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Editorial

The Sensory-Cognitive Interplay: Insights into Neural Mechanisms and Circuits

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Senses are our interface for acting in the external world. Consequently, sensory-motor information grounds and drives our higher cognitive processes. At the same time, we are impinged by a multitude of sensory inputs with variable saliency. It is therefore crucial that the processing of sensory inputs and motor signals is modulated by cognitive and executive mechanisms such as expectation, memory, attention, emotion, planning, monitoring. This is needed to highlight sensory information that is currently relevant for task goals, and to adapt motor control and behavior accordingly. The strict intertwining of sensory, motor, and cognitive functions is evidenced in aging and in neurological disorders. Indeed, sensory-motor dysfunctions often accompany higher-level dysfunctions in older populations [1] and in neurological subjects (e.g., in dyslexia, attention deficit hyperactivity disorders, or autism spectrum disorders) [2,3].

Neuroscience research is of course extremely rich in theoretical, computational and empirical studies that investigate cross-talk between sensory and cognitive systems. The present Special Issue aims to provide further contributions to this central neuroscience topic by addressing questions such as: What mechanisms underlie the tight sensory-motor-cognitive interplay that allows external events and internally-driven representations to interact and achieve the desired goal? What are the factors, either innate or related to learning and development, that contribute to the adaptive optimization of this interplay? What are the electrophysiological brain signatures of sensory-cognitive communication? Additional insights into these issues are fundamental for improving our basic neurophysiopathological knowledge and may also lead to novel solutions for alleviating sensory/cognitive/motor disabilities.

An influential theory about brain information processing [4] considers the sensory and cognitive processes within a hierarchical structure. This reflects the neuroanatomic cortical organization, where sensory processes are located at the bottom (low-level sensory temporo-parieto-occipital areas) and cognitive/executive functions at the top (high-level associative fronto-parietal areas). Information processing takes place via bottom-up (feedforward) connections that mainly convey sensory-driven representations, as well as top-down (feedback) connections that mainly convey internally- and goal-driven representations. The latter can modulate sensory processing and affect motor responses. Within this framework, brain rhythms play a pivotal role as they are functionally implicated in neuronal processing and communications, as well as in the dynamic shaping of functional interactions among brain regions [5].

The paper by Magosso *et al*. [6] in this Special Issue investigates the above aspects in relation to attention. Although attention is an elusive concept, it can be defined as the ability to prioritize the processing of a subset of information deemed to be of the highest relevance to the organism's goals, at the expense of less relevant information. Thus, attention is a mechanism that clearly involves sensory-cognitive interplay, by modulating the processing of external and/or internal items depending on the task goal. By estimating cortical source activity from electroencephalographic signals (EEG), Magosso and coworkers analyse the role of alpha and theta rhythm and functional directed connectivity in these two bands under three different attention conditions: internal attention, external attention, and internal-external attention competition. Their results show peculiar patterns of power and connectivity in the two bands, emphasizing the role of theta rhythm and top-down theta connectivity in internal focus and executive control, and the role of alpha rhythm in inhibiting sensory distracting processes via both top-down and bottom-up influences.

The paper by Grossberg in this Special Issue focuses on attention, too [7]. The author provides an extensive review that describes the mechanisms by which different types of attention operate in different brain systems within the framework of the Adaptive Resonance Theory (ART). This is a neural theory of how the brain autonomously learns to attend, recognize, and predict objects and events in a changing world. ART neural models have been progressively developed over the past 40 years. They are described with an emphasis on the mechanisms that implement object attention and spatial attention, as well as the link between attention and learning, and even between attention and consciousness. A key feature of the neural models presented in Grossberg's paper is the interaction of bottom-up sensory input pathways with top-down modulatory signals.

The paper by Borra and Magosso [8] is also related to attention. This work focuses on event-related potentials (ERPs) in EEG signals as electrophysiological brain signatures of the sensory-cognitive processing of incoming stimuli. The investigated ERP is P300 (or P3), an attention-dependent response to sensory inputs, and its two subcomponents, P3a and P3b, that differentially reflect attention allocation and stimulus evaluation. The study by Borra and Magosso proposes and investigates the potential of an artificial intelligence method (based on deep learning) as an analysis tool for the P3 components in EEG signals. Their results indicate the proposed method is able to extract P3 signatures even at single trial and single subject level, in contrast with ERP canonical analysis that is based on averaging across trials and subjects. Hence, this method may help to better characterize the relationships between EEG signatures, sensory-cognitive interaction, and behavioral performance.

The above papers investigate data and models of healthy subjects, even though these also have implications for elucidating the mechanisms of brain disorders (see in particular Grossberg [7]). The investigation of sensory-cognitive interactions is also of great value in neurological conditions in order to better understand the underlying neuropathological mechanisms and thus make progress with remediation. In this regard, Dushanova and Tsokov [9] investigate EEG-based functional connectivity in different frequency bands during word/pseudoword tasks performed by dyslexic children before and after visual nonverbal training. The authors compare the properties of the functional networks in dyslexic children with those of control children. Metrics derived from Graph Theory (such as small world propensity, betweenness centrality, hubs distribution) are used to synthetically and efficiently characterize functional networks topology. The results show that, after training, functional networks in dyslexics become more similar to controls. This suggests that by affecting the dorsal visual pathway, visual nonverbal training may influence the semantic's network functioning related to word meaning and structure.

The two other papers in this Special Issue emphasize sensory-motor aspects and their link with cognitive functions. Passarelli *et al*. [10] present a thorough review of the Superior Parietal Lobule (SPL) in primates as a sensory-motor hub that plays a crucial role in high-level cognitive functions such as perception for action, spatial representations and visuospatial attention. Their paper reviews the connectional organization of SPL in macaques, which is characterized by feedback and feedforward thalamocortical and cortico-cortical connections. They also highlight the similarities between human and macaque SPL organization in physiological and lesioned conditions. This interspecies homology may foster translational research useful for clinical applications, as well as the development of technologies (e.g., brain-computer interfaces) to regain motor or cognitive functions in patients with disabilities.

Finally, the paper by Turovsky *et al*. [11] analyses the relationship between the genetic characteristics of healthy subjects and success in performing a sensory-motor task that consists of using a video-oculographic interface (i.e., control of a virtual marker via eye movements from a start to a goal-point bypassing obstacles). The authors found an association between task performance and variants in the brain-derived neurotrophic factor (*BDNF*) gene, which has been implicated in synaptic plasticity, working memory, and long-term potentiation. Their results support the assumption that working memory is crucial for success in video-oculographic interface management, that these processes are at least in part genetically determined, and that understanding genetic determinants can help to optimize training for human-computer interface operations in people with disabilities.

Taken together, the contributions in this Special Issue offer novel data, findings, and views on the close nexus between sensory, cognitive, and motor systems. A few general considerations can be drawn from the present collection. First, it clearly emerges from the papers that this research field benefits from the use of a broad array of techniques and methods, both traditional and more recently developed. Indeed, each of the following techniques has been exploited in this Issue: EEG and event-related potentials associated with scalp and cortical functional connectivity, graph theory, electro-oculographic recordings, invasive neurophysiological measures in animals paired with structural and functional investigations in humans (e.g., fMRI, diffusion tensor imaging, tractography), neurocomputational modeling, artificial intelligence techniques, and genotyping. The results derived from the application of these techniques provide support for some main mechanisms that can subserve the interrelationships between cognitive and sensory-motor domains. These include recurrent (feedback and feedforward) connections among lower-level and higher-level cortical regions, different functional connectivity networks mediated by different brain rhythms, enhancement and inhibition, and finally learning and plasticity driven by experience and training but that are also influenced by genetic factors. Furthermore, the papers emphasize the relevance of electrophysiological signatures of sensory-cognitive interplay (e.g., event-related potentials, topology of EEG functional networks, eye-movement characteristics) that could be useful biomarkers for the diagnosis and monitoring of disorder conditions. In addition, these papers may stimulate the improvement and development of methods for alleviating sensory-motor or cognitive disabilities. Although this Special Issue does not directly cover many aspects of sensory-cognitive interplay (e.g., multisensory integration, peripersonal space representation, emotion conditioning, alterations in high-incidence disorders such as autism spectrum disorder, schizophrenia, Alzheimer's disease), the presented papers nevertheless contribute to a better overall understanding of the connection between body and mind and could promote further research on this topic.

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Author Contributions

EM and MU conceived the manuscript. EM wrote the original draft. MU reviewed and edited the manuscript. Both authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

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