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Models and theories of brain function in cognition within a framework of behavioral cognitive psychology

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Abstract

The present article presents a nonexhaustive collection of contemporary models and theories on brain function and discusses these models and theories within a framework of explanatory formulations in behavioral cognitive psychology. Such a mission was accomplished by evaluating the cognitive implications in the explanatory formulations with respect to established laws/principles and models/theories of behavioral cognitive psychology. The article also points to problem areas of behavioral cognitive psychology for which the explanatory formulations have solutions to offer. The article shows that the cinematographic hypothesis, the new visual model, the synergetic model, and the theory of whole-brain-work emphasize various aspects of perception. The formulations on P300 theory emphasize attention and also working memory. The theory on cognits is a comprehensive account of memory. Characteristic to all of these explanatory formulations and also to that on the complexity and its evolution and that on neurocognitive networks is the emphasis on selective distribution, integration to the point of supersynergy, and dynamicity. Such a viewpoint was not only applied to the operations of the brain but also of cognition. With such a conceptualization, the explanatory formulations could account for cognitive processes other than the ones emphasized. A common aspect in a majority of the formulations is the utilization of the oscillatory activity as the valid activity of the brain. The article points out that a frontier in cognitive psychophysiology would be the study of the genetics of brain oscillations.

Keywords: Models; Theories; Dynamic systems; Oscillatory activity; Cognition; Cognitive processes; Brain/mind issue

1. The explanatory formulations: models and theories

The present special issue includes formulations that explain how the brain functions during cognitive processing. The basic form of explanatory formulations is theory. Theoretical formulations are based not only on working hypotheses, empirically derived facts and operational identification, but also on postulates. Theories thus consist of generalized descriptions about interrelationships among postulates/abstract concepts which are created by inductive generalization. Theories also allow deductions from the interrelated postulates/concepts that are in the form of testable hypothesis (Underwood, 1957a,b; McGuigan, 1983; Holland et al., 1986). The function of postulated concept in theories is to bring independent phenomena of the brain and mind and also their relationship under a minimum number of assumptions.

Freeman makes the following general assumption: maintaining a stable state of self-organized criticality in the face of unpredictable variations in the environment requires continual aperiodic state transitions in the cerebral cortex. In the cinematographic hypothesis, he postulates frames. However, using appropriate electrode arrays and techniques of signal analysis, frames were shown to be neurophysiological entities. As repetitive amplitude-modulation/phase-modulation field patterns, frames occurred at the theta band and had carrier frequencies at the beta and gamma bands; they were thus transformed from postulates to measurable entities.

The explanatory formulations by Fuster and Başar are also empirical–postulational theories. The postulated process in Fuster's theory is the 'cognit'; in Başar's, it is the 'whole-brain-work'. The postulates on cognits and whole-brain-work are all

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scientifically sound concepts since, in all of them, the relationship of the postulates to the stimulus variables on the one hand and to the response variables on the other are well-defined. This is critical for ruling out the danger of ending up with a 'little man or midget' in the head that some postulates in the literature have ended up with.

Başar's theory on whole-brain-work is the first explanatory formulation in the literature where oscillatory activity is used in a comprehensive theory on the brain. The theory rests on one set of principles that describe the mechanisms according to which cognitive processes are represented by oscillations that are selectively distributed in the whole brain. The other set of principles describe the mechanisms that underlie the supersynergy or superbinding that the brain manifests during cognitive processing. These mechanisms describe integration over the spatial axis as integration of selectively coherent oscillatory activity; and integration over the temporal axis as specific amplitude and phase relationship between oscillations of various frequency bands (principle of superposition).

Some of the explanatory formulations are empirical in nature. They are not based on postulates but are in the form of operational identifications which are generalized from empirical findings and which help to keep the number of phenomena at a minimum (Bridgman, 1927).

The P300 theory by Polich and Criado represents an empirical explanation. It is based on intensive studies and research findings of Polich and his group as well as those of other scientists. One representation of the empirical nature of the P300 theory is the operational identification of novelty P300 with P3a as a result of which the separate existence of novelty P3 became unnecessary. Bressler and Tognoli formulation includes empirically derived operational principles that govern the organization and functioning of neurocognitive networks. These principles describe how networks are selectively structured and how they are also flexible.

As an explanatory system, a model represents an attempt to understand the unknown through the known. Models identify the events in the known system with those in the investigated system and shows that certain relationships among the terms in the known system hold for events in the investigated system (Conway, 1997; Cooper, 2002).

For Galambos, the word model is a general term that also includes theory. He accordingly identifies the formulations on bat echolocation, auditory tuning curves and the retinal functional units as models. However, like the empirically based explanation on P300, these are also empirical explanations; all are directly based on empirical data and all consist of what was experimentally obtained. The discovery of auditory tuning curves on pitch perception provided neurophysiological evidence for what was up to that point a collection of empirical data and postulational concepts. Analogously, the retinal functional units provided neurophysiological evidence for also the concept of top-down processing on visual perception.

Bullock's formulation is based on a concept that is generalized from empirical findings: complexity. It is acknowledged in the formulation that the clearly simpler and more advanced phyla, classes and orders can be ranked with respect to the degree of complexity in anatomy, physiology and behavior. However, the empirically oriented Bullock points out that measuring different grades of complexity, i.e. assigning even semi-quantitative data, has as yet not been possible. Accordingly, it may be that the existing techniques are not yet appropriate to measure this general concept; it may also be that the concept needs to be revised.

Haken's formulation represents an explanatory model. He conceives the brain as a synergetic system and applies control parameters, order parameters and the slaving principle whereby synergetic systems are analyzed. The concepts that characterize synergetic systems, namely instability, self-organization and emergence of new qualities, are used in explaining physically measured global events and psychological phenomena. The model allows deductions that can account for a spectrum of phenomena ranging from perception to consciousness.

Explanation is ultimately a statement about the cause of an event. At Gregor Mendel's time, the word 'gene' was a postulational concept. If Begleiter and Porjesz had conducted their studies at Mendel's time, they would have inferred a 'genetic' structure/process that intervened between the observables as causing the response typical to a specific disorder, e.g. alcoholism. At present, genes are observable and measurable biological entities. Begleiter and Porjesz study the observable and measurable genes and show that they are among the causal factors of complex psychiatric disorders.

2. Specific cognitive processes and the related explanatory formulations

The present section discusses the models/theories of the present issue. These discussions were made with respect to the laws/principles and models/theories that take place within the established literature of behavioral cognitive psychology (Anderson, 1995, 1996; Seager, 1999; Eysenck, 2001; French and Cleeremans, 2002; Parker et al., 2002).

2.1. Rationale for choosing behavioral cognitive psychology as reference

The scientific study of cognition dates back to the founding of the science of psychology, which was then named physiological psychology. According to the founder, Wundt (1904), the legitimate areas were sensation, perception and emotion. Shortly after, higher mental processes were also included in the 'new' psychology, due largely to experimental studies of Ebbinghaus (1885/1913) on memory. The progress in the field halted for a brief period of time between 1950 and 1970 because of the impact of classical/radical behaviorism which held that mental concepts are unnecessary when explaining behavior (Boring, 1950). Behavioral cognitive psychology re-emerged, however mainly due to the developments in information theory, artificial intelligence and linguistic (Eysenck, 2001). In this reemergence publication of Miller's (1956) article, 'The magical number seven, plus or minus two…' and the book of Neisser (1967), 'Cognitive Psychology' were milestones.