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International Journal of Psychophysiology 60 (2006) 186 – 193

INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY

www.elsevier.com/locate/ijpsycho

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

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Received 10 December 2005; received in revised form 23 December 2005; accepted 23 December 2005
Available online 28 February 2006

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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doi:10.1016/j.ijpsycho.2005.12.011

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 semiquantitative 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.

Studies on cognition thus have a history as old as the science of psychology itself. Experimental cognitive psychology, the discipline which studies cognitive processes on the basis of gross behavioral responses, is largely based on experimental studies on normal individuals. The scientific observation of the cognitive phenomena, the formulation of laws/principles that govern the relationships and the models/theories that explain them have largely been achieved in experimental cognitive psychology. Other approaches such as cognitive neuropsychology, cognitive science, and cognitive neuroscience that deal with cognition use the information in behavioral cognitive psychology as their starting point. (Anderson, 1995, 1996). In fact, any reference to cognition has to take into account the reliable phenomena and the explanatory formulations of cognitive psychology. The present survey discusses the extent to which the explanatory formulations in this special issue account for these models and theories.

Meanwhile, what can be observed in cognitive psychology are only the stimuli and the gross behavioral response. In behavioral psychology, cognition is not directly observed; it is an intervening variable which can only be inferred from the functional relationship between the stimulus and response The intricate experimental designs and sophisticated techniques of statistical analysis are all for achieving valid inferences on this intervening variable. The models/theories in this special issue, on the other hand, are based on electrophysiological representations of cognitive processes and these can be directly observed and measured. These explanatory formulations are thus in a position to offer solutions to some of the problems in behavioral cognitive psychology. Accordingly, besides discussing the explanatory formulations within the context of the information in behavioral cognitive psychology, the present section points to some of the solutions that the explanatory formulations in this special issue offer to the problems inherent to the field of behavioral cognitive psychology.

2.2. Perception

A debate in behavioral cognitive psychology has been on whether stimuli are directly perceived or whether perception is an active, constructive process that is influenced by the observer's hypotheses, expectations and knowledge about the stimuli. According to the direct approach (Gibson, 1950), there is enough information available in sensory stimulation than is generally realized, especially when the observer is in motion. According to the constructivist approach (Bruner, 1957; Neisser, 1967; Gregory, 1980), perception is much more complicated than is assumed by Gibson. Attachment of meaning is a critical part of perception and this includes expectations, knowledge, motivations and emotions, shortly, the context.

Among the nine explanatory formulations in this special issue, five directly deal with perception. The theory of Galambos on the visual system resolves the controversy between the two perceptual approaches in cognitive psychology. The morphology of the optic nerve volley that the retinal functional units (RFUs) deliver was found to be similar to the field potentials that are recorded from the structures higher up in the system, from the optic chiasm and the visual cortex. These findings show that the information retina acquires during one fixation, as represented by an RFU, determines the potentials higher up in the system. Accordingly, mutilation of RFU's results in systematic changes in perceptual experience. These findings support the direct theory of perception. On the other hand, sleep was found to modulate the rat RFU amplitude, suggesting that the retina is continuously under brain control. Similarity between the retinal RFU and visual evoked potential decreased as luminance levels decreased. This suggests the influence of the higher centers at the lower luminance levels whereby meaning would be ascribed to imperceptible or ambiguous stimuli. These findings support the constructivist theories and indicate that perception is a top-down process. In all, the new visual system model shows that both behavioral theories of perception are valid. The applicability of the theoretical explanations may vary in different stimulus configurations and this would depend on a host of factors, two of which are stimulus ambiguity and uncertainty.

Stimulus context has a modulatory role in perception; context includes expectations, emotion and motivation. A test of Galambos's model may thus include the effect of these variables on RFU's. It also remains to be seen whether the new visual system model is specific to only visual perception; or it would be gradually transformed into a general model of perception with the to-be-discovered analogues in the other modalities.

Another group of established theories in behavioral cognitive psychology pertains to the parameters or processes of object recognition, another major topic of perception. Among these well-known theories are template matching, feature analysis, computational approach and recognition by components (Neisser, 1964; Marr, 1982; Biederman, 1987; Larsen and Bundesen, 1992). Central to all these theories is an attempt to find an object/pattern in long-term memory that best fits the presented stimulus. In template theory, the comparison is made to a miniature copy; in feature analysis, to a combination of features; in computational approach, to three-dimensional representations that are described through edge, contour, blob, depth, orientation, shading, motion, texture, shape, binocular disparity; and in recognition by components, to a configuration of geons (geometric ions) that are described with edge (necessitating all characteristics that the computational model uses) along with contour and geometric shapes. These theories are applicable to a specific set of stimuli and dimensionality (template and feature analysis to two dimensional patterns, computational approach and recognition by components to three-dimensional objects); all are bottom-up; all work for stimuli that observer is already familiar with; and finally, all fail to take into account the effect of context (Anderson, 1995, 1996; Bechtel and Graham, 1998; Eysenck, 2001).

The preceding discussion shows that each behavioral theory of perception relies on different sets of stimulus characteristics or parameters. The cinematographic theory of perception relies on frames or wave packets and uses an entirely different set of parameters that consist of time range, carrier frequency, mean pattern duration and diameter. The tests of the theory show that, regardless of modality of stimulation but only for conditioned stimulus that is followed by reinforcement, there is an early, small pattern in the related primary sensory area; this early stage is characterized with carrier frequency in the gamma band. Some 500 ms later, there is a large pattern over multiple sensory areas; this later stage of processing is characterized with carrier frequency in the beta band. In stimulus not followed by reinforcement; the carrier frequency demonstrates pattern and texture differences. Experimental tests will show whether and to what extent these electrophysiological parameters overlap with the cognitive parameters. In case the electrophysiological parameters sufficiently represent objects for their valid recognition, the parameters in the cinematographic hypothesis will replace the numerous and usually irreconcilable parameters of object recognition that exist in the behavioral cognitive theories.

Another approach that presently dominates the field of perception originates from the Gestalt school. According to the laws of organization that were originally formulated by such representatives of Gestalt psychology as Wertheimer, Koffka and Köhler 'the whole is greater than the sum of its parts' (Köhler, 1942; Asch, 1946). Accordingly, mere knowledge on stimulus parameters is not sufficient for predicting how the stimulus will be perceived. The critical factor in perception is how stimuli are organized. Presently, Gestalt principles have an important place in contemporary cognitive psychology. The shortcoming of the Gestaltian approach is that these principles describe perception but can not explain it. They can not provide answers to why there is such an organization. In the cinematographic theory, large patterns integrate local patterns in multiple modalities; this is why the stimulus is perceived as an organized whole or as a 'gestalt'. Future work will show whether this integration will sufficiently explain why perception occurs according to the gestalt laws of organization.

Another answer to why perceptual organization occurs is provided by Haken in his synergetic model. The experience of reversing percepts is a phenomenon that Gestalt psychologists were very much interested in and they had described it through the law of figure-ground organization. Haken explains this phenomenon through the oscillation of order parameters. Each specific reversal and the related percept is the result of one of the order parameters. Similarly, changing percepts that are obtained upon ambiguous stimuli are explained through the bistability of order parameters.

Perception of faces basically depends on visual perception. However, being a complex phenomenon, the explanatory formulations that had been developed for visual perception could not sufficiently account for face perception. Models and theories had thus to be furnished with a set of parameters that is unique to it. The well-known model of Bruce and Young (1986) makes use of a total of eight processes. Recognition of familiar faces requires structural encoding, face recognition memory units, stored information on personal identity, and generation of the stored name. Processing of unfamiliar faces requires, besides structural encoding, facial expression analysis, facial speech analysis and selective visual processing. In the interactive activation and competition model (Burton and Bruce, 1993), these parameters are designed into a connectionistic system of interrelated factors.

Face recognition is explained by Başar within the context of the theory of whole-brain-work. As would be predicted from the behavioral theories, the configuration of oscillatory responses and the characteristics of these responses were found to differ for flash stimuli and for faces, even though both were visually presented. Also in line with the behavioral theories, the characteristics of the oscillatory responses differed for the familiar and unfamiliar faces. A task for future studies on the theory of whole-brain-work may be to use the experimentally tested parameters of the behavioral models as stimuli and make an in-depth investigation of the oscillatory dynamics of face perception. Such studies may delineate the neural basis of the behaviorally derived parameters and also provide a robust framework by which the phenomenal meaning of the various oscillatory responses can be evaluated.

2.3. Attention

Information processing operates on a system with limited resources; the process of allocating the limited resources is called attention. The explanatory formulation in this special issue that directly touched the issue of attention is the P300 theory of Polich and Criado. According to this theory, P300 generation originates from an interaction between frontal lobe (P3a) and hippocampal/temporal–parietal (P3b) activity. The P3a subcomponent, which is specifically obtained when discriminability of the target is low and/or distracter stimuli is highly salient, represents the outcome of the interruption of the focal attention to the task. It thus represents the disruption of attentional engagement during task processing. Accordingly, P3a represents a case of divided attention where, as with P3a, similarity, difficulty, and novelty of stimuli have a negative effect on behavior.

The divided attention, the ability to attend to more than one stimulus simultaneously, is specifically explained in behavioral cognitive psychology by theories on central capacity and multiple resources (Kahneman, 1973; Norman and Bobrow, 1975; Wickens, 1984). Although these theories tap the very essence of attention, namely, allocation of resources; behavioral theories on capacity suffer from vicious circularity. In these theories, response variations are attributed to variations in capacity and variations in capacity are in turn inferred from response variations. Concepts on capacity could thus not be operationally defined and this made their scientific value disputable. P300 theory shows that P3a can be used for measuring the degree to which focal attention to a primary task is disrupted by the attention-demanding distracter stimuli. The amplitude and variations in P3a may thus provide valid measures on the capacity, a process the behavioral theories of attention could not satisfactorily measure.

The amplitude of P3b represents the executive control of attention, or using a related term, focused attention (Mesulam, 1990; Posner and Petersen, 1990). The focusing of attention (selective attention) and the time-sharing operations in dual-task conditions are controlled by the central executive (Baddeley, 1986, 1997). This is one of the three main components of working memory; P3b is thus also related to working memory operations. The central executive has a limited capacity which can not, however, be easily measured by the techniques of behavioral cognitive psychology. P3b, it's amplitude and latency variations, provide a means for measuring, this time, the capacity of the central executive.

Though not as closely involved as the P300 theory, other explanatory formulations in this special issue also treat attention. The cinematographic theory suggests that selective attention can be represented with a specific amplitude-modulation pattern sequence in the prestimulus interval. According to the synergetic model, attention operates through the closing and opening of quasi-attractors which are governed by different order parameters.

As did also the early theories of behavioral cognitive psychology (Broadbent, 1958; Deutsch and Deutsch, 1963; Treisman, 1964), the explanations in this special issue have mainly been on selective and focused attention. Attention, however, is a complex phenomenon. Besides the aforementioned ones, attention involves orientation, vigilance, effort, arousal and activation (Kahneman, 1973; Norman and Bobrow, 1975; Sokolov, 1975; Wickens, 1984). Other alternative approaches discriminate the sensory, motor and motivational components of attention; or emphasize executive control (Posner and Petersen, 1990; Baddeley, 1997). It may be expected that in the near future, the explanatory formulations in this special issue will be so modified as to account for also these different processes that pertain to attention.

2.4. Memory

The explanatory formulation in this special issue that directly deals with memory is Fuster's theory on cognits. According to this theory, information acquired through the senses make up the perceptual memory; this includes phyletic sensory, polysensory, episodic, semantic and conceptual memory. Information related to movement make up the executive memory; this type includes phyletic motor memory, acts, programs, plans and conceptual memory for actions. Although differentiated as such, the neurophysiological bases of these functions are distributed, interactive, overlapping and hierarchically organized. It follows that the different forms of memory are also highly interrelated, vertically within cognits and horizontally between cognits. According to the theory, there is thus not only a hierarchical but also a heterarchical organization of memory and the memory code is essentially a relational one.

Behavioral studies did find that there are different types of memory and such findings formed the basis of theories on episodic and semantic memory (Tulving, 1972), implicit and explicit memory (Graf and Schacter, 1985), declarative and nondeclarative memory (Squire, 1992). Meanwhile, other behavioral studies and especially studies on amnesic patients indicate similarities and inter-connections between the episodic and semantic memory. Fuster's theory, where different forms of memory evolve from each other and all ultimately evolve from phyletic memory, shows that interrelation between episodic and semantic memory is not only possible but is also the more natural occurrence. Fuster's theory shows that behavioral cognitive psychology has to re-think the validity of discrete forms of memory.

The cognits theory does not only explain memory but also allows deductions on a spectrum of processes that here-to-forth received independent treatment in cognitive psychology. Among these processes are attention, face recognition, working memory, language, creativity and intelligence. If diverse processes of cognition all have memory as the common factor, then memory is, ultimately, the common paradigm or the basic law of cognition, a statement that describes a relationship by which nature operates. Future research will show whether such a generality is valid.

Memory has always been the major area of interest in behavioral cognitive psychology. In this field, experimental studies have distinguished subprocesses of memory, and these have led to laws and theories about memory. Any general theory on memory has either to assimilate these into its framework or has to show that the findings and formulations are not valid. Memory starts with the encoding and storage operations. Multistore model of memory delineated the sensory, short-term and long-term stores and these were differentiated on the basis of temporal duration, storage capacity, forgetting mechanism and effects of brain damage (Atkinson and Shiffrin, 1968). In the working memory model, there is an active processing of phonological and visuospatial stimuli and a central executive that controls rehearsal and storage (Baddeley, 1986, 1997). Conditions for the degree of stability of long-term memory traces were described by the levels of processing theory (Craik and Lockhart, 1972); strength of the memory trace was described through the power law of learning (Newell and Rosenbloom, 1981); accessing a memory was explained by activation theories and through the concept of spreading activation (Anderson, 1996); retention and retrieval processes in memory were described by the power law of forgetting (Wickelgren, 1975). Other established explanations in behavioral cognitive psychology on memory include trace theory, the theory of cue-dependent forgetting, schemas (Bartlett, 1932; Tulving, 1974). Whether the comprehensive theory by Fuster will be able to account for the various aspects of memory that were treated by the explanatory formulations in behavioral cognitive psychology will be demonstrated by future research.

3. Dynamic systems

The information processing models represent one of the basic approaches in behavioral cognitive psychology. According to these models, cognitive processes are sequentially organized toward a response (Sternberg, 1969). Another basic approach in behavioral cognitive psychology reduces the abstract accounts in information processing models to basic elements. According to the working hypothesis in this approach, higher level functions can be achieved by connecting together basic elements. Such a hypothesis is highly plausible since it is based on associationism, the oldest law of behavior. According to connectionism, the basic units are neural-like elements; they accumulate activation and send inhibitory and excitatory influences to other units. Advanced forms of such models ended up in parallel and distributed networks. McClelland and Rumelhart (1981) explained word-perception through parallel and distributed networks; propositional models used networks of nodes and links in explaining propositional information; semantic network models explained conceptual knowledge again using such an organization (Quillian, 1966).

However, the connectionist models have the following shortcomings when it comes to explaining human cognition. The models and the neural networks are passive things whereas human behavior is intentional and goal-directed. Cognition shows emergent properties which connectionist models can not simulate. Finally, a connectionistic model is built by some external being whereas biological systems evolve, and this evolution not only has a quasi-directed element (better adapted ones produce more offsprings) but also a random element (random genetic variations). The better alternative to cognition would thus be to treat it as a dynamic process since, as other dynamic systems, cognition changes over time; it models the continuously changing nature of states; there are multiple, simultaneously occurring interactions between different operations of cognition; and there is a self-organization in cognition that leads to emergence of new properties (in this special issue: Başar; Bressler and Tognoli; Bullock; Freeman; Fuster; Haken; also see James, 1890; Elman, 1998).

The theories and models in this special issue consider the brain as a dynamic system that operates on the basis of selectively distributed networks which work in an integrative fashion. The dynamic structure of the brain is used as the basis of cognition, an entity to whose nature dynamic operation is much more suitable. In Başar's theory of whole-brain-work, the valid indices of brain activity and cognition are the oscillations. The theory asserts that there is a selective distribution of these oscillations in the brain and there is selective cooperation among the related brain structures. The extent of this cooperation is such as to produce superbinding and/or supersynergy. This leads to a reciprocal interaction of attention, perception, learning, and remembering, the SLPR alliance. In the brain, there is thus a fusion in function, space, and time.

The theory of Bressler and Tognoli on neurocognitive networks explains the coordination dynamics of the brain and of cognition. Brain becomes selectively structured through temporal, spatial and coordinative selectivity. As applied to cognition; attention, for example, is selectivity of the coordination process in advance of and during processing, and working memory is the persistence of a state of coordination over time in the absence of behavior. The mark of dynamic systems is flexibility. The selectively structured system in Bressler and Tognoli theory is endowed with flexibility through interareal constraint. The brain in this theory has thus an ever-changing neural context and within this evolve the dynamics of local assemblies. Such a dynamics allows for a flexible formation of cognitively relevant coordination patterns and thus a dynamic cognition that evolves through a set of coordination states.

Theory of oscillatory neural assemblies and theory of neourocognitive networks directly attack the dynamics issue and provide its principles. Even if not the main concern, all models/theories in this special issue regard the brain and cognition as dynamic entities that require patterns highly complex of selective interactions between all levels. The most characteristic feature of Fuster's theory is the hierarchical and heterarchical interconnections between a spectrum of processes that range from the phyletic to the conceptual, and from the perceptual to the executive. Freeman's theory basically explains perception. According to this theory, however, neocortex comprises a scale-free network as a result of which it can form almost instantly spatial patterns of any size from several hypercolumns to a whole cerebral hemisphere. This is how gestalts, perceptual wholes, get formed. This is how the brain is remarkably flexible when it comes to adapting to unexpected situations but yet it can also maintain a stable identity and order in the face of rapid change. Dynamic systems are marked with self-organization and emergence of new properties. Haken's synergetic model directly attacks these characteristics and explains the brain and cognitions through control and order parameters and the slaving principle. Dynamic systems are complex and they evolve. Bullock treats exactly these two concepts, basing his formulations on numerous experimental studies on species that represent different parts of the evolutionary scale.

The visual model of Galambos and the P300 theory of Polich and Criado show the relevance of dynamicity and selective integration at the level of not the whole brain but at a level of selected functional systems. According to the visual model of Galambos, perception is the result of the dynamic interaction between bottom-up and top-down processes involving structures at all levels of the visual pathway. According to Polich and Criado, the cognitive processes that are related to P300 are a consequence of the dynamic interactions between P3a and P3b, and the interactions in the brain structures that produce them.

4. Closing remarks

The present article discusses the theories and models on brain function within the framework of established explanatory formulations in behavioral cognitive psychology. Cognition (cogito) pertains to all internal mental processes; an exceedingly large area. The models and theories in this special issue were concentrated on selected processes in cognition. However, in almost all formulations selective distribution, integration to the point of supersynergy, and dynamism characterized the brain and cognition. In such systems, components—be it neural or cognitive—do not exist in isolation but are realized within the context of an integrated whole. With such a conceptualization, the explanatory formulations in the issue could be adapted to also some other cognitive processes. Future research will show the degree to which these models and theories will account for the spectrum of cognitive processes that make up the standard topics of behavioral cognitive psychology (Anderson, 1995; Baddeley, 1997; Seager, 1999; Eysenck, 2001; French and Cleeremans, 2002; Parker et al., 2002).

All explanatory formulations in this special issue were based on electrophysiological data and most of the formulations were tested on humans and infrahumans. In defining complexity, Bullock used many indexes, yet he could not find complexity differences in the evoked or spontaneous potentials between simpler and more complex species. There seems to be a dilemma here: studies show and explanatory formulations assume that brain is a dynamic system and that cognition can also be explained through the workings of such a system. Yet differences in complexity, a mark of the dynamic systems, can not be obtained in the evolutionary scale. Could it be that complexity differences are not quantitative but are qualitative; could it be that, being unique to each level in the evolutionary scale, they have to be defined by different sets of parameters? Is a specific complexity configuration an emergent property for a given level? The question posed by Bullock on how brains evolve complexity is vitally important for the formulations on dynamic systems.

Galambos points out that unsolvable problems usually await new techniques and new paradigms. One time, the paradigm change was the study of oscillatory responses next to and possibly in preference to the time-domain potentials (Berger, 1929; Mountcastle, 1992). There were times when the reliability and validity of the oscillatory responses were discussed. Presently, the question is no more on these points. So much so that many of the explanatory formulations presented in this special issue are based on the oscillations of the brain. Science seeks for causality and for the empirically minded scientist, the independent variable is the cause. Yet, science seeks for the ultimate cause; these are sometimes defined as postulates and research then shows that the postulated is an objectively measurable entity. What are the ultimate causes of the oscillations? This special issue presents a new paradigm and related techniques that may guide the search for the ultimate cause: the study of genetics. The paradigm change of the present may thus be the approach of Begleiter and Porjesz, namely, the study of the genetics of the brain oscillations. These authors open new horizons to cognitive psychophysiology and, at large, neuroscience, especially since the genetics is not of the oscillations only, but as is demonstrated by the authors and in line with the approach of psychophysical interactionism, also of cognition.

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