Chapter 1

Sensorimotor Integration and Attention: An Electrophysiological Analysis

Bruna Velasques, Mauricio Cagy,
Roberto Piedade and Pedro Ribeiro

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/55199

1. Introduction

Selective attention is fundamental for the information processing. The perceptive system receives different external and internal stimuli at all times and our organism needs to be capable to perceive environmental stimuli, in order to discriminate the difference among these stimuli and, thus, archive relevant information in the brain. In such manner, the attention process becomes a determinant mechanism in the sensorimotor integration.

In the last decades, researchers in sensorimotor integration have been concerned in establishing the relevant and fundamental elements that better explain the relation among individual, task and environment in the motor action production. The maintenance of movement stability is the main goal of the central nervous system (CNS) in dealing with visual stimuli. In the CNS, the sensorimotor integration is subdivided into three different levels: the most inferior level, considered the first stage, is the spinal cord; the second level regards several subcortical areas, such as reticular formation, vestibular nuclei, superior colliculus, cerebellum and basal ganglia. These areas receive information from the spinal cord and assist in the postural stability control; the last stage, considered the superior level, is associated with the cerebral cortex and is responsible for movement refinement and gesture diversification. The main objective of the present chapter is to investigate and to present the findings that point to a relation between the attention and sensorimotor integration, highlighting the participating electrophysiology and the cortical areas.

Hence, the present chapter will describe some cortical structures and the electrophysiological processes that occur during the sensorimotor integration, focusing on the role of attention. Moreover, this chapter will analyze the recent findings in sensorimotor integration highlighting how attention participates in this mechanism, it will describe the electrophysiological data around the cortical information processing, explain the main electrophysiological characteristics of attention, and it will illustrate the experiments involving brain mapping, attention and sensorimotor integration.

2. Cortical structures and sensorimotor integration: The role of attention

The sensorimotor integration is the process that organizes all types of sensory information and transforms it into a motor command. Attention is a cognitive function that underlies the sensorimotor integration process with its three stages: stimuli identification and selection; motor command organization; and motor execution. In this sense, it is observed that cortical areas involved in sensorimotor integration and attention overlap. The cortical structures most associated with sensorimotor integration and attention are the parietal, occipital, frontal, motor and somatomotor cortices.

The parietal cortex is widely involved in visuospatial sensorimotor integration. Particularly, the lateral intraparietal area (LIP) is an important region, which is connected with frontal areas that participate in the control and programming of eye movements (frontal eye field) and receive visual inputs from multiple visual areas [1]. The high amount of connections with other cortical and subcortical areas makes this region a relevant zone of association.

Attention is a cognitive process responsible for selecting and focusing on one or more features of the environment, while others are ignored, and for establishing the relationship among these features [2, 3]. It is a multidimensional capacity and it is directly related to memory and learning. Furthermore, attention processes are involved in the different information processing stages [4].

Neural mechanisms involved in attention interact among themselves, and we can highlight two main ones: top-down (i.e., voluntary attention) and bottom-up (i.e., reflexive attention). The top-down mechanism is based on the integration among previous knowledge, expectations and individual goals, in order to make a decision associated with attention shifting [4,5,6]. This mechanism influences the direction of sensorial, perceptual and decision processes. Specifically, the frontal and parietal cortices are involved in the voluntary mechanism [7,8]. The classic paradigm to study voluntary attention consists of the presentation of information as a signal (for example, a visual cue) that enables the subject to predict relevant features of the experimental set, such as the location and direction of the target stimulus [9]. In contrast, the bottom-up mechanism, or reflexive attention, is triggered by the physical features of the stimulus; in other words, the attention orientation is not directly controlled by the voluntary systems [8,9]. For example, a red flower will stand out more in a green field than in a colored flowers field. The ability to identify the flower depends on its difference or similarity in relation to other distractors. In another example, a sudden movement in the peripheral vision is immediately perceived, and this stops the action that was being executed in order to direct the attention to the new stimulus

http://dx.doi.org/10.5772/55199

(sudden movement). Likewise, an individual crossing a busy street will be attracted by a sudden braking car, even if the vehicle was not coming his/her way. This effect of interruption and exogenous direction is based on the stimulus features and it is considered integrant part of the defense system [8,10,11]. The top-down and bottom-up mechanisms interact among them and sometimes compete for control of the neural processing and, consequently, execute the movement [3]. Recent investigations demonstrate an overlapping among the cortical areas involved in top-down and bottom-up attention. The task execution requiring both kinds of attention demonstrates activation of the parietal cortex and the premotor areas [5].

However, the voluntary attention condition also presents right prefrontal cortex activity. This area is associated with working memory, which may indicate that it is engaged voluntarily. In addition, the temporal-parietal junction activation is slightly different between the two kinds of attention, with a high involvement of the lateral, anterior and superior portion when reflexive attention is used [12]. Despite these small differences in the activated regions, in general an overlapping occurs among the areas participating in the two kinds of attention. Specifically, both attentions present activation of premotor region, frontal eye field (FEF) and superior parietal cortex, even if this last region exhibits more participation in the reflexive attention [8,12]. Despite these findings, few studies have shown how these areas interact with each other.

Thus, the mechanisms involved in attention process depend on the organization and integration of multiple cerebral centers. In this context, the participation of several structures and neural circuits demonstrates that attention is a process organized in a complex way related to the network integration of these components [8,13]. In particular, an experiment was conducted in which subjects were exposed to two initial conditions: presentation of visual images on a screen and a blank screen presentation. The subjects were instructed to maintain gaze in a central point in both conditions. During the visual presentation, four colored complex images were showed. These images could appear in different ways: in a sequential manner, each image on a different screen, or the four images on the same screen simultaneously. Moreover, two conditions were tested: i) no attention paid to the stimulus condition, where the subjects were instructed to maintain the gaze on a fixed point and to ignore the peripheral visual stimuli; ii) attention paid to the stimulus condition, where the subjects were instructed to direct the attention covertly to the place next to the fixation point and count the occurrence of these images [14]. The task begins with the presentation of a reference point near the fixed point, and the subjects were oriented to direct their attention to the target location immediately after the reference point presentation and to wait for the stimulus appearance (expectation period). Hence, attention effects could be studied in the presence and absence of visual stimuli. The authors verified a cortical activity increase during both conditions; attention directed to a specific location and expectation of visual stimuli occurrence. In particular, they found greater activation in frontal and parietal cortices when compared to the visual areas. This suggests that parietal and frontal cortices influence the early stages of scene scanning and they act as primary sources in the voluntary attention mechanism [13,15].

In this manner, attention can be classified according to its shifting nature: overt or covert attention. The overt attention is defined as an act to direct the sensory organs toward the stimuli and it is associated with both reflexive and voluntary attention [8,16]. On the other hand, covert attention is the act of mentally focus on one of the possible sensorial stimuli (vision, kinesthesia, hearing, etc) and it is associated with voluntary attention. Covert attention is the ability to attend a location or set without executing eye movements [11,17]. Thus, when staring at a fixed point represented by an asterisk (*), you perceive that it is possible to read the words around the point or to detect the objects' colors without moving your eyes. This kind of shifting is voluntary or endogenously controlled, because the attention direction depends only on the observer. Studies suggest that covert visual attention is a mechanism used to explore the visual field of interest [17]. For example, when someone is driving or maintaining their eyes on the road, even if the eyes do not move, the attention could shift from the road to their thoughts. The eyes maintain the focus on the object attended previously – the road, though attention has shifted [18]. In the last 30 years, researches based on a paradigm developed by Posner et al [19] have dominated the studies of oriented attention. This paradigm examines the advantage in indicating, by the use of a visual cue, the location where the target is more likely to appear. The participants are instructed to not perform any kind of overt attention, i.e. eye movement. The subjects are oriented to respond to the target as soon as detected. Two kinds of visual cues are presented: central and peripheral. The central cue is displayed directly on the fovea and indicates if the target will appear on the right or left portion of the screen. This condition is called central because of two reasons: it is centered in the visual field and it requires a central processing to interpret a symbol in a direction towards which the attention could be endogenously guided [20,21]. The peripheral cue is presented in the peripheral visual field on the screen portion where the target will appear, and it is represented by a flash of light. In the control group, none of the cues are presented. The results using this paradigm show that subjects responded faster to the target presented in the same location of the cue than when the target is showed in a different location from the cue. This demonstrates that visual attention is oriented in a covert way, with the absence of overt eye movement [22].

Despite an early distinction between overt and covert attention, recent findings point to an overlapping of cortical areas related to the shifting gaze – overt attention – and of those areas which participate in the covert attention mechanism. In particular, these studies verified an activity of the frontal cortex, especially of the pre-central sulcus, of the intraparietal cortex and of the lateral occipital cortex [23]. Experiments using Functional Magnetic Resonance Imaging (fMRI) investigated shifting attention tasks, both covert and overt, and verified an activation in the same areas – frontal, parietal and temporal cortices. Moreover, they demonstrated a higher activation during covert attention when compared to overt attention [14,24]. However, the right dorsolateral frontal cortex was activated only during covert attention shift, and this region is typically associated with voluntary attention and working memory [24]. Beauchamp et al. [23] reproduced these results through the execution of an experiment using both conditions: covert and overt attention. The results found were in agreement with previous studies, that is, Beauchamp et al. [23] verified that the same neural mechanisms were involved in overt and covert attention shifting.

Several studies involving covert attention orientation task revealed the involvement of cortical and subcortical areas in the control of attention direction toward visual stimuli. In particular, the attention visual model developed by Posner [6] establishes the existence of three distinct systems related to attention that work in directing voluntary attention. The systems are: posterior, anterior and vigilance.

The first one, the posterior system, is responsible for stimulus selection and localization, and for shifting attention between stimuli [22]. Moreover, it is associated with shifting of covert attention and it involves three structures: posterior parietal cortex, superior colliculus and pulvinar thalamic nucleus. The posterior parietal cortex acts in the attention disengagement from a particular stimulus; the superior colliculus is associated with the attention shifting; and the pulvinar thalamic nucleus is responsible for attention engagement with a novel stimulus [20,22].

The anterior system is involved in the detection of relevant stimuli and in the motor response preparation. This system comprises the frontal cortex, the cingulate cortex and the basal ganglia, and it is involved in the attention recruitment for the stimulus detection and in the control of brain areas for the performance of complex cognitive tasks, such as object recognition [25].

The last system proposed by Posner, the vigilance system, is characterized by alertness maintenance, in other words, it keeps the overall responsiveness of the nervous system attentive to external events. This system includes the frontal and parietal cortexes, specifically of the right hemisphere. Furthermore, there is the involvement of the reticular formation and the locus coeruleus, which in general increase the body alertness and attention guidance system modulation.

According to Raz and Buhle [7], the circuits mediating the attention process are associated with three types of networks which modulate attention: alerting, orienting and executive. The alerting network is associated with readiness in preparing the response to an imminent stimulus and can be interpreted as a basic "net" for all other attention functions. Recent data demonstrated that this “net” is represented in cortical and subcortical areas of the right hemisphere, in which the anterior cingulate cortex acts as a central coordinator of alertness structures [14,23]. The orienting network is related to the selection of specific information among multiple sensory stimuli. Finally, the executive network involves planning and decision making, error detection, difficulty or danger judgment, emotion and thought regulation. Despite the description of such model, there is a difficulty in establishing the neural circuits associated with each of these networks.

Knudsen [26] described a general attention model, which could be identified by four fundamental processes: working memory, top-down sensitivity control, competitive selection, and automatic bottom-up filtering for salient stimuli. The working memory acts in the temporary storage of information. The top-down sensitivity control enables higher cognitive information processing in such a way that it controls the intensity of the competing information channels' signals for accessing working memory, and it gives an advantage to the most intense channel in the competitive selection [2,14,27]. This, on the other hand, could be the process determining which information will access the working memory. Finally, the automatic bottom-up filtering for salient stimuli improves the response to rare, or biological relevant - instinctive or learned – information [4,25,28,29]. Thus, we can think in different hierarchical levels in the attention processing. And, according to the nature of the information or the task, the spatial maps may enhance or inhibit the activity in sensory areas, and induce oriented behaviors as well as eye movement.

3. The role of attention on the sensorimotor integration process

During the last decades, researchers that have been investigating sensorimotor integration have been concerned with establishing relevant elements to better explain the relationship among individual, task and environment in the production of the motor action [30]. In this context, theoretical models have been proposed. The models are necessary because they express the main aspects of a phenomenon, and reduce its complexity allowing the understanding of its properties [31,32]. In many sensorimotor integration models the memory system receives special attention, because it composes the comparison system, fundamental for error correction. In particular, the capacity to select, store and recover information is manipulated depending on the type of memory involved, implicit or explicit [33].

The motor control field is divided according to three distinct aspects: postural control, gait and voluntary action [34]. In gait regulation and voluntary action, visual information is essential to guarantee the movement performance [35]. Surely, the ability to walk or take a pen can be performed without light stimuli; for example, the case of an individual with visual deficit or the time when we try to get a glass of water during the night represent our ability to execute tasks without visual information [36]. But, if we consider the system integrity as a whole, vision is important in the motor action production. Specially, the sensorimotor integration models consider that the light stimulus coming from the environment and from the objects is the first stage of a wider process called decision making [37]. Thus, once volition to perform a motor action is removed de from the model,, the visual system is what determines part of this process; or, at least, it is through the vision that the initial stages of information processing are established [38]. The maintenance of the movement stability is the main goal of the central nervous system (CNS) when dealing with visual information [39,40]. Hence, the decision making depends on a repertoire of information that is registered on different cortical and subcortical structures, in order for the gesture stability to be achieved and maintained, especially where the channel input is the visual system [41]. According to Gibson, it is through the visual system that we interpret the relationship among individual, task and environment [42]. The Ecological Theory proposed by Gibson establishes a close relationship between individual and environment [43]. In the years that followed the pioneer ideas of Gibson, the researchers investigated their concepts and hypotheses that explain the functioning between the visual system and its relationship with the environment, in particular, the effect of this relationship on decision making [44].

In 1902, Raymond Dodge found 5 ocular movements responsible for maintaining the fovea in a target: three movements sustain the fovea in the visual target (saccade, smooth pursuit and vergence) and two more stabilize the eye during the head movement (vestibulo-ocular reflex and optokinetic reflex) [3,45]. These five ocular movements are responsible for the coupling relationship integrity among individual, task and environment [46]. As predicted by the sensorimotor integration models, the five ocular movements are not the only elements in the information flow related to information processing [47]; but, they participate in the early stage of information processing.

We know that the early stage of information processing is integrated with all the processing aspects, such as: selection, planning and motor response execution [38]. In this way, when we think about delays and errors in the information flow during the decision making processing, part of it is due to the early stages [48]. As previously mentioned, delays and errors are also related with other stages of processing; in particular, they occur when we compare new, or recent, information with that already stored; when this happens, we can observe indecision in the response selection in a situation that extrapolates normal parameters [33]. Researchers that study sensorimotor integration believe that the extrapolation of these parameters is associated with pathology, specific tasks and with environments which generate difficulty or ambiguity in the repertoire [49]. It is more difficult to control the motor action when tasks are executed in an environment of low stability, or with more unpredictability. Summarizing, the ocular movements are considered to be the gateway to information processing; specifically, these movements play a key role in maintaining the fovea on the target and in the stability of the eye when the head is moving. The combination of eye movements is part of a bigger system that integrates the individual with the environment, considering cognitive and volitional aspects [50].

In this context, the saccade is defined as a very quick movement (± 200 msec) of the eyeball from a fixed point to another, in order to focus the eye on different parts of the visual field in a short time interval [50]. The purpose of the saccade is to move the eyes very rapidly. The saccade occurs in fractions of seconds and at an angular speed of up to 900º/s [3]. This velocity is determined by the distance between the target and the fovea. It is possible to change the amplitude and direction of the saccadic movement, but not its velocity. In general, the saccadic movement is not modified by visual stimuli; this modification only occurs in the posterior saccade. The saccade only slows down under special conditions, such as: fatigue, drug and disease, such as schizophrenia. It is also produced by other stimuli besides the visual ones, such as sounds, information from the somatosensory system, spatial memories and even verbal commands [51,52].

Studies demonstrate that saccade reaction time decreases when other stimuli sources (hearing or touching) are presented in a temporal or spatial proximity to the visual source [53]. These results are found even in conditions where the individuals are instructed to ignore the secondary stimuli in tasks that involve focal attention. Data suggest a spatial-temporal interdependence in the neural structure involved in saccadic eye movement origin, such as the superior coliculus. The coliculus is a fundamental structure in the sensorimotor integration process [54]. Models using neural networks mainly seek to explain multisensorial spatial integration by a convergence process between information coming from vision, hearing and touch, and sensorimotor structures necessary to maintain the coordination between head and eyes. In this context, recent experiments explore stochastic models - time-window-of-integration model – in an attempt to include the temporal aspects of the integration process, since the former models have only approached the spatial issue. Thus, these experiments compare the model prediction with data extracted from visual-tactile tasks involving focused attention [53].

In the Central Nervous System (CNS), the sensorimotor integration process is subdivided into three different levels. In the hierarchical concept, these three levels are integrated. Starting from the bottom, the first stage (inferior level) of sensorimotor integration presents the spinal cord [55]. There we find the final common pathway of the motor neurons which innervate the corresponding muscle fibers. At this stage, there is the first level of integration between the afferents coming from different joints, muscles and skin, and the descendants coming from the cerebral cortex, facilitated by spinal interneurons [56]. At this stage of the sensorimotor integration, standardized events occur, such as: rapid removal (reflex) of one or more members caused by aversive stimuli, or responses that arise while walking [57].

The second stage of the sensorimotor integration takes place in several subcortical structures: reticular formation, vestibular nucleus, superior coliculus, cerebellum and basal ganglia. These structures receive spinal cord information and help in the postural stability control, as well as in the walking process [58]. For example, in the postural control the information from visual and somatosensory stimuli is important to maintain balance.

Finally, the superior stage of movement control is associated with the cerebral cortex [59]. In the cerebral cortex, we found structures that enable movement sophistication, a gesture diversification and a control on the supposed degrees of freedom, a term coined by Nicolai Berstei in 1949. The involvement of different cortical structures contributes to the formation of a sensory frame of reference with the participation of perceptive processes and, consequently, several kinds of memory [60]. As mentioned previously, the beginning of these connection networks and the various stages of sensorimotor integration are activated when the environment is rich in visual stimuli and requests saccadic eye movement.

Sensorimotor integration models, involving vision, are proposed in several situations; for example, Teixeira [61] explores the relationship between the environment information flow and the central nervous system functions. The model describes the sensorial information traffic in the CNS and the stages of information processing [62]. The first stage of this model refers to the stimulus transduction by the sensorial systems; the second one is related to executive function processing; and the third one is associated with substructures coordination in the movement production [40]. In detail, the model divides the information flow into three different stages where the attention affects them directly or indirectly. The first level, also called pre-attentive, refers to the sensorial information reception and to the more elementary perception processes. At this level, the sensorial system as a whole receives information from the internal and external environments [63]. This level is automatic, that is, the sensorial stimuli are not integrated yet to the executive functions, such as memory and attention. On the other hand, at the second level of the model, the attention has a fundamental role, since the internal and external stimuli pass through a conscious process [64]. This level is identified by a pre-thought about small details of the action; in particular, the prefrontal cortex participates in this entire module. A relevant aspect of this level is the comparison between new sensorial stimuli and elements previously stored in the memory [3]. Finally, the third level is called sub-attention and it is the stage where the motor control structures are integrated. This level is characterized by a high degree of sophistication, since the pre-conceived motor pattern becomes real with an originating intention [65].

4. Conclusion

The present chapter described the importance of attention in the sensorimotor integration. Specifically, we addressed the cortical and subcortical structures that are involved in the information processing, and the role of attention in the stages of sensorimotor integration. We emphasized the saccadic eye movement as a behavioral measure used to access the attention and sensorimotor integration. We identified a wide participation of the parietal and frontal cortices in the three mechanisms investigated, i.e., attention, information processing and sensorimotor integration. These cortical structures are considered strategic because of their communication network with other areas. The parietal region is directly associated with sensorial and multisensorial integration and the frontal area coordinates the attention process and the motor planning. The parietal and frontal cortices work together, but their participation is different depending on location or task context; researchers also observed an overlapping between these areas during attention and sensorimotor integration.

These regions influence two main attention mechanisms: top-down (i.e., voluntary attention) and bottom-up (i.e., reflexive attention). They interact between them and sometimes compete for control of the neural processing for the movement execution. Both types of attention also present activation of premotor region, frontal eye field (FEF) and superior parietal cortex. Furthermore, the attention mechanism has different hierarchical levels that depend on the nature of the information or the task. In this sense, the degree of attention in both sensorimotor integration and information processing will also depend on the information nature. In other words, attention is a fundamental element in the sensorimotor integration, and it is a feature that contributes to a better performance of a motor task.

Author details

Bruna Velasques[3,4,5,6*], Mauricio Cagy[1], Roberto Piedade[2] and Pedro Ribeiro[2,4,5]

*Address all correspondence to: bruna_velasques@yahoo.com.br

1 Biomedical Engineering Program, Universidade Federal do Rio de Janeiro, Rio de Janeiro, , Brazil

2 Brain Mapping and Sensory Motor Integration, Institute of Psychiatry of the Federal University of Rio de Janeiro (IPUB/UFRJ), Rio de Janeiro, Brazil

3 Neurophysiology and Neuropsychology of Attention, Institute of Psychiatry of the Federal University of Rio de Janeiro (IPUB/UFRJ), Rio de Janeiro, Brazil

4 Institute of Applied Neuroscience (INA), Rio de Janeiro, Brazil

5 School of Physical Education, Bioscience Department (EEFD/UFRJ), Rio de Janeiro, Brazil

6 Neuromuscular Research Laboratory, National Institute of Traumatology and Orthopedics (NITO), Rio de Janeiro, Brazil

References

[1] Gotlieb, J, & Snyder, L. H. Spatial and non-spatial functions of the parietal cortex. Curr Opin Neurobiol. (2010). , 20(6), 731-40.

[2] Estévez-gonzález, A, García-sánchez, C, & Junqué, C. La attención: una compleja función cerebral. Revista de Neurología.(1997). , 25(148), 1989-97.

[3] Kandel, E, Schwartz, S, & Jessel, T. Principles of Neuroscience. 4. ed. New York: McGraw-Hill; (2000).

[4] Gilbert, C. D, & Sigman, M. Brain states: top-down influences in sensory processing. Neuron. (2007). , 54(5), 677-96.

[5] Esterman, M, Prinzmetal, W, Degutis, J, Landau, A, Hazeltina, E, Verstynen, T, & Robertson, L. Voluntary and involuntary attention affect face discrimination differently. Neuropsychologia. (2008). , 46(4), 1032-40.

[6] Posner, M. I. Orienting of attention. Q J Exp Psychol. (1980). , 1, 3-25.

[7] Raz, A, & Buhle, J. Typologies of attentional networks. Nat Rev Neurosci. (2006). , 7(5), 367-79.

[8] Shipp, S. The brain circuitry of attention. Trends Cogn Sci. (2004). , 8(5), 223-230.

[9] Corbetta, M, & Shulman, G. L. Control of goal-directed and stimulus-driven attention in the brain. Nat Rev Neurosci. (2002). , 3, 201-15.

[10] Kowler, E, Anderson, E, Dosher, B, & Blaser, E. The role of attention in the programming of saccades. Vision Research. (1995). , 35(13), 1897-916.

[11] Sheliga, B. M, Riggio, L, & Rizzolatti, G. Orienting of attention and eye movements. Exp Brain Res. (1994). , 98(3), 507-22.

[12] Mcdowell, J. E, Dyckman, K. A, Austin, B. P, & Clementz, B. A. Neurophysiology and neuroanatomy of reflexive and volitional saccades: evidence from studies of humans. Brain Cogn. (2008). , 68(3), 255-70.

[13] Kastner, S, Pinsk, M. A, De Weerd, P, Desimone, R, & Ungerleider, L. G. Increased activity in human visual cortex during directed attention in the absence of visual stimulation. Neuron. (1999). , 22(4), 751-61.

[14] Corbetta, M, Patel, G, & Shulman, G. L. The reorienting system of the human brain: from environment to theory of mind. Neuron. (2008). , 58(3), 306-24.

[15] Astafiev, S. V, Shulman, G. L, Stanley, C. M, Snyder, A. Z, Van Essen, D. C, & Coerbetta, M. Functional organization of human intraparietal and frontal cortex for attending, looking, and pointing. J Neurosci. (2003). , 23, 4689-4699.

[16] Ignashchenkova, A, Dicke, P. W, Haarmeier, T, & Thier, P. Neuron-specific contribution of the superior colliculus to overt and covert shifts of attention. Nat Neurosci. (2004). , 7(1), 56-64.

[17] Moore, T, Armstrong, K. M, & Fallah, M. Visuomotor origins of covert spatial attention. Neuron.(2003). , 40(4), 671-68.

[18] Hoffman, J. E, & Subramaniam, B. The role of visual attention in saccadic eye movements. Percept Psychophys. (1995). , 57(6), 787-795.

[19] Posner, M. I. Snyder CRR, Davidson BJ. Attention and the detection of signals. J Exp Psychol: General.(1980). , 109, 160-174.

[20] Posner, M. I, & Badgaiyan, R. D. Attention and neural networks. In: RW Parks, DS Levine, DL Long (eds) Fundamentals of Neural Network Modelling. Cambridge, MA: MIT Press; (1998).

[21] Posner, M. I, Walker, J. A, Friedrick, F. J, & Rafal, R. D. Effects of parietal injury on covert orienting of visual attention. J Neurosci. (1984). , 4, 1863-74.

[22] Posner, M. I, & Petersen, S. E. (1990). The attentional system of the human brain. Annu Rev Neurosci. 1990;, 13, 25-42.

[23] Beauchamp, M. S, Petit, L, Ellmore, T. M, Ingeholm, J, & Haxby, J. V. A parametric fMRI study of overt and covert shifts of visuospatial attention. NeuroImage. (2001). , 14(2), 310-21.

[24] Nobre, A. C, Gitelman, D. R, Dias, E. C, & Mesulam, M. M. Covert visual spatial orienting and saccades: overlapping neural systems. NeuroImage. (2000). , 11, 210-6.

[25] Nabas, T. R, & Xavier, G. F. Atenção. In: Andrade, V. M., Santos, F. H. e Bueno, O. F. A. (eds.). Neuropsicologia Hoje. Porto Alegre: Artes Médicas; (2004).

[26] Knudsen, E. I. Fundamental components of attention. Annu Rev Neurosci. (2007). , 30, 57-78.

[27] Allport, A. Attention and control: have we been asking the wrong questions? A critical review of twenty-five years. In: Meyer, D. E. & Kornblum, S. (eds.) Attention and performance. New Jersey: Erlbaum; (1993).

[28] Pierrot-deseilligny, C, Müri, R. M, Nyffeler, T, & Milea, D. The role of the human dorsal lateral prefrontal cortex in ocular motor behavior. Ann N Y Acad Sci.(2005). , 1039, 239-51.

[29] Pierrot-deseilligny, C, Rivaud, S, Gaymard, B, & Agid, Y. Cortical control of reflexive visually-guided saccades. Brain.(1991). , 114, 1473-85.

[30] Bruno, N, & Battaglini, P. P. Integrating perception and action through cognitive neuropsychology (broadly conceived). Cogn Neuropsychol. (2008).

[31] Brozovic, M, Gail, A, & Andersen, R. A. Gain mechanisms for contextually guided visuomotor transformations. J Neurosci. (2007). , 27(39), 10588-96.

[32] Song, D, Lan, N, Loeb, G. E, & Gordon, J. Model-based sensorimotor integration for multi-joint control: development of a virtual arm model. Ann Biomed Eng.(2008). , 36(6), 1033-48.

[33] Krakauer, J. W. Motor learning and consolidation: the case of visuomotor rotation. Adv Exp Med Biol.(2009). , 629, 405-21.

[34] Carver, S, Kiemel, T, & Jeka, J. J. Modeling the dynamics of sensory reweighting. Biol Cyber. (2006). , 95(2), 123-34.

[35] Krieghoff, V, Brass, M, Prinz, W, & Waszak, F. Dissociating what and when of intentional actions. Front Hum Neurosci.(2009).

[36] Magescas, F, Urquizar, C, & Prablanc, C. Two modes of error processing in reaching. Exp Brain Res. (2009). , 193(3), 337-50.

[37] Puga, F, Sampaio, I, Veiga, H, Ferreira, C, Cagy, M, Piedade, R, & Ribeiro, P. The effects of bromazepam on the early stage of visual information processing (Arq de Neuropsiquiatr.(2007). A):955-9., 100.

[38] Proteau, L, Roujoula, A, & Messier, J. Evidence for continuous processing of visual information in a manual video-aiming task. J Motor Behaviour. (2009). , 41(3), 219-31.

[39] Pascolo, P. B, Carniel, R, & Pinese, B. Human stability in the erect stance: alcohol effects and audio-visual perturbations. J Biomech.(2009). , 42(4), 504-509.

[40] Konczak, J. Vander Velden H, Jaeger L. Learning to play the violin: motor control by freezing, not freeing degrees of freedom. J M Behav.(2009). , 41(3), 243-252.

[41] Lu, M. K, Bliem, B, Jung, P, Arai, N, Tsai, C. H, & Ziemann, U. Modulation of preparatory volitional motor cortical activity by paired associative transcranial magnetic stimulation. Hum Brain Mapp. (2009). , 30(11), 3645-56.

[42] Franz, V. H, Hesse, C, & Kollath, S. Visual illusions, delayed grasping, and memory: No shift from dorsal to ventral control. Neuropsychologia. (2009). , 47(6), 1518-31.

[43] Goodale, M. A. Action without perception in human vision. Cogn Neuropsychol. (2008).

[44] Konkle, T, Wang, Q, Hayward, V, & Moore, C. I. Motion aftereffects transfer between touch and vision. Curr Biol. (2009). , 19(9), 745-50.

[45] Tanaka, K, Abe, C, Awazu, C, & Morita, H. Vestibular system plays a significant role in arterial pressure control during head-up tilt in young subjects. Auton Neurosci. (2009).

[46] Fishbach, A, & Mussa-ivaldi, F. A. Seeing versus believing: conflicting immediate and predicted feedback lead to suboptimal motor performance. J Neurosci.(2008). , 28(52), 14140-14146.

[47] Soto, D, Hodsoll, J, Rotshtein, P, & Humphreys, G. W. Automatic guidance of attention from working memory. Trends Cogn Sci.(2008). , 12(9), 342-8.

[48] Kaku, Y, Yoshida, K, & Iwamoto, Y. Learning signals from the superior colliculus for adaptation of saccadic eye movements in the monkey. J Neurosci.(2009). , 29(16), 5266-5275.

[49] Bastian, A. J. Understanding sensorimotor adaptation and learning for rehabilitation. Curr Opin Neurol.(2008). , 21(6), 628-33.

[50] Hutton, S. B. (2008). Cognitive control of saccadic eye movements. Brain Cogn. 2008;, 68(3), 327-340.

[51] Berman, R. A, Joiner, W. M, Cavanaugh, J, & Wurtz, R. H. Modulation of presaccadic activity in the frontal eye field by the superior colliculus. J Neurophysiol.(2009). , 101(6), 2934-42.

[52] Wurtz, R. H. Vision for the control of movement. Invest Ophthalmol Vis Sci.(1996). , 11, 2130-45.

[53] Colonius, H, Diederich, A, & Steenken, R. Time-Window-of-Integration (TWIN) Model for Saccadic Reaction Time: Effect of Auditory Masker Level on Visual-Auditory Spatial Interaction in Elevation. Brain Topogr. (2009).

[54] Stein, B. E, Stanford, T. R, & Rowland, B. A. The neural basis of multisensory integration in the midbrain: Its organization and maturation. Hear Res. (2009).

[55] Hotz-boendermaker, S, Funk, M, Summers, P, Brugger, P, Hepp-reymond, M. C, Curt, A, & Kollias, S. S. Preservation of motor programs in paraplegics as demonstrated by attempted and imagined foot movements. NeuroImage. (2008). , 39(1), 383-94.

[56] Perez, M. A, Lundbye-jensen, J, & Nielsen, J. B. Changes in corticospinal drive to spinal motoneurones following visuo-motor skill learning in humans. J Physiol.(2006). Pt 3):843-55.

[57] Knikou, M. The H-reflex as a probe: pathways and pitfalls. J Neurosci Methods. (2008). , 171(1), 1-12.

[58] Glasauer, S, Amarim, M. A, Viaud-delmon, I, & Berthoz, A. Differential effects of labyrinthine dysfunction on distance and direction during blindfolded walking of a triangular path. Exp Brain Res.(2002). , 145(4), 489-97.

[59] Hattori, N, Shibasaki, H, Wheaton, L, Wu, T, Matsuhashi, M, & Hallet, M. Discrete parieto-frontal functional connectivity related to grasping. J Neurophysiol.(2008).

[60] Chen, T. L, Babiloni, C, Ferretti, A, Perrucci, M. G, Romani, G. L, Rossini, P. M, & Tartaro, A. Del Gratta C. Human secondary somatosensory cortex is involved in the processing of somatosensory rare stimuli: an fMRI study. NeuroImage. (2008). , 40(4), 1765-71.

[61] Teixeira, L. A, & Teixeira, M. C. Shift of manual preference in right-handers following unimanual practice. Brain Cogn.(2007). , 65(3), 238-43.

[62] Schmidt, R. A. Motor schema theory after 27 years: reflections and implications for a new theory. Res Q Exerc Sport.(2003). , 74(4), 366-75.

[63] Salillas, E, El Yagoubi, R, & Semenza, C. Sensory and cognitive processes of shifts of spatial attention induced by numbers: an ERP study. Cortex.(2008). , 44(4), 406-13.

[64] Theeuwes, J, Belopolsky, A, & Olivers, C. N. Interactions between working memory, attention and eye movements. Acta Psychol (Amst). (2009). , 132(2), 106-14.

[65] Royer, A. S, & He, B. Goal selection versus process control in a brain-computer interface based on sensorimotor rhythms. J Neural Eng. (2009). Feb;6(1):016005.