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PSYCHOPHYSICAL DUALISM FROM THE POINT OF VIEW OF A WORKING PSYCHOLOGIST

ABSTRACT. Cognitive neuroscience constitutes the third phase of development of the field of cognitive psychophysiology since it was established about half a century ago. A critical historical overview is given of this development, focusing on recurring problems that keep frustrating great expectations. It is argued that psychology has to regain its independent status with respect to cognitive neuroscience and should take psychophysical dualism seriously. A constructive quantum physical model for psychophysical interaction is presented, based on a new stochastic interpretation of the quantum potential in the de Broglie–Bohm theory. This model can be applied to analyze cognitive information processing in psychological experiments. It is shown that the quantum potential shares several features with Duns Scotus' notion of contingent causality.

1. INTRODUCTION

Cognitive psychophysiology arose in the roaring sixties of the previous century as the scientific study of relationships between physiological response systems (brain, heart, respiratory system, etc.) and human cognitive information processing. In the more recent "era of the brain" cognitive psychophysiology merged with biologically inspired computational approaches (e.g., artificial neural network modeling) to become the dominant paradigm of cognitive neuroscience. Prominent within cognitive neuroscience are the noninvasive brain-imaging techniques that yield the anatomical locations of brain areas undergoing changes in activity in association with the execution of cognitive tasks.

The emergence of cognitive neuroscience, giving rise to the prospect of explaining psychological processes as the result of patterned brain processes, has put strains on the status of psychology as an independent science. In some senses (to be specified below) the *Psychologismusstreit*, which arose when psychology was established as an independent empirical science, is having a second round. Psychology needs to reconsider its *raison d'etre* because of the reductive tendencies inherent in cognitive neuroscience. In this spirit, the relevance of the cognitive neuroscientific brain imaging paradigms for psychology will be questioned in what follows. I should make clear that I am not a professional philosopher but a psychologist, working mainly in the fields of mathematical psychology, psychometrics, and cognitive psychophysiology.[1] I have been actively involved in cognitive psychophysiological research during more than three decades, and have no inclination to leave this challenging field of research. Hence my critical remarks should be understood as a token of *Was-sich liebt, das-neckt sich.* In the second part of this paper a constructive psychophysical dualism is outlined, based on the de Broglie–Bohm quantum potential, interpreted in terms of Duns Scotus' notion of contingent causality.

2. SOME REMARKS ABOUT THE RECENT HISTORY OF COGNITIVE PSYCHOPHYSIOLOGY

In its earliest phase the newly emerging field of cognitive psychophysiology was reigned by a single dominant paradigm. In schematic outline, this paradigm involved multi-lead noninvasive registrations of the neocortical electromagnetic field fluctuations (so-called electroencephalogram and/or magneto-encephalogram of human subjects) associated with the execution of simple cognitive tasks. Readers are referred to, e.g., Donchin (1984) for an authoritative overview. I will describe a popular instance of this approach, the oddball experiment, in somewhat more detail (also for the purpose of later reference). Let the letters F and R be our visual stimulus set. At each trial the subject S is shown either an F (with high probability, $\text{Prob}(F) = 0.75$, say, which is why F is called the "Frequent"), or an R (with probability $\text{Prob}(R) = 1 - \text{Prob}(F)$, called the "Rare"). As soon as a new trial is started by the presentation of an instance of the stimulus set, neocortical electromagnetic field registration is triggered and continues during the next 1 s, say. S usually is instructed to react to the occurrence of each Rare, or else count the total number of "Rares" across trials, to be reported at the end of the random sequence of stimulus-presentations. The oddball experiment often is replicated with distinct subjects, S_i, $i = 1,2,..., N$. The neocortical electromagnetic field registrations thus obtained are pooled across trials (and in case subjects are replicated, also across subjects), the result of which is called the averaged evoked (electromagnetic) potential field. This averaged (pooled) evoked potential field is interpreted as the invariant "brain response" to the cognitive task. It constitutes a spatio-temporal electrophysiological process (dependent upon location in the neocortex and upon clock time since stimulus onset). The final step is to decompose the averaged evoked potential field into components. Components are assigned heuristic functional interpretations that are suggested by the information processing stages supposed to occur during the execution of the cognitive oddball task. The largest "brain response" component typically obtained in the oddball task is the famous P300, a positive deflection of the averaged neocortical electromagnetic field occurring at about 300 ms after stimulus onset, and substantially elevated in case the stimulus presented is the "Rare." This positive deflection, which occurs at large areas across the neocortex, can sometimes be so elevated that it can be detected by eye in the raw single-trial registrations.

In the seventies of the previous century hopes were high that the paradigm described above would generate significant progress in cognitive psychology at large. More specifically, it was hoped that distinct "brain response" components, in particular the P300 component, "would index some specific cognitive process that had already been hypothesized on the basis of behavioral studies, so that the P300 could be used as a metric for studying and possibly localizing that process" (Regan, 1989, p. 236). Donchin, without question the leader of this paradigm, published an optimistic paper in Science (Donchin, 1975). The whole paradigm, however, is now more or less forgotten. What happened?

It turned out that the persistent attempts to obtain a cognitively relevant and unambiguous functional interpretation of "brain response" components simply failed to converge. Failed, because of a cumulating process of various factors, including a too naïve application of signal processing techniques used to obtain the desired decomposition of the "brain response." For instance, it was standard to assume that "brain response" components are invariant across trials of an experiment as well as across distinct subjects. Yet in detailed comparisons of raw single-trial "brain response" components, it was consistently found that the presumed invariance is completely lacking (e.g., Molenaar and Roelofs, 1987). Also, the cognitive processes hypothesized on the basis of behavioral studies turned out to be ill-defined ("cognitive wheels") and unreliable; a state of affairs that still obtains (see below). Without the availability of unambiguous cognitive components obtained in reliable task analyses, the whole paradigm is based on quicksand. In 1989 Regan summarized the situation as follows (Regan, 1989, p. 236): "But in the ensuing 20 years this hope has not been fulfilled. The P300 has been found to correlate with very many variables. Even by 1969 Sutton was able to list 29 correlates of P300.''

Coming to its final stages, the focus of this unsuccessful paradigm was shifted considerably. Regan (1989, p. 237) commented on the situation in 1989: ''After a period of disappointment and reevaluation, some (but not all) authors have adopted a new and more aggressive view, most directly expressed in Donchin's words: 'Our task is to determine the functional role of the [P300, PM] component rather than to seek preconceived correlations between the component and ill-defined psychological constructs.' From this viewpoint, rather than being a metric for studying some phenomenon of interest [i.e., cognition, PM], P300 *is* the phenomenon of interest.'' (italics in original). Of course the dedicated study of the P300 as an electrophysiological phenomenon in itself is an interesting field of research, but I claim that it is, for obvious reasons, no longer directly relevant to psychology. Moreover, its logical role as phenomenon to be explained disqualifies P300 as a possible causal actor in reductionistic endeavors.

Then a breakthrough occurred, spurred (as so often in cognitive psychophysiology) by purely technical developments in biophysics. The standard computational method to obtain ''brain response'' components always had been a naïve application of multivariate statistical techniques (principal component analysis; cf. Donchin, 1966). Call this computational decomposition method the Donchin method (as many colleagues did in those days). The Donchin method can be characterized as a general-purpose decomposition technique that does not use specific knowledge about the processes generating the data. It even appears to have been used in the metereological analyses yielding the well-known, but spurious, hockey-stick components which inspired the Kyoto treaty. Each ''brain response,'' however, is a spatio-temporal electrophysiological process obeying Maxwell's electromagnetic laws. Under plausible assumptions (''head model'') it follows straightforwardly from Maxwell's laws that the observed neocortical electromagnetic potential field can be represented to first order as being caused by dipole sources (an explicit derivation is given in Huizenga, 1995, Appendix B). Each dipole source can be interpreted as representing the synchronous action of a compact area of cortical nerve cells and hence is called an ''equivalent'' dipole model of a neural source. An equivalent dipole is characterized by its location in the brain, its orientation and strength. The new biophysically inspired decomposition method therefore is called the method of equivalent dipole modeling. It replaced the fallible Donchin method in the initial paradigm, yielding "brain response" components in the form of equivalent dipoles, each with its own location, orientation and strength.

Again hopes were high that with this principled biophysical decomposition method of the observed neocortical electromagnetic field it would become possible to realize the aims of cognitive psychophysiology (e.g., Wood, 1982; Wood et al., 1985). But until now progress in this direction has been as slow as in the early days. To wit, the biophysical and statistical aspects of equivalent dipole modeling have been refined substantially (cf. Huizenga et al., 2002). But it turns out to be as difficult as before to determine which aspects of cognitive information processing are associated with the activity of the neural dipole sources thus identified. We still lack adequate cognitive task analyses and postulate invariances across trials and/or subjects where none may obtain. In fact, at present it is not even known what are the neural dipole sources underlying P300.

Meanwhile a third change of paradigm has taken place, namely the analysis of neural sources underlying "brain responses" by means of functional magnetic resonance imaging techniques (e.g., Petersen et al., 1988). Whereas the equivalent dipole method has high time resolution (at the level of milliseconds), its spatial resolution appears to be low. In contrast, fMRI has high spatial resolution, but at the cost of a lower time resolution. Hence fMRI brain maps show spectacular anatomical detail, but have been pooled across substantial time spans. In the next section this latest development will be discussed in somewhat more detail.

3. BRAIN WARPING

The sequence of three paradigms described above is an idealization. In reality all kinds of shades and mixtures of the paradigms are encountered. Yet the idealization is not without relevance in that it shows an increasing trend towards localization. "Brain response" components obtained in the initial paradigm by means of the Donchin method (being linear combinations of the multi-lead electromagnetic field registrations) only have vague boundaries and usually cover large (in terms of inter-neuron distances) areas of the neocortex. For instance the so-called topographic map of P300 is not well-defined, certainly not in comparison with the results obtained in the later paradigms. In the second paradigm each equivalent dipole represents a neural source, or "brain response" component, the main characteristics of which are its location, orientation and strength. Hence the precise location of an equivalent dipole source in the brain constitutes one of its defining characteristics (and often is used to infer its presumed functional contribution to information processing). Yet it always concerns an "equivalent" dipole model that represents the collective action of a compact area of neurons, where the boundaries of the latter area are fuzzy. In the most recent third paradigm, based on MRI measurements of local energy consumption in the brain, the importance of anatomical localization is even greater in that it is the single defining characteristic of "brain response" components. The strength of the latter components (i.e., elevation or decrease with respect to some baseline condition) often only serves subsidiary purposes. In this so-called brain-imaging paradigm, precise anatomical localization is of prime importance and drives the functional interpretation of components thus obtained.

But each human brain is unique in many respects. The genotype of each human subject (much of which is expressed in the brain) is unique, as well as various aspects of the environments in which this particular subject is embedded. Moreover, the growth of neural networks during ontogenesis is governed by self-organizing processes (so-called nonlinear epigenetic processes), which create intrinsic variability in their products (even if, for instance in computer simulations, genetic and environmental influences are kept constant; cf. Molenaar et al., 1993). Hence the question arises how one could define "location in the brain" in a uniform manner. The answer given in the brain-imaging paradigm is: by means of brain warping.

In brain warping the unique anatomical features of a human brain are conceived of as "deformations" of a common architecture (e.g., as illustrated in Figure 6 in Toga and Thompson, 1999, Chapter 1, p.11). These "deformations" are "normalized" by means of smooth spatial transformations. An excellent survey of such transformation techniques can be found in Toga (1999). The geometrical transformations used in warping constitute powerful diffeomorphisms that enable the smooth transformation of your head into mine (Figure 14 in Miller et al., 1999, Chapter 7, p. 127), or the smooth transformation of a dot into the letter C (Figure 4 in Miller et al., 1999, Chapter 7, p.122). The transformational power of brain warping is impressive, indeed, but is it warranted?

It can be shown that treating unique features of individual brains as deformations with respect to a common underlying architecture is a poor model for the class of brain (growth) processes concerned (Molenaar, 2004, 2003, Chapter 3). This will be explained more fully below. Moreover, the question arises how the actual topological features of observed brain maps of different human subjects before warping are affected by the elastic transformations involved in warping towards a common map. Can the common "anatomical brain space" thus created be assigned any reality? To the best of my knowledge, these fundamental questions have not yet been answered. Can they be neglected? To suggest a preliminary answer, I will close this section with the presentation of some results obtained in the brain-imaging paradigm.

In cognitive psychology there exists an experimental reaction time design that has status comparable to the oddball design in cognitive psychophysiology. It is the memory set experiment of Sternberg (Sternberg, 1969); an instance of the so-called additive factor method (see the later chapters in Townsend and Ashby, 1983, for a thorough introduction). The task is simple: the memory set consists of 6 letters, say, and in each trial a letter is presented. The experimental subject has to indicate as quickly and accurately as possible whether the letter presented belongs to the memory set or not. The Sternberg experiment also has been used in brain imaging; the results of a small meta-analysis are shown in the following figure taken from Smith and Jonides, 2002, p. 170).

These results are based on strong assumptions about invariances across trials, subjects (if not forced by brain warping), and other assumptions of homogeneity. I claim, however, that they are very disappointing given the simplicity of the Sternberg experiment. The number of neural sources is too large and it is very hard to determine the possible contribution of each neural source to the information processing going on in the Sternberg task. Still, these results have been obtained at relatively high financial costs (MRI is costly). It is to these budgetary aspects that we will return in a later section.

4. SOME CONCLUSIONS THUS FAR

Cognitive neuroscience constitutes the third phase of development of the field of cognitive psychophysiology since it was established about half a century ago. The earlier two phases (like the current third

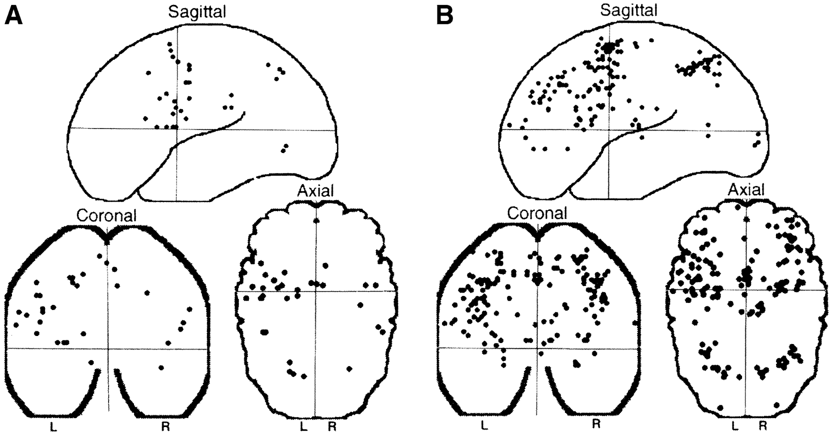

Figure 1. Neuroimaging results for verbal working memory are summarized by sets of three warped projections. Included in the summary are published PET or fMRI studies of working memory that reported coordinates of activation and had memory load of six or fewer items. Each projection collapses one plane of view for each activation focus – sagittal, coronal and axial. Taken from Smith and Jonides, 2002, p. 170, cf. their Figure 11.3 for further details.

phase) were each heralded with great expectations concerning the possibilities to explain the presumed psychological processes underlying human cognitive information processing in terms of elementary "brain responses" (represented by, respectively, averaged evoked potentials and equivalent neural dipoles). Yet for each of these initial phases, these expectations have not been fulfilled for mainly the same reasons. Firstly, there do not exist well-established unique decompositions at the level of psychological information processing, not even for the simplest cognitive tasks such as the oddball and Sternberg tasks described above (cf. Townsend and Ashby, 1983, for alternative parallel and serial decompositions of the Sternberg task). Hence the search for elementary brain systems (modules) underlying such psychological component processes becomes severely ill defined. Secondly, there exists profound heterogeneity and variability (both within and between persons) at the levels of anatomical brain structures (e.g., Edelman, 1987, Fig. 2.6), brain functioning (e.g., Molenaar and Roelofs, 1987) and information processing (see below). The use of averaging, pooling and warping to arrive at nomothetic communalities is a poor approach in this context. This will be elaborated somewhat further in the next section.

Because the same unresolved problems affect the current third phase of cognitive neuroscience, it is to be expected that it will again, like the earlier two phases described above, fail to fulfill the great expectations that it has evoked. Considered from a biophysical perspective, moreover, fMRI is a much cruder brain imaging technique than equivalent neural dipole modeling and, in contrast to neural source modeling, its time resolution does not well match the time scale (milliseconds) at which elementary human cognitive information processing proceeds. Enough reasons, I conclude, to question the relevancy of cognitive neuroscience for psychology.

5. ON PSYCHOLOGICAL SCIENCE

In this section some special features of scientific psychology will be discussed in an attempt to further distinguish it from cognitive neuroscience and its associated reductive physicalistic tendencies. It will be argued that in important respects psychology has to be a person-specific science, in a way that is reminiscent of the idiographic type of science discussed by the neo-Kantians (Windelbandt, Rickert), whereas cognitive neuroscience aims to be a typical nomothetic science. In addition it will be shown that the empirical facts of scientific psychology include fictitious states of affairs.

At several places in the foregoing sections reference has been made to the heterogeneity (uniqueness) of human persons in various psychologically relevant respects. The profoundness of this heterogeneity has only recently been appreciated more fully, because the main emphasis in scientific psychology predominantly has been on the establishment of nomothetic regularities induced from the study of interindividual variation. The implicit assumption was that such nomothetic regularities governing the variation between persons also would explain the structure of variation within individual persons (i.e., explain each person's life trajectory). The latter assumption, however, is incorrect with respect to all psychological processes with time-varying characteristics. This is a direct consequence of the so-called classical ergodic theorems (cf. Molenaar, 2004, for further details). Hence the scientific psychological study of development, learning, homeostasis, and all other processes with time-varying characteristics has to be based on intensive time-dependent measurement of intra-individual variation (time series designs) in order to obtain valid results. The first results of such dedicated study of intra-individual variation show that the heterogeneity of human persons is much more widespread than expected. For instance, the structure of daily responses of individual persons to a standardized personality inventory all differ in qualitatively important respects, while none of these person-specific structures equals the normative factorial pattern of the inventory (cf. Molenaar, 2004).

In contrast to cognitive neuroscience, which is of relatively recent origin, cognitive neuropsychology has a much longer history, extending at least back to the nineteenth century. The focus of cognitive neuropsychology is on individual assessment, but in order to comply with psychology's traditional focus on nomothetic regularities, strong assumptions have been made as to interindividual homogeneity. In a handbook contribution, Coltheart (2001) summarizes the assumptions used in cognitive neuropsychology. I mention two of these assumptions: (a) architectural uniformity across persons, (b) functional modules are anatomically modular. According to (a) we all share the same anatomy, up to the smallest levels, and unique individual features are treated as (random) deformations from this ideal. Reiterating my earlier remarks, the validity of this presumed "world of Quetelet" as expressed by assumption (a) is challenged on mathematical-statistical grounds in Molenaar (2004). Moreover, actual growth of neural networks during individual ontogenesis is characterized by unique anatomical and functional variation created by self-organizing epigenetic processes (cf. Molenaar et al., 1993).

According to assumption (b) cognition is organized as a system of functional modules, where each functional module bears a one-to-one relationship to some anatomical module. Assumption (b) postulates *a priori* that there exists a strong architectural equivalence between cognition (mind) and brain anatomy (body). Hence the results obtained under this assumption cannot be used in discussions about psychophysical dualism. For an extensive methodological critique of modular decomposition of cognition, the reader is referred to Uttal (2001). The postulated equivalence between cognitive and brain modules is rejected in a recent study of Cox and Savoy (2003), who find substantial interindividual heterogeneity in brain representation of the same cognitive task (a clear case of multiple instantiation).[2]

A second special feature of scientific psychology concerns the nature of its empirical data base. That is, the facts of psychological science. Putnam (2004) has given compelling arguments against the tenability of both the classical empiricist (Hume) and the logical positivist (Carnap) definitions of facts in terms of observation terms. Putnam concludes that “from Hume on, empiricists – and not only empiricists but many others as well, in and outside of philosophy – failed to appreciate the ways in which factual description and valuation can and must be *entangled* (Putnam, 2004, pp. 26–27; italics in original). This in itself is an important observation for psychological science (see next section). But even under the definition of facts in terms of observation terms, the class of psychological facts include what can best be referred to as fictitious facts. A striking example of the importance of such fictitious facts is given in a recent interview with the neurologist Vermeulen, head of the department of neurology at the Amsterdam Medical Center, in the Dutch national newspaper Trouw (Brandt, 2005). Vermeulen indicates that at least 25% of the patients who are referred to the neurological clinic turn out to suffer from complaints without any somatic cause. These patients often suffer severely and cannot be cured by medication. According to Vermeulen, their only hope at recovery is psychological treatment.

6. A SECOND PSYCHOLOGISMUSSTREIT

Several aspects of the discussion thus far remind one of the Psychologismusstreit that took place at the time when psychology was established as an independent science. For instance, the issues of physicalistic reduction of an imperialistic cognitive neuroscience, the person-specificity of psychology, the fictitious contents of its factual base. In this section this analogy will be elaborated somewhat further, this time focussing on a more mundane aspect.

The original cognitive psychophysiological paradigm was based on electro-encephalographic registrations at only a small set of leads (up to 15 channels). The equipment to carry out this kind of registrations is commercially available at reasonable costs. In the equivalent dipole modeling paradigm the number of channels has to be much larger (at least more than 30 channels), but this can be carried out with the commercially available modern equipment for electro-encephalographic registration. Equivalent dipole modeling of the magneto-encephalogram requires special hardware (squid) and hence the costs involved increase substantially. Moving to the brain imaging paradigm, the costs involved in magnetic resonance imaging increase another order of magnitude; too high for the research budgets of many university departments of psychology. The very high costs involved in fMRI registrations have created a pressure on the budget of these departments.

Perhaps psychology is in crisis. It has to reflect again on its reasons to be an independent science. More specifically, psychology should actively defend her legitimate rights to be an independent science alongside all others. This call to philosophical action has occurred earlier in history, namely when psychology established itself as a science, independent from philosophy. The foundational issues raised in this so-called Psychologismusstreit have been aptly summarized by Kusch (1995) and Rath (1994). The perceived need to defend their funding resources induced the scientific philosophers at the time to publish a Petition, written by Natorp, Rickert, Windelband (all belonging to the Neokantian school) and Husserl, and signed by almost all others.

Petition by Natorp, Husserl, Rickert & Windelband 1912 (in Kusch, 1995):

> The undersigned teachers of philosophy at institutions of higher education in Germany, Austria and Switzerland see themselves as having cause to make a statement directed against the filling of chairs of philosophy with representatives of experimental psychology. ... Experimental psychology should therefore be supported only by the establishment of its own professorships, and everywhere where previously philosophical professorships are occupied by psychologists new chairs of philosophy should be created.

The foundational issues concerning psychology constitute the main themes of recently published biographies of Heinrich Rickert (Krijnen, 2001), Gustav Fechner (Heidelberger, 1993) and Ernst Mach (Banks, 2003). I claim that these issues, first and foremost the mind-body relationship, have been neglected within the relative safety of psychology being recognized as an established science during most of the past century, but now should be addressed again in our battle against the current crisis.

7. MIND AND MAXWELL

It is a well-established fact that cognitive information processing is associated with fluctuations of the electromagnetic potential field of the brain. The physical theory for such brain potentials is Maxwell's theory. In fact, a quasi-static approximation in which the electric and magnetic component fields are decoupled will suffice (see Plonsey, 1969, for details). The ensuing biophysical theory can be formulated in terms of neural sources (dipoles, etc.) whose electric and magnetic fluctuations explain the registered brain potential fields (cf. Nunez, 1981, for details).

Is this association between cognitive information processing and brain potential fluctuations in some sense more compatible with physicalistic monism than with psychophysical dualism? In this section I will answer this question negatively, arguing that there is no incompatibility whatsoever between psychophysical dualism and Maxwell's theory of electromagnetism. What follows has been inspired by Mohrhoff (2004) and Köhler and Mutschler (2003).

The Maxwell equations can be expressed in various forms. For our purposes we choose a simple form in real physical space (using the Lorentz gauge; cf. Cohen-Tannoudji et al., 1989, p. 10). Let Υ denote the d'Alembertian operator: $\Upsilon = \partial^2/c^2\partial t^2 - \Delta$, where Δ denotes the Laplacian: $\Delta = \partial^2/\partial x^2 + \partial^2/\partial y^2 + \partial^2/\partial z^2$; t is time in seconds, and x, y and z denote distances along the three Euclidian axes in meters. The speed of light is denoted by c ($2.998*10^8$ m/s). Let $\mathbf{r}$ denote the 3-variate vector denoting distance from the origin in Euclidian space. Then the Maxwell–Lorentz equation for the scalar potential $U(\mathbf{r},t)$ is (Cohen-Tannoudji, 1989, eq. A.14.a):

$$\Upsilon U(\mathbf{r}, t) = \Sigma_i q_i \delta[\mathbf{r} - \mathbf{r}_i(t)] \quad (\mathrm{A})$$

To reiterate, from this expression (A) one can straightforwardly derive the equivalent dipole model for electro-encephalogram registrations by introducing the specific boundary conditions ("head model").

Expression (A) specifies how time-dependent changes in the location $\mathbf{r}_i(t)$ of each elementary charge q_i determine the scalar potential (a similar expression can be given for the vector potential). The only reason for introducing (A) is to show that it does not put any restriction on the possible causes of the time-dependent changes in location, $\mathbf{r}_i(t)$, driving the space-time variations of $U(\mathbf{r},t)$. The Maxwell equations do not include an extra expression explaining the path taken by each i-th elementary charged particle. Whatever causes changes in each charged particle's position, whether it is an immaterial mind, a physical object, or some unknown force, it does not matter at all. Insofar as any phenomenon, regardless of its nature, leaves electrical traces in real physical space, it obeys to that extent (suitable analogues of) expression (A). Consequently, I claim that nothing in Maxwell's theory underlying equivalent dipole modeling rules out the possibility that the electro-encephalographic variations observed in cognitive psychophysiological experiments are caused by nonmaterial minds.

But perhaps more can be said. Suppose one is a physicalist who would like to reduce psychology to electrophysiological investigations. Then regularities (invariances) in the domain of psychology presumably have to be caused by regularities (invariances) in the electrophysiological domain. The latter regularities in the electrophysiological domain have to be deduced from (suitable analogues of) expression (A), together with the appropriate boundary conditions. It is clear from the mathematical form of expression (A) that it only defines a large "space of possible electrical behavior." The boundary conditions commonly used in equivalent dipole modeling do not suffice at all to carry the manifold of regularities characterizing psychological processes in all their fullness. How to extend the boundary conditions for (A) in a nontrivial way in order to explain all psychological processes is unknown and, I predict, impossible to solve.

8. TOWARDS A CONSTRUCTIVE PSYCHOPHYSICAL DUALISM

In the previous section it was indicated that Maxwell's theory is compatible with psychophysical dualism in that the motion of point sources can be caused by operations of the mind. This compatibility is strikingly similar to Kant's view on how free will is compatible with deterministic reality. In the words of Munzel (1999, p. 73):

> As themselves "appearances in the world of sense," human beings are "one of the causes of nature whose causality must fall under empirical laws. As such, like all other natural things, they must accordingly also have an empirical character" (KrV A546/B574). Such laws of nature are, of course, laws of the understanding (in its strict, critical sense), but it would not "in the least detract from" the operations of the latter if one were to "assume that among the causes of nature, there are some which have an intelligible capacity," such that while the actions determined thereby are not empirically conditioned, yet in their appearance the actions are in complete accord with the laws of empirical causality (KrV A542/B570, A545/B573).

I consider such compatibility of free will and physical reality to be an essential ingredient of a constructive psychophysical dualism (cf. also Stapp, 1993, p. 91) and therefore it will be the focus of this section. The denotation 'constructive' should be understood as a formulation of psychophysical dualism that enriches psychological science. More specifically, the aim is to sketch the outline of a class of psychophysical dualistic models that can be used in empirical psychological research. In what follows, I will first delineate an appropriate theoretical model of physical reality, and then proceed with an interpretation of this model that points the way to a constructive psychophysical dualism.

The theoretical framework to describe physical reality should not be taken to be classical physics but, for the reasons given in Stapp (1993), quantum physics. Our preferred choice is the de Broglie–Bohm interpretation of quantum mechanics, the advantages of which in comparison with alternative (e.g., Copenhagen, modal, etc.) interpretations are explained in detail in Holland (1993; see also Dürr, 2001). In the simplest nonrelativistic case the de Broglie–Bohm interpretation yields a quantum theory of motion for a system composed of particle + wave. The wave is the solution to the Schrödinger equation:

$$i\hbar\partial\psi(\mathbf{r},t)/\partial t = (-\hbar^2/2m\nabla^2 + V(\mathbf{r},t))\psi(\mathbf{r},t) \quad \text{(B1)}$$

where i denotes the imaginary unit, $\hbar$ is Planck's constant divided by 2π, ∇ is the gradient operator, and $V(\mathbf{r},t)$ is the potential energy due to an external classical potential field. Writing $\psi(\mathbf{r},t) = R(\mathbf{r},t)\exp[iS(\mathbf{r},t)/\hbar]$, where $R \geq 0$ and S are real-valued fields, inserting this in (B1) and separating imaginary and real parts yields, respectively:

$$\partial R^2/\partial t + \nabla\cdot(R^2\nabla S/m) = 0 \quad (\mathrm{B1^a})$$

$$\partial S/\partial t + (\nabla S)^2/2m - \hbar^2/2m(\nabla^2 R/R) + V = 0 \quad (\mathrm{B1^b})$$

($\mathrm{B1^a}$)can be shown to be a conservation equation; ($\mathrm{B1^b}$) is a generalized Hamilton–Jacobi equation on which the particle + wave concept is based that underlies the de Broglie–Bohm interpretation (Holland, 1993, pp. 72–76). Both ($\mathrm{B1^a}$) and ($\mathrm{B1^b}$) will be discussed shortly; for now it is noted that $Q(\mathbf{r},t) = -\hbar^2/2m(\nabla^2 R(\mathbf{r},t)/R(\mathbf{r},t))$ in ($\mathrm{B1^b}$) is the *quantum potential*. The equation of motion for the particle is:

$$md^2\mathbf{r}/dt^2 = -\nabla V(\mathbf{r},t) - \nabla Q(\mathbf{r},t) \quad \text{(B2)}$$

where d/dt denotes the time rate of change with respect to a moving point in configuration space.

All the so-called nonclassical quantum effects (superposition, tunneling, etc.) are only due to the presence of the quantum potential field. The quantum potential Q is special in that it affects the particle, but is itself not affected by the particle. Another special property of the quantum potential is its independence of the intensity of the wave: multiplication of R by a real constant a does not affect Q (note that R itself is identified up to a multiplicative constant). Thus, contrary what one might expect in a classical wave, a particle does not respond to the intensity of the wave in its vicinity, but rather to its form. Accordingly, one can interpret Q as an 'information potential,' meaning that a particle moves under its own energy, but is guided by Q. Holland (1993, p. 91) qualifies this interpretation as follows: "...it should be emphasized that while the quantum field does not push on the particle as we might expect a classical wave to, it does nevertheless guide the particle by exerting a direct force on it via Q. The particle responds to more subtle features of ψ than the intensity. ...Moreover, the quantum potential energy is not generally small in comparison with the kinetic and classical potential energies...."

To introduce probability in the de Broglie–Bohm interpretation, consider an ensemble of identical particles + waves such that each element of the emsemble comprises a particle and wave that is indistinguishable, i.e., that obeys the same instances of (B1) and (B2), apart from freedom in initial conditions. We restrict attention to the case where we have maximal knowledge of the initial state of the wave part, i.e., $\psi(\mathbf{r},0)$ is fixed, but only partial knowledge of the initial particle position (cf. Holland, 1993, pp. 102–104 for the general case). Let $P(\mathbf{r},0)$ denote the distribution of initial positions. Then it is postulated in the de Broglie–Bohm interpretation that $R^2(\mathbf{r},0)$ is normalizable and $P(\mathbf{r},0) = R^2(\mathbf{r},0)$. It is noted that $R^2(\mathbf{r},0)$ satisfies ($B1^a$), consequently probability thus defined is properly conserved in time. With respect to this postulate, Holland (1993, p. 102) comments: "This introduction of probability is no more intrinsic to the basic [de Broglie–Bohm, PM] theory of motion than it is in classical mechanics, but is postulated for practical reasons. As to why the probability density should be given by R^2 and not some other function is at this stage left unexplained. In this regard we are in the same position as the conventional [Copenhagen, PM] approach where $|\psi|^2$ is postulated to represent a probability density for no other theoretical reason at all – it is justified *a posteriori* by comparison with experiment" (italics in original).

It is noted that $P(\mathbf{r},0)$ represents our partial knowledge about initial particle positions that in themselves are well defined. Infinitesimal differences in initial coordinates can be rapidly amplified (sensitive dependence of quantum motion on initial conditions) so that in the long run the motion is unpredicatable, yet deterministic (Holland, 1993, pp. 274–276). This interpretation of $P(\mathbf{r},0)$ as representing uncertainty due to the grossness of our instruments and the presence of random background noise corresponds with Stapp's (1993, p. 91) concept of probability as reflecting our partial knowledge of a world where "Naught happens for nothing, but everything from a ground and of necessity." Stapp (1993, p. 189) is positive about the de Broglie–Bohm interpretation, but complains that ``Bohm's model does however retain one feature of classical physics that can be regarded as objectionable, at least aesthetically. This is the need for an arbitrary-looking choice of initial conditions."

It is possible, however, to give an alternative probabilistic interpretation of the quantum potential in terms of the stochastic mechanics approach of Nelson (1985; cf. also Blanchard et al., 1987). Stochastic mechanics is based on the theory of diffusion processes. Hence there is no need to introduce probability in the way criticized by Stapp, although the role of probability in diffusion processes would seem to be more fundamental than the representation of partial knowledge of initial conditions (amplified by sensitive dependence) in an otherwise deterministic world. It will be shown that within stochastic mechanics a Hamilton–Jacobi equation can be derived that is equivalent to (B1^{b}), thus allowing for the identification of the quantum potential as being of purely diffusive origin.

What follows is based on Peña and Cetto (1996). Consider an ensemble of particles undergoing stochastic motion. Define two kinds of time derivative for the smoothed motion over time intervals that are much smaller than the characteristic time of the systematic motion, but much larger than the correlation time of the stochastic process. The first smoothed time derivative is the systematic derivative, $\mathscr{D}_{\mathrm{c}} = \partial/\partial t + \mathbf{v}\cdot\nabla$, where $\mathbf{v}(\mathbf{r},t) = \mathscr{D}_{\mathrm{c}}\mathbf{r}$ is the systematic velocity. For the simple case of an orthogonal isotropic process with common diffusion coefficient D (see Peña and Cetto, 1996, pp. 39–40, for the general case), the second smoothed derivative is the stochastic derivative, $\mathscr{D}_{\mathrm{s}} = \mathbf{u}\cdot\nabla + D\nabla^2$, where $\mathbf{u}(\mathbf{r},t) = \mathscr{D}_{\mathrm{s}}\mathbf{r}$ is the stochastic velocity. Using continuity and the Fokker-Planck equations associated with the spatial density $P(\mathbf{r},t)$ (e.g., Gardiner, 2004), it follows that the stochastic velocity equals $\mathbf{u} = D\nabla\ P/P$, while the systematic velocity can be written in the form $\mathbf{v} = 2D\nabla\ S$. The equation of motion then becomes: $m(\mathscr{D}_{\mathrm{c}}\mathbf{v} - \mathscr{D}_{\mathrm{s}}\mathbf{u}) = -\nabla V$, which, using the definitions of the derivatives, can be brought into:

$$2mD\partial S/\partial t + 1/2m(\mathbf{v}^2 - \mathbf{u}^2) - mD\nabla\cdot\mathbf{u} + V = 0 \quad (C)$$

(C) is of the same form as ($B1^b$), cf. also Nelson, 1985, p. 76. Substituting $D = \hbar/2m$ in (C), which is required in stochastic mechanics to recover the Schrödinger equation, it is seen that the quantum potential only depends upon the stochastic velocity:

$$Q = -1/2\hbar(m\mathbf{u}^2 + \hbar\nabla\cdot\mathbf{u})$$

With respect to the equivalence between ($B1^b$) and (C) Peña and Cetto (1996, p. 45) remark: "It is clear that the terms that give rise to the quantum potential come from the stochastic velocity **u**, and thus they have a kinematical (diffusive) meaning." Neither $\mathscr{D}_s$ nor **u** exist when the motion is regular, i.e., in the Newtonian limit, and the same holds for the quantum potential.

Having our preferred theoretical description of physical reality in place, we now introduce the following additional observations. Firstly, Kakutani (1944; cf. also Doob, 2001) has proven the formal equivalence of classical potential theory and diffusion theory. Secondly, we saw that the quantum potential can be interpreted as representing energy due to diffusive motions. Thirdly, the class of diffusion models is the most successful in explaining response times in elementary cognitive information processing tasks like the oddball task described above (cf. Luce, 1986, Chapter 9). Given Kakutani's result mentioned in the first observation, these diffusion models can be rewritten in terms of potential theory. Together these observations suggest to augment the diffusion models explaining cognitive response times with quantum potentials, thus arriving at an extended class of mathematical psychological models that are compatible with quantum physics. The reason for doing so is to arrive at a constructive psychophysical dualism as defined above, in which the quantum potential is considered to correspond with the operations of the mind. To defend this interpretation, I will argue that the special properties of the quantum potential correspond to central notions related to free will as expressed in the metaphysics of Duns Scotus.

Over the past thirty years there is a renewed attention for the philosophy of Duns Scotus (cf. Ingham and Dreyer, 2004; Williams, 2003). The affinities between Duns Scotus' metaphysics and quantum physics have been described from a more general perspective by Schmidt (2003). For our present purpose we will only consider the scotic notion of contingent causality. The following concise description is based on Sylwanowicz (1996; cf. Söder, 1999, for additional details about Scotus' theory of contingency). According to Scotus, the will and the intellect are powers of the individual, human soul. The human soul is conceived of as a self-moving process of activity that differentiates itself in two modes of causative action: natural causation (intellection) and contingent causation (willing). Contingent causality refers to the power to will X and the power to will not-X instantaneously, i.e., at the same time. The willed event X, while actual, is not necessary, nor is the truth of its existence a necessary truth. In contrast, natural causality is not capable of producing the opposite of the effect it is actually causing at the same time. Moreover, Scotus conceives of the free will as a self-moving instantaneous causative process that is unlike its effect, the act X. The act X is qualitatively different from the power to will X: it is not contained in it, nor is the possible act not-X contained in the power to will not-X. The act may be tainted (sinful), yet the power to will X is not and "*remains the sheer energy it was before, independent of the tainted actuality of the fait accompli*" (Sylwanowicz, 1996, p. 59; italics in original). A final aspect of Scotus' conception that is relevant for our purposes concerns the field character of the contingent causative process constituting the human free will. The activity intrinsic to this process can be present independently of a concrete unity which would keep it within its definite bounds. Accordingly, change is the result of a kind of "infection" by a quality which progressively, as an intrinsic process, imposes its presence onto a thing. There is no need for substantial contact. We have action at a distance (Sylwanowicz, 1996, pp. 174–176).

The above sketch of Scotus' conception of the human free will is conformable with Kant's compatibilism as expressed in our earlier quote from Munzel (1999). Five aspects of Scotus' notion of contingent causality appear to correspond with the properties of the quantum potential. Firstly, the superposition of the power to will X and the power to will not-X at the same time; an essential ingredient of contingent causality. The superposition in quantum mechanics is, as indicated above, due to the quantum potential. Secondly, the conception of the will as sheer energy; the quantum potential also is a form of energy. Thirdly, the evolution of the free will at a level different from the completed act and unaffected by the nature of this act, akin to the lack of influence of the particle on the quantum potential. Fourthly, the field character of the intrinsic activity essential to the instantaneous causative action at a distance of the will, which corresponds to the quantum potential being an energy field. Fifthly and finally, the apparent wholism of Scotus' ontology of self-differentiating self-moving processes is noted. For a corresponding wholistic interpretation of the quantum potential, see Bohm (1980).

9. CLOSING THOUGHTS

The constructive psychophysical dualism sketched in the previous section is based on the de Broglie–Bohm quantum potential, interpreted as representing energy due to diffusive motions. This makes possible to augment standard diffusion models of human information processing with quantum potentials. In this way a class of constructive mathematical psychological models is obtained that can be useful in putting suitable aspects related to psychophysical dualism to empirical tests. Five corespondences were noted between the quantum potential and Duns Scotus' conception of the contingent causal action of free will. Our description of a class of constructive models thus interpreted is no more than a first outline, a proposal based on plausibility arguments, in order to advance the interest in psychophysical dualism within psychological science. The possibility to construct plausible mathematical models that can be fitted to real data is an essential aspect of this endeavor.

In this paper, no philosophical arguments have been given in favor of psychophysical dualism. As to that, the reader is referred to Meixner's impressive treatise on this subject (Meixner, 2004); his Chapter IV presents eleven good arguments for dualism. Also the logical arguments given in Bringsjord and Zenzen (2003) I find very compelling in this respect. From the point of view of a working psychologist I can only add that each human person who seeks psychological advice or treatment, does so in ways that can only be fully understood and accommodated in terms of psychophysical dualism. This is how they understand themselves, their questions and their psychological problems. The complexities of a person's feelings, unique personality, ethical struggles and fictitious disabilities by far transcend any reductionistic physicalistic scheme currently conceivable. To paraphrase Cassirer (1953): A kinematical analysis would leave entirely unexplained the ethical motives of Socrates for taking the poison.[3]

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NOTE

[1] My published papers are listed at http://www.hhdev.psu.edu/hdfs/faculty/molenaar.html

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