Chapter 8
Whole-Brain Work

8.1 The Theory of the Whole-Brain Work: An Approach to Brain Function by Means of Brain Dynamics

Chronological evolution of our conceptual framework evolved in the last 20–25 years and is based on empirical foundations from several laboratories.

The theory of whole-brain work proposes that integrative brain function is based on the coexistence and cooperative action of many interwoven and interacting sub-mechanisms. In its extension, the theory includes mechanisms that consist of super-synergy, superbinding and reciprocal interaction of attention, perception, learning, and remembering (APLR-alliance). This theory is based on empirical evidence and can be described in a number of sub-mechanisms.

In the following discussion, these mechanisms were grouped under four structural and/or functional levels.

8.1.1 Level A: From Single Neurons to Oscillatory Dynamics of Neural Populations

1. The neuron is the basic signaling element of the brain.
2. Since morphologically different neurons or neural networks are excitable upon sensory-cognitive stimulation, the type of the neuronal assembly does not play a major role in the frequency tuning of oscillatory networks. Research has shown that neural populations in the cerebral *cortex, hippocampus*, and *cerebellum* are all tuned to the very same frequency ranges, although these structures have completely different neural organizations (Başar 1998, 1999; Eckhorn et al. 1988; Llinas 1988; Singer 1989; Steriade et al. 1992). It is therefore suggested that all brain networks communicate by means of the same set of frequency codes of EEG-oscillations.
3. Intrinsic oscillatory activity of single neurons forms the basis of the natural frequencies of neural assemblies. Oscillatory activity of the neural assemblies of the brain consists of the alpha, beta, gamma, theta, and delta frequencies.

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These frequencies are the natural frequencies and thus the real responses of the brain (Başar et al. 2001a–c).

4. *Feature detectors* (Sokolov 2001), *place cells*, and *memory cells* (Fuster 1995a) are empirically established neural elements. However, a crucial turning point occurred with so-called “grandmother” experiments, which showed that large groups of neural populations were selectively activated on complex semantic and episodic inputs to the brain, and that complex percepts cannot be processed only by means of cardinal cells (Başar 2004; Bullock 1992; Edelman 1978, and experiments described in Sect.8.1.3). In attempts to describe the integrative functions of the brain, these experiments, and other similar studies, replaced the functional role of the single neurons with neural assemblies (Başar et al. 2001a). The emphasis on neural assemblies is the major point that differentiates our theory from Sherrington’s neuron doctrine and Barlow’s new perception doctrine (Barlow 1995).
5. Sokolov (2001) has excellently described and also constructively criticized the role of feature detectors. However, integrative functioning of the brain requires the selectively distributed and coherent neural populations in concert with the feature detectors.
6. The brain has *response susceptibilities*. These susceptibilities mostly originate from its intrinsic rhythmic activity, i.e., its spontaneous activity (Başar 1980, 1983a, b; Başar et al. 1992; Narici et al. 1990). A brain system responds to external or internal stimuli with those rhythms or frequency components that are among its intrinsic (natural) rhythms. Accordingly, if a given frequency range does not exist in its spontaneous activity, it will also be absent in the evoked activity. Conversely, if activity in a given frequency range does not exist in the evoked activity, it will also be absent in the spontaneous activity.

The rule of response susceptibility is demonstrated and explained in detail in Chapter 11 as well as included in the discussion of Chapter 21.

7. There is an inverse relationship between EEG and event-related potentials. The amplitude of the EEG thus serves as a control parameter for responsiveness of the brain, which can be obtained in the form of evoked potentials or event-related potentials (Barry et al. 2003; Başar 1998; Başar et al. 2003; Rahn and Başar 1993a).
8. The EEG is a *quasi-deterministic or a chaotic signal* and should not be considered as simple background noise (see also Chapter 14). This characteristic, and the concept of response susceptibility, lead to the conclusion that the oscillatory activity that forms the EEG governs the most general transfer functions in the brain (Başar 1990).
9. Oscillatory neural tissues that are selectively distributed in the whole brain are activated on sensory-cognitive input. The oscillatory activity of neural tissues may be described through a number of response parameters. Different tasks and the functions that they elicit are represented by different configuration of parameters. Because of this characteristic, the same frequency range is used in the brain to perform not just one but multiple functions. The response parameters of the oscillatory activity is as follows: enhancement (amplitude), delay (latency), blocking or

desynchronization, prolongation (duration), degree of coherence between different oscillations and degree of entropy (Başar 2004; Başar et al. 1999a, b; Kocsis et al. 2001; Miltner et al. 1999; Neuper and Pfurtscheller 1998a, b; Pfurtscheller 1997, 2001; Pfurtscheller et al. 1999, 2006; Rosso et al. 2001, 2002; Schürmann et al. 2000).

10. The number of oscillations and the ensemble of parameters that are obtained under a given condition increase as the complexity of the stimulus increases, or as the recognition of the stimulus becomes difficult (Başar 1980, 1999; Başar et al. 2000, 2001a). For comparison of stimulation with complex signals, the reader is referred to Chapter 12.

8.1.2 Level B: Super-Synergy of Neural Assemblies

According to the theory of whole-brain work, super-synergy consists of the following mechanisms (numbers 11–18):

11. In simple binding, there is temporal coherence between cells in cortical columns. This has been demonstrated by several authors (Eckhorn et al. 1988; Gray and Singer 1989).
12. Each function is represented in the brain by the superposition of the oscillations in various frequency ranges. The values of the oscillations vary across a number of response parameters (Principle 9). The comparative polarity and phase angle of different oscillations are decisive in producing function-specific configurations. Neuron assemblies do not obey the *all-or-none rule* that the single neurons obey (Chen and Herrmann 2001; Karakaş et al. 2000a, b; Klimesch et al. 2000a, b).
13. The *superposition* principle indicates synergy between the alpha, beta, gamma, theta, and delta oscillations during performance of sensory-cognitive tasks. Thus, according to the superposition principle, integrative brain function operates through the combined action of multiple oscillations (see also Sects.8.1.3 and 8.1.4).
14. The *response susceptibility* of the brain activates resonant communications in the brain by facilitating electrical processing between networks (Başar 2004; Başar et al. 1997a, b). This could also be interpreted as a general tuning process between neural populations and feature detectors (Sokolov 2001).
15. *Parallel processing in the brain shows selectivity*. The selectivity in parallel processing is produced by variations in the *degree of spatial coherences* that occur over long distances between brain structures/neural assemblies (Başar 1980, 1983a, b; Başar et al. 1999a; Kocsis et al. 2001; Miltner et al. 1999; Schürmann et al. 2000).
16. Temporal and spatial changes of entropy in the brain demonstrate that the oscillatory activity is a controlling factor in the functions of the brain (Beim-Graben 2001; Beim-Graben et al. 2000; Quiroga et al. 2001; Yordanova et al. 2002).
17. The *superbinding* mechanism can be denoted, according to the previous explanations, as an ensemble of mechanisms consisting of “superposition,

activation of selectively distributed oscillatory systems, and the existence of selectively distributed long distance coherences." The concept of *super-synergy* includes superbinding and, additionally, entropy, and the role of EEG-oscillations as control parameter in the brain's responsiveness.

18. *Complex matching in the whole brain* is proposed as a mechanism contributing to the machineries of memory and remembering (see especially Figs.7.5 and 7.6).

8.1.3 Level C: Integration of Attention, Perception, Learning, and Remembering

Extension of the theory of whole-brain work to cognitive processing is governed by the following principles:

19. *All brain functions are inseparable from memory function* (Fuster 1995, 1997; Hayek 1952). As in all integrative brain functions, memory is manifested as multiple and superimposed oscillations. A specific superposition of oscillations, each of which is characterized by the response parameters in Item 9, represents the configuration that is specific to the given type of memory.
20. *Attention, perception, learning and remembering* (APLR-alliance) are interrelated. As the grandmother experiments demonstrated (Başar 2004; Başar et al. 2003), memory-related oscillations are selectively distributed within the brain. They have dynamic properties and evolve on exogenous and endogenous input to the brain. Memory states have no exact boundaries along the time space. There is a hierarchical order that takes place on a continuum, but the boundaries of memory states merge into each other. Memory functions, from the simplest sensory memories to the most complex semantic and episodic memories, are manifested in distributed multiple oscillations in the whole brain.
21. In our theoretical framework, we introduced the expression evolving memory or memory building. The critical factor in memory building is the APLR-alliance. This concept represents a constant reciprocal activation within its sub-processes. Evolving memory has a controlling role in integrative brain functions (Barry et al. 2003a; Edelman 1978; Tononi et al. 1992). The hierarchy of memories is not manifested with separable states, since the memory manifests rapid transitions. Therefore, we suggest using the term memory states rather than memory stores,a concept in which memory is considered to take place in successive stages. These explanations do not apply, however, to persistent memory, which can be inborn or obtained through over-learned engrams or habits (see also Chapter 7).

8.1.4 Level D: Causality in Brain Responsiveness

To discover the cause of an event is to discover something among its temporal antecedents such that, if it had not been present, the event would not have occurred. In the introduction causality was described as conceptualized by Newton, Galileo, and Einstein. The present section considers causality as it pertains specifically to the responsiveness of the brain. The theory of whole-brain work presently considers three groups of factors as causes of the brain responses.

8.1.4.1 Genetically Fixed Causal Factors

The brain and the CNS-ganglia contain genetically coded networks. The phyletic memory networks that are inborn play essential roles in the responsiveness of neural populations. Accordingly, (1) occipital networks in the mammalian brain respond to light stimulation with enhanced 12 Hz oscillations (Başar 2004). On the other hand, temporal auditory areas that do not react to light stimulation respond to auditory stimuli with 10 Hz enhanced oscillations. (2) The ray brain reacts with 10 Hz oscillations to electrical stimuli (electroception); the human brain, on the other hand, does not have this ability (Başar 2004). (3) Like alpha networks, there are selectively distributed gamma networks in the brain. These networks show obligatory responses to sensory stimuli (Karakaş and Başar 1998). (4) Reflexes are genetically coded. The so-called “pre-potent responses” (Miller 2000) in reflexive actions also partially represent this type of causality. (5) The findings of Sokolov (1975) on the orienting response and the genetically fixed causal factors have to be emphasized: There are expectation cells that fire on expected input; sensory-reporting cells, which fire in response to actual stimulus; and comparator cells, which fire whenever there is a discrepancy between stimuli (Başar 2004).

The group of Begleiter and Porjesz (2006) recently launched a fundamental approach to examine the genetic underpinnings of neural oscillations. It is proposed that the genetic underpinnings of these oscillations are likely to stem from regulatory genes, which control the neurochemical processes of the brain, and therefore influence neural function. According to the work of this group, genetic analysis of human brain oscillations may identify genetic loci underlying the functional organization of human neuroelectric activity, and brain oscillations represent important correlates of human information processing and cognition.

Present behavior influences immediate future behavior. The plasticity in this adaptive behavior is demonstrated in the oscillations, showing that oscillatory plasticity is an additional causal factor in brain responsiveness. In auditory and visual memory task experiments, the EEG oscillations manifest a high degree of plasticity: The reciprocal activation of the APLR alliance (Başar 2004) also affects the future responsiveness of the brain, attesting to the presence of *oscillatory plasticity* in the higher cognitive processes.

The brain theory explained in the present chapter stems from the accumulation of findings over many years, and is also a consequence of Chapter 6 and 7. In the coming chapter, this theory will be linked with the coordination in the vegetative system.

To understand what is meant by the “mind,” Part III describes several types of brains, thus opening the way to the differentiation of mind levels.

The framework established in this chapter is re-evaluated in the concluding chapters of Part VI.