logical thinking process with logically definable concepts.

The above implies that the relationship between quantum and classical is analogous to the relation between conceptual and aconceptual. We would then have, on the one hand, the *quantum world* of inseparable objects and discontinuous processes, and the *classical world* of separable objects and causal, continuous processes as a special case, and, on the other hand the *aconceptual mind* with alogical processes and the *conceptual mind* engaged in logical thinking as a special case of it (cf. Pylkkö 1998). Note that such a view of the aconceptual mind can also be used to characterize the pure, contentless consciousness that is said to be experienced in meditational states in classical Indian practises (cf. Velmans 2009).

The suggestion that there are analogies between quantum processes and thought (which was put forward by already Niels Bohr) is also the starting point of a new field of research known as quantum cognition or quantum interaction where one uses the ideas and tools of quantum theory to model aspects of cognition and other phenomena (without making the stronger assumption that those phenomena are literally quantum mechanical, see Pylkkänen 2015a). Bohm’s 1951 discussion anticipates qualitatively many ideas in quantum cognition. Such ideas have been developed in considerable mathematical detail in recent research (for a brief review and references to the relevant literature, see Wang et al. 2013)

3. THE ONTOLOGICAL INTERPRETATION OF QUANTUM THEORY

After completing his textbook *Quantum theory* Bohm still felt he could not understand the theory properly. Discussions with Einstein in Princeton led him to search for an alternative interpretation. What worried Einstein and Bohm was not merely the famous indeterminism of usual quantum theory but also the fact that the usual interpretation did not give a description of physical reality over and above predicting experimental phenomena. In other words, the usual interpretation did not provide a quantum ontology, or a description of the nature of quantum systems, regardless of whether or not they are being observed.

Bohm soon realized that the major equation of quantum theory, the Schrödinger equation, could be rewritten in a form which was very much like the Hamilton-Jacobi formulation of classical mechanics, except for an extra term which had the dimensions of energy. He realized that quantum theory could be interpreted as describing the movement of a particle (such as an electron) which was influenced not merely by classical fields (such as the electromagnetic) but also by a new type of quantum mechanical field that always accompanies it (Bohm 1952). Thus, an electron is not a particle OR a wave, but it is a particle AND a wave. In fact, Bohm had independently rediscovered the "pilot wave" theory which de Broglie had presented already in the 1927 Solvay conference. Bohm was able to answer some old objections to de Broglie's theory and also provided the first consistent account of measurement in terms of this theory (for a description of the Bohm theory which includes a brief review of criticisms against it, see Goldstein 2013). Given this background, the theory is often called the de Broglie– Bohm theory or interpretation. One of the key advantages of the de Broglie-Bohm interpretation is that it provides an ontological description of individual quantum systems and this is why in later work Bohm and his colleague Basil Hiley decided to call their developed version of this interpretation the *ontological interpretation* of quantum theory (Bohm and Hiley 1987, 1993; for a recent discussion of the metaphysical issue of individuality in the Bohm approach, see Pylkkänen, Hiley and Pättiniemi 2016). While Bohm never took this interpretation to be a final theory, he felt it was important as a starting point for further development.

One such development turned out to be potentially very relevant to our understanding of living and mental phenomena. For Bohm drew attention in the 1980s to how the ontological interpretation contains a new type of energy (mathematically described by the quantum potential, which arises from the quantum field). The curious feature is that the size of the quantum potential depends only upon the form of the quantum wave, and not on the amplitude of the wave. It looks as if the quantum field literally IN-FORMS or puts form into the energy of the particle. Bohm thus proposed that the way this energy affects the particle can be understood via a new notion of *active information*. He further suggested that this energy might be relevant for understanding features of living and especially mental phenomena (Bohm 1990). The relevance of active information to the traditional philosophical problem of mental causation was explored in more detail by Pylkkänen in 1992 (see also Pylkkänen 2007) and after Bohm's death by Hiley and Pylkkänen (2005).

While the notion of active information at the quantum level has not yet been widely discussed, some leading thinkers do take take the idea seriously, for example Quentin Smith (2002). Also, an interesting adaptation of the active information scheme to neuroscience has been proposed by Thomas Filk (2012). In the field of the social sciences, Andrei Khrennikov (2004) has made imaginative use of the proposal and the Bohm theory has also been applied to financial processes by Olga Choustova (2007) and Emmanuel Haven (2005). Of course, the notion of "quantum information" has been widely discussed in recent years (see. e.g. Bouwmeester et al. 2000). The advantages of the concept of active information over quantum information, when discussing some quantum experiments, have been argued for by Owen Maroney (2002); see also Maroney and Hiley (1999).

Note that there are by now different versions of the de Broglie-Bohm theory, for example Goldstein's (2013) "Bohmian mechanics" and Bohm and Hiley's (1993) "ontological interpretation". A balanced attempt to reconcile the different approaches is made by Holland (2011).

4. THE IMPLICATE ORDER

We mentioned above that Bohm never offered the pilot wave theory as a final theory. He did try to develop the scheme further in the 1950s, but due to some difficulties in this work he began in the early 1960s to develop – often in discussions with Hiley - a more *general conceptual framework* which takes as constraints both the results of relativity and quantum theory. In particular he argued that both relativity and quantum theory challenge the "mechanistic order", but their basic concepts directly contradict each other. He argued that we need in physics a new theory that starts from what relativity and quantum theory have in common, namely *undivided wholeness*. The challenge then became to develop new notions of order that are appropriate to describe such undivided wholeness. The most important new concept was that of *implicate order*, which Bohm illustrated with the hologram and with a device consisting of two concentric cylinders with glycerine between them. Placing droplets of ink to the glycerine and turning the outer cylinder allows one to illustrate (as an analogy to what happens in a quantum theoretical description of a "particle") how the order of a part is enfolded to the whole (so that it is "implicate") and (because of reversibility) can be unfolded (become "explicate"). The implicate order arises from considering the meaning of quantum theory and relativity, but Bohm claimed that it applies even more obviously in other domains such as the biological domain, and especially in cognitive processes and conscious experience. This framework provides an entirely new paradigm in which to try to understand the nature of conscious experience, mental processes and their relation to the underlying neurophysiological and physical processes. Bohm presented this framework in his book *Wholeness and the Implicate Order* (1980), and it has been further explored in e.g. Pylkkänen (2007).

The strongly holistic nature of the implicate order approach also reflects Bohm's engagement with Eastern philosophy, and in particular his discussions with J. Krishnamurti (see Krishnamurti and Bohm 2014).

One feature that may be confusing is that Bohm himself tried many different ways to approach quantum theory in his research, and also discussed the mind-body problem and conscious experience in different ways, corresponding to the different interpretations of quantum theory he was considering. Which of these views, if any, is correct, one might ask? To understand this potentially confusing situation, it is important to consider Bohm's epistemological views, in particular his views about the nature of scientific theories. A theory for Bohm is, as the etymology of the word suggests, a *way of looking* at the world, rather than something that gives us a literally true and final description of the way the world is. I suggest that it is in this spirit that we ought to consider Bohm's various suggestions: as tools that we can use to gain a better understanding of both quantum and relativistic phenomena and their relation to phenomena of classical physics, as well as biological and mental phenomena. Different tools are useful for different purposes, and reveal reality from a particular side or point of view. Sometimes the views offered by the different theories are in contradiction with each other, but at any given period of research it may often be premature to try to make a final decision between them. In the latter part of the paper I will thus briefly show how some of the above theoretical ideas can be used as tools to gain a better understanding of some well-known problems in the philosophy of mind and cognitive science.

5. THE PROBLEM OF MENTAL CAUSATION

The problem of mental causation is the problem of understanding how mental states (as non-physical states) could possibly influence the course of physical processes without, for example, violating the energy conversation laws. Bohm and Hiley's ontological interpretation of quantum theory suggests that an entirely new kind of energy operates in situations where quantum theory is required, an energy best understood as "active information". If mental states and their informational content can be understood as some higher-order organisation of this new "quantum potential energy" then an entirely new way of understanding mental causation, or how "mind" could affect "matter" (and vice versa) opens up (see Bohm 1990; Pylkkänen 1995, 2007; Hiley and Pylkkänen 2005).

6. THE GENERAL MIND-BODY PROBLEM

The general mind-body problem is closely connected to the problem of mental causation. This is the well known problem of whether mind and body are to be understood as two different (possibly interacting) things, or whether one is the aspect of the other, or whether one is an illusion, or whether both are aspects of some neutral ground. When discussing the implicate order, Bohm (1980) offers us a version of the idea that mind and body have a common ground beyond them both.

He uses the well-known non-locality of quantum theory as an analogy to illustrate the relation of mind and body. He suggests that in quantum theory two systems that are non-locally connected can each be seen as a three-dimensional projection of an underlying six-dimensional reality. This idea is well illustrated (as an analogy) by a situation where a big fish is swimming in a rectangular fish tank and two cameras are situated on the sides of the tank, one looking the fish from the back, the other from the side, and we are then shown the images from the two cameras in two monitors placed next to each other. Here we have two two-dimensional correlated projections of a three-dimensional reality (one monitor showing the fish from the side and the other from the back). Analogously to both quantum non-locality and the fish-tank example, Bohm proposed that mind and body can likewise be seen as correlated projections from an underlying ground. This means that mind and body do not interact causally or mechanically, but their correlated relationship is to be understood in the fact that they have a common ground out of which they are constantly projected as mutually correlated aspects.

Note that this idea seems to differ in a significant way from the idea explained above, where active information was used to explain how mind affects matter and vice versa. Bohm's various ideas about the relation of mind and body are indeed different, depending on whether he is writing in the context of the implicate order or the ontological interpretation (for Bohm's own attempt to reconcile the implicate order and the ontological interpretation, see Bohm 1987). Making explicit these different ideas and considering their connection to each other is a challenge for future research. If the tensions between the different schemes can be dealt with coherently, there is a possibility here of understanding in a new way a major traditional philosophical problem, illustrating the potential value of a "quantum approach" to the mind.

7. TIME CONSCIOUSNESS

The problem of time consciousness was considered by e.g. Broad and Husserl and has recently been discussed by e.g. van Gelder (1999), Varela (1999) and Dainton (2000, 2001). The essence of the problem is how to understand our experience of temporal objects as temporal. When I am listening to music, for example, how am I to understand the status of the sounds that I first heard a very short time ago? Are the past sounds that still seem to "reverberate" in consciousness to be understood as mechanical memories? Husserl certainly did not think so but thought that the sounds heard a short while ago are perceived (retained and apprehended) under the mode "just past". But what must the ontology of conscious experience be like to make possible such "perception of the just past" (as opposed to a mechanical recall from memory)? Van Gelder, Varela and Dainton each propose different ways of looking at this issue in the contemporary context, and so did Bohm in chapter 7 of his *Wholeness and the Implicate Order*.

Bohm's idea is that listening to music provides a very good example of an implicate order, and that indeed we are directly perceiving an implicate order when listening to music. In Bohm's scheme the "just past" sounds (as well as visual and other sensory images) can be seen as elements that are enfolding into the deeper levels of the implicate order of conscious experience. We can thus understand musical experience as something where different elements (e.g. individual sounds) are *co-present* at *different degrees of enfoldment*, which is typical for the implicate order in general. Note that this example is not claiming that our experience of listening to music is, ontologically speaking, a quantum process. But it is suggesting that holistic phenomena in different levels (conscious experience, biological phenomena, physical phenomena) have the implicate order in common, and this makes it possible to understand these phenomena as a coherent whole, including the way they "enfold" and "unfold" each other (for a more detailed discussion, see Pylkkänen 2007, chapter 5). Surely, one might argue, such unified understanding has been an underlying aim of science and philosophy. Again, such unified understanding is not meant to be taken as a literal and final description of the way the world is, but rather as a way of looking or understanding the world and our place in it from a particular point of view.

The *prima facie* advantage of the theory of time consciousness that can be developed on the basis of Bohm's implicate order is that, unlike the views of Broad, Husserl, van Gelder, Varela and Dainton, Bohm's view coheres in a deep way with the fundamental concepts of contemporary physics. Given that a satisfactory theory of time consciousness ought to provide us with not just a phenomenological description of experienced time but also an account of the relation between experienced time and other levels of time (neural, chemical, physical etc), Bohm's scheme seems to be a promising alternative to explore.

The above examples building upon Bohm's programme are very much abstractions from "work in progress". It is hoped that they go some way towards illustrating the potential philosophical power of not just Bohm's approach, but also of "quantum approaches to mind" more generally. In the spirit of this paper the other quantum approaches (e.g. Penrose and Hameroff's model, quantum brain dynamics, etc.) can be seen not only as "competitors" but also as different ways of looking at this domain, as other kind of tools which provide a different and more complete view of this rapidly developing terrain (for a review, see Atmanspacher 2011).

8. DISCUSSION

We have above briefly discussed various ways in which the physicist David Bohm discussed mind and consciousness in the course of his long career. We saw how Bohm's starting point was to notice certain analogies between thought and quantum processes. He then speculated that these analogies could be explained in qualitative way if the neural processes underlying thought involved certain kinds of quantum effects. In later work he developed new schemes for quantum theory, and continued to consider the relation of mind and matter in the context of these schemes. The pilot wave theory, under Bohm and Hiley's (1993) ontological interpretation, seems particularly interesting for those who try to understand the place of mind in nature. If information plays an active role even at the fundamental quantum level, it is perhaps not so surprising or anomalous that the information contained in mental states can guide physical action. The implicate order, in turn, provides a very general scheme in which physical, biological and psychological processes can be understood in terms of some common notions and principles. It involves a radical questioning of the mechanistic world-view, where systems are typically understood in terms of entities in mechanical interaction (cf. Ladyman and Ross's (2007) criticism of the mechanistic world-view).

How does Bohm's approach compare with other contemporary views? It is characteristic of consciousness studies that there are widely different approaches. At one end there are eliminativist physicalist views which argue that conscious experience (or at least some of its key feautres) do not really exist, and that matter is the primary reality (see Churchland 2013). At the other end there are views - often found in Eastern approaches - which claim that consciousness is the primary reality and that the external world of matter is some kind of illusion or an appearance, a creation of consciousness (cf. Velmans 2009). The Bohmian view suggests a middle way between these extremes. It acknowledges that there exists a world independently of the human mind. Is this world the physical world? Bohm would say that the world is fundamentally a more neutral and comprehensive ground which contains the mental and the physical as its aspects, or "projections" (see Bohm 1980; Pylkkänen 2007; Atmanspacher 2011).

We noted above that this view involves some tensions, given Bohm's different schemes in physics. In the context of the ontological interpretation it is tempting to assume that just as the pilot wave guides the electron, so the mind (understood as a more complex, quantum-like field) quides the body. Yet in the context of the implicate order scheme Bohm proposed that mind and body are "correlated projections" from a higher-dimensional underlying reality, which seems to contradict the idea that they are autonomous aspects which can influence each other. Thus, it seems that Bohm did not end up with a single definite view regarding the nature and relation of mind and matter. This can be seen as a weakness of his approach. However, given the difficulty of the mind-matter problem it seems reasonable at this point to keep various options open and explore their mutual relations, strengths and weaknessess in a spirit of genuine dialogue.

Acknowledgement

The work for this paper was partially funded by the Fetzer Franklin Fund of the John E. Fetzer Memorial Trust.

Bibliography

Atmanspacher, H. (2011). Quantum Approaches to Consciousness, *The Stanford Encyclopedia of Philosophy*, E. N. Zalta (ed.), URL = http://plato.stanford.edu/archives/sum2011/entries/qt-consciousness/

Bohm, D. (1952), A Suggested Interpretation of the Quantum Theory in Terms of "Hidden Variables" I and II, *Phys. Rev.*, **85** (2): 166-179 and 180-193.

Bohm, D. (1980) *Wholeness and the Implicate Order*. London: Routledge.

Bohm, D. (1987): Hidden Variables and the Implicate Order, in *Quantum Implications: Essays in Honour of David Bohm* , ed. by B. J Hiley and F. D. Peat (Routledge, London)

Bohm, D. and Hiley, B. J. (1987), An Ontological Basis for Quantum Theory: I. Non-relativistic Particle Systems. Phys. Rep. 144 (6): 323-348.

Bohm, D. and Hiley, B.J. (1993) *The Undivided Universe. An Ontological Interpretation of Quantum Theory*. London: Routledge.

Bouwmeester, D., Ekert, A. and Zeilinger, A.K. Eds. (2000) *The Physics of Quantum Information: Quantum Cryptography, Quantum Teleportation, Quantum Computation*. Heidelberg and Berlin: Spinger.

Choustova, O. (2007) Toward quantum-like modeling of financial processes, *J. Phys.: Conf. Ser*. 70, 012006.

Churchland, P. (2013) *Matter and Consciousness*. Third edition. Cambridge, Mass.: MIT Press.

Dainton, B. (2000) *Stream of Consciousness. Unity and continuity in conscious experience*. London and New York: Routledge.

Dainton, B. (2001) *Time and Space*. Chesham: Acumen.

Filk, T. (2012) Quantum-Like Behavior of Classical Systems, in *Quantum Interaction: Lecture Notes in Computer Science* Vol. 7620, pp. 196-206.

Goldstein, S. (2013), Bohmian Mechanics, *The Stanford Encyclopedia of Philosophy* (Spring 2013 Edition), Edward N. Zalta (ed.), URL = http://plato.stanford.edu/archives/spr2013/entries/qm-bohm/

Haven, E. (2005) Pilot-wave theory and financial option pricing. *International J. of Theoretical Physics* 44, 1957-1962.

Hiley, B.J. and Pylkkänen, P. (2005) Can mind affect matter via active information? *Mind and Matter* **3**, *2*, 7-26. URL = http://www.mindmatter.de/resources/pdf/hileywww.pdf

Holland, P. (2011) A quantum of history. *Contemp. Phys.* 52, 355.

Khrennikov, A. (2004) *Information Dynamics in Cognitive, Psychological and Anomalous Phenomena*. Series *Fundamental Theories of Physics*. V. 138. Kluwer, Dordrecht.

Krishnamurti and Bohm (2014) *The Ending of Time: Where Philosophy and Physics Meet*. Revised and expanded edition. New York: HarperCollins.

Ladyman, J. and Ross. D. (2007), *Every Thing Must Go. Metaphysics Naturalized.* Oxford University Press: Oxford.

Maleeh, R. and Amani, P. (2012) Bohm's theory of the relationship of mind and matter revisited. *Neuroquantology*, *10*, 150–163.

Maroney, O. (2002) *Information and Entropy in Quantum theory*. PhD thesis, Birkbeck College, University of London. http://www.bbk.ac.uk/tpru/OwenMaroney/thesis/thesis.html.

Maroney, O. and Hiley, B.J. (1999) Quantum State Teleportation Understood Through the Bohm Interpretation, *Foundations of Physics*, Vol . 29, No. 9, pp. 1403-1415.

Petitot, J. et al. eds, (1999) *Naturalizing phenomenology*. Stanford University Press.

Pylkkänen, P. (1992) *Mind, Matter and Active Information: The Relevance of David Bohm's Interpretation of Quantum Theory to Cognitive Science*. Reports from the Department of Philosophy, University of Helsinki, No 2, 1992. [PhD dissertation].

Pylkkänen, P. (1995) Mental Causation and Quantum Ontology, in L.Haaparanta et.al. (Eds), *Mind and Cognition, Acta Philosophica Fennica 58*. Helsinki: The Philosophical Society of Finland.

Pylkkänen, P. (2007) *Mind, Matter and the Implicate Order*. Springer Frontiers Collection: Heidelberg and New York.

Pylkkänen, P. (2014) Can quantum analogies help us to understand the process of thought?, *Mind and Matter* 12 (1), 61-91.

http://www.mindmatter.de/resources/pdf/pylkkaenen_www.pdf

Pylkkänen, P. (2015a) Weak vs. strong quantum cognition, in Liljenström, H. ed. *Proceedings of ICCN the 4th International Conference on Cognitive Neurodynamics*. Springer.

http://link.springer.com/chapter/10.1007%2F978-94-017-9548-7_58

Pylkkänen, P. (2015b). Fundamental physics and the mind – is there a connection?, in Atmanspacher, H., Bergomi, C., Filk, T., Kitto, K. eds., *Quantum Interaction 2014: 8th International Conference, QI 2014*, selected papers pp. 3-11. Heidelberg: Springer http://dx.doi.org/10.1007/978-3-319-15931-7_1

Pylkkänen, P., Hiley, B.J. & Pättiniemi, I., (2015) Bohm's approach and individuality, in Guay, A. & Pradeu, T. eds. *Individuals Across the Sciences*. Oxford University Press, Oxford. http://arxiv.org/abs/1405.4772

Pylkkö, P. (1998) *The Aconceptual Mind: Heideggerian Themes in Holistic Naturalism*. Amsterdam and Philadelphia: John Benjamins.

Smith, Q. (2003) Why cognitive scientists cannot ignore quantum mechanics? In *Consciousness: New Philosophical Perspectives*; Smith, Q., A. Jokic Eds.; Oxford University

Press: Oxford.

Van Gelder, T. (1999) Wooden Iron? Husserlian phenomenology meets cognitive science, in Petitot et al. eds, 1999.

Varela, F.J. (1999) *The specious present: A neurophenomenology of time consciousness*, in Petitot et al. eds, 1999.

Velmans, M. (2009) How to define consciousness – And how not to define consciousness. *Journal of Consciousness Studies*, 16(5), pp 139-156.

Wang, Z., Busemeyer, J. R., Atmanspacher, H., & Pothos, E. M. (2013) The potential of using quantum theory to build models of cognition. *Topics in Cognitive Science*, 5, 672–688.