

## Sensorimotor integration: basic concepts, abnormalities related to movement disorders and sensorimotor training-induced cortical reorganization

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**Introduction.** Sensorimotor integration is defined as the capability of the central nervous system to integrate different sources of stimuli, and parallelly, to transform such inputs in motor actions.

**Aim.** To review the basic principles of sensorimotor integration, such as, its neural bases and its elementary mechanisms involved in specific goal-directed tasks performed by healthy subjects, and the abnormalities reported in the most common movement disorders, such as, Parkinson's disease, dystonia and stroke, like the cortical reorganization-related mechanisms.

**Development and conclusions.** Whether these disorders are associated with an abnormal peripheral sensory input or defective central processing is still unclear, but most of the data support a central mechanism. We found that the sensorimotor integration process plays a potential role in elementary mechanisms involved in specific goal-directed tasks performed by healthy subjects and in occurrence of abnormalities in most common movement disorders and, moreover, play a potential role on the acquisition of abilities that have as critical factor the coupling of different sensory data which will constitute the basis of elaboration of motor outputs consciously goal-directed.

**Key words.** Binding. Dystonia. Parkinson's disease. Saccadic movements. Sensorimotor integration. Stroke. Time-to-contact.

### Introduction

The sensorimotor integration is a brain process that allows, by complex neural operations, the execution of a certain voluntary motor behavior in response to specific demands of the environment [1]. In other words, it is the dynamic combination of sensory information into intentional motor response [2]. Thus, the behavior pattern of healthy subjects or movement disorder's patients depends on the sensorimotor integration process [3]. Many studies deal with the sensorimotor integration process to elucidate the brain functions, to clarify the pathophysiological mechanisms of movement disorders and to improve neurofunctional rehabilitation strategies based on the ability to reorganize the central nervous system (CNS). Within this context, this study reviews different aspects involved in the sensorimotor integration processes of which over the years characterizes the field and in parallel became the focus of intense investigation of several laboratories.

The present paper reviewed the basic principles of sensorimotor integration, such as, its neural bases and its elementary mechanisms involved in specific goal-directed tasks performed by healthy subjects (i.e., saccadic movements, typewriting, shooting and time-to-contact tasks). Moreover, we reviewed the abnormalities reported in the most common movement disorders, like the cortical reorganization-related mechanisms. According to above topics, we developed a strategy for searching studies in the main data bases. The computer-supported search used the following databases: Pubmed/Medline, ISI Web of Knowledge, Cochrane data base and Scielo. The search terms, 'binding', 'cortical reorganization', 'dystonia', 'Parkinson's disease', 'saccadic movements', 'sensorimotor training', 'shooting', 'stroke' and 'time-to-contact' in combination with 'sensorimotor integration'. Abstracts and reports including findings of critical importance from meetings and conferences were included only when no full, published-paper were available on the topic. Only papers, such as, critical and

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systematic reviews, meta-analyses and experimental and clinical reports published in English and conducted from 1976 up to 2010 were preferentially reviewed.

### The neural bases of sensorimotor integration process

The establishment of an overall view about the functional contributions of different brain regions is fundamental to the sensorimotor integration process. Experimental evidence suggests that sensorimotor actions flow from the synchronized activity among the medullar, subcortical and cortical levels, making circuits in series and parallel. In an attempt to elucidate how cortical areas are organized among themselves to generate such precise motor patterns in harmony with sensory demands of the environment, two basic principles were formulated. The first principle proposes that each brain area involved in the production of movements shows a somatotopic representation of the body, it means, a map of the extremities [4]. The second principle focus on the existence of a hierarchy with three organizational levels: medullar, subcortical and cortical [5], which will be detailed below.

The medullar level is considered the most inferior or primitive inside the sensorimotor integration process. On this level occurs the initial association between the afferent information coming from the skin, muscles and joints. The movement patterns derived from operations at this level include stereotyped motor outputs such as withdrawal reflex and basic standards of locomotion. However, those stereotyped activities are generally replaced, during the majority of daily living tasks, by other more elaborated motor patterns set going through descending projections that arrive at the medulla coming from highest-levels of the brain, which means, in the subcortical and cortical levels [5].

The second level of sensorimotor integration is the subcortical level and it is responsible for selection and organization of motor repertoires of the spinal cord that are used for the control of the axial musculature solicited for the postural stabilization. Substrates like, vestibular nuclei, reticular formation and superior colliculus are essential to the second hierarchical level operation which also includes a regulation of oscillatory patterns during the locomotion. Compensatory reactions to disturbances of the postural axis happen through retroaction circuits and they are constituted in more elaborated responses than medullar reflexes [6]. Other patterns

present in that level include the anticipatory postural adjustments to voluntary movement which esteem disturbances of the axial axis caused by the individual's own motor actions [7]. Within this context, the axial musculature is activated before and during the act of lifting up an object (e.g., a box). In addition, substrates like basal ganglia and cerebellum play important functions during planning and control of voluntary motor actions [8]. Both basal ganglia and cerebellum establish a complex circuit with different cortical areas, being reported by some authors as subsidiary systems to cortical operations.

The third level of sensorimotor integration occurs in the cerebral cortex, more specifically in the association areas, which playing a relevant role in this process. Those areas are not purely motor nether purely sensory, they work integrating different sensory information into processing of neural networks responsible for a motor act execution. That process of integration is also mediated by cognitive aspects such as attention, emotion, planning, memory and others. The information from environment is received by specific pathways for each sensory modality and the cortical inputs for that information are the different primary sensory areas (auditory, visual, somesthetic, etc). These areas transmit the information to unimodal association areas (UAA) that integrate separated aspects of the same sensory modality (e.g., pressure, temperature and pain from the somesthetic way; or also shape, color and movement from the visual way). After that, the different UAA converge to the multimodal association areas (MAA) which are in smaller number. At least, three MAA are recognized: the posterior association area (i.e., in the parietal cortex), the limbic association area (i.e., in the temporal cortex) and the anterior association area (i.e., in the prefrontal cortex) [4]. The result of operations in this high-level of sensory integration is sent to the premotor and primary motor areas of the cerebral cortex. In this way, the primary motor cortex (M1) becomes the information output, transmitting by the corticospinal pathways, motor commands to the effectors' limbs (e.g., muscle extremities).

### The elementary mechanisms of sensorimotor integration process in healthy subjects: specific paradigms

Understanding the neural network of the human motor control system is an important issue in integrative neuroscience. Voluntary motor performance is resulting from a continuous processing of CNS

which integrates information coming from multiple sensory channels, in order to prepare motor acts, and to improve the execution of allowing the performance of specific, goal-directed tasks. In this section, we present the elementary mechanisms involved in sensorimotor integration process in specific goal-directed tasks performed by healthy subjects.

### Sensorimotor integration and saccadic eye movement

The visual system is one of the most important sensory systems for humans and responsible for various aspects of human behavior, including such as spatial orientation and object detection. Vision determines the early stages of information processing and ocular movements are the main entrance for external stimuli [9]. Specifically, ocular movements play a main role in information processing. In 1902, Raymond Dodge described five ocular movements responsible for locating and focusing on an object. Three of these movement are responsible for maintaining the object in the fovea (i.e., saccade, smooth pursuit and vergences), and two stabilize the eyes during head motion (i.e., vestibulo-ocular and optokinetic) [10]. This combination of ocular movements is part of a major system of integration among the individual, their environment, as well as their motivation and cognitive characteristics [11].

Particularly, saccadic eye movement involves the selection of certain relevant aspects and objects in the environment [12]. Models of sensorimotor integration contend that visual stimulus come from the environment and the objects is the first stage of a broader process, the decision making [13]. In the last decades, researches in sensorimotor integration look for relevant elements that better explain the relation among individual, task and environment in the production of motor action [14]. If we consider the integrity of system as a whole, the vision has a great importance in the production of motor action. According to the investigations, is through the visual system that we interpret all the process of connection among environment, individual and task [15].

Saccadic eye movement is defined as a fast movement of the eyeball (i.e., ~200 ms) at a fixation point to another. Saccade has the purpose of focusing the eye in different parts of the visual field in short time interval [11]. Fatigue, drugs abuse and some pathologies, such as schizophrenia slowing the saccadic eye movement [16]. This movement elicited by a visual stimulus requires of a coordination among sensory and association areas. This process enables the brain to identify, to analyze and

to register the stimulus for later motor areas preparing the neural networks responsible for a motor act execution [17]. Therefore, the integration between the visual stimulus and the eye movement represents a finely kind of sensorimotor integration. Previous study shows that latency of saccadic eye movement is lower when other stimulus source (hearing or touching) area presented at a similar time and space relationship [18]. These findings demonstrate the involvement of these same neural substrates in the multisensory interaction process. Models using neural network explain the multisensory integration as a convergence process among visual, hearing and touch information, and sensorimotor substrates, which are necessary to maintain the coordination between head and eyes [19].

### Sensorimotor integration and shooting

During motor learning, sensory system is the responsible for providing different information with cortical and subcortical areas through its multiple receptors [20]. In motor learning perspective, when a subject learns a certain task, multiple feedback mechanisms are involved in this process, because learning a motor gesture involve an integration among sensory stimuli and feedforward of motor mechanisms [21]. In final phase of learning, dependence on sensory stimuli is essential. One example of that synchronism is the coordination among visual and somatosensory stimuli when accurate adjustments are performed in order to adapt a stimulus to the other one to achieve a specific goal. Moreover, movement coordination is achieved by progressive adjustments in motor patterns through the error computation retrieved of the task [22].

The ability of nervous system to converge on several sources of information is requirement for the maintenance of motor control. The fusion of sensory stimuli provides stability, correction and maintenance of the motor act, and the multiplicity of sensory system allow subject recognize and distinguish objects and targets, at the same time it identifies the constant changes occurred in the environment [23]. One example of this phenomenon is the practice of target shooting that represents a complex perceptive-motor demanding a high level of focal attention of the practicing, fine motor control, postural stability, and determiner features for a skilful performance. Those demands include the integration of temporal and spatial sensory information as whole, i.e., visual, vestibular and proprioceptive information [24].

Novice shooters must firstly learn the rule and the competition strategies, as well as to dominate

the fundamental skills of shot, such as shot position, holding the gun, aiming period and trigger pull, which require thought and attention of specific training points regarding to each component of action. However, in most advanced stages of learning the subject better understand the rules and strategies, and automatically execute the fundamental skills, thus, reducing the task complexity [25]. Consequently, shooter can focus selectively on superior demands of shot, such as how integrate the best moment to pull the trigger with the continuous flow of the visual and proprioceptive feedback during aiming period. Even though, minimizing separately the regulation of each component of process, result in a sophistication of perceptivomotor process, leading to improvement of accuracy and movement [26].

### Sensorimotor integration and the binding problem

Understanding how cerebral cortex integrates sensory and perceptive stimuli of different natures and as from these stimuli how it produces a conscious experience is essential for studying superior cognitive processes. This issue has been described in the literature as perceptual binding [27]. The binding problem tries to understand how a unified sensation is produced by the distributed activities of the central nervous system [28]. Investigations in neuroanatomy and neurophysiology have demonstrated that the features of sensory input are segregated into different aspects in the brain [29]. Thus, the question is how these properties are integrated in the brain and translated in an object identity.

In the last years, studies using the EEG identified a higher frequency band ranging between 30 and 100 Hz, named as gamma-band, largely related to cognitive functions [30]. Some studies have been suggesting gamma is responsible for communication between cortical areas during performance of sensorimotor integration tasks [31]. These findings indicate that gamma plays an important role in early stages of information processing and of sensorimotor integration process [32]. Oscillations in gamma point out to cortical operation during recognizing of familiar objects, and are related to the efficiency of forthcoming of sensory information in the relevant sensory cortical areas [33]. Recently, Hermann et al [32] demonstrated through gamma oscillation that is possible to identify cognitive processes involved in the perception and comparison mechanisms related to stored memory content.

Previous studies support the hypothesis that synchronization of neural assembles on gamma is

deeply related to sensory processing [34]. A few studies showed that cognitive process, such as attention, memory and object representation generate and modulate gamma response [35]. Thus, investigations of gamma activity during tasks involving sensorimotor integration may clearly the endogenous process that modulates the neural networks and the communication among cortical areas during complex cognitive functions [36].

### Sensorimotor integration and time-to-contact

The voluntary motor act receives several mechanisms of sensory 'feedback' to allow a feedforward of whole motor control process. Those aspects are essential for adjustment, correction and new patterns of voluntary movement [37]. In the act of catching an object, visual information is essential for performing the adjustment, as changes in the angular displacement of a segment to reach the target [38]. Within this context, the vision has a prominence point in the hierarchy of motor control and sensorimotor integration. The analysis of the object size, the displacement speed and the variety of shapes are important aspects in the visuomotor integration.

In 1966, Gibson [39] started researching the paradigm of object perception and the time-to-contact starting from the study of marine birds' behavior. The investigations were accomplished analyzing the diving precision aspects of these birds to reach the target (i.e., fish). All those information about visual perception were named by Lee [40] as visual proprioception. This sensory modality is defined as the ensemble of sensory information supplied by vision to task executor, referring to the proprioception and the movement of the body in space. Those investigations concluded that the ratio between speed and the retina expansion is that makes possible to the nervous system 'calculate' the time to intercept an object [41]. This calculation, in other words, the ratio between speed and expansion of an object image in the retina is named variable *tau* [42]. In this context, the relation occurs between the size of the image divided by the ratio of its changing and determines the exact time perception of the object interception. This aspect of the visual system became fundamental for the execution of many tasks in our daily living, e.g. either hit or catch a thrown ball [43].

Based on the variable *tau* concept and the time-to-contact, several authors tried to elucidate and understand this mechanism in many experimental conditions [44]. Analyzing the time-to-contact, Senot et al. [44] investigated the anticipation process, the visual and non-visual information, the gravity

acceleration and its influence in the reaction time during the object interception. The experiment consisted of an interception task when subjects had to repel a ball with the racket in two conditions: 'over' and 'under'. The subjects were positioned on two virtual positions, seated with a superior and an inferior vision of the ball thrown. Like this, the ball was thrown in favor of and against the gravity with different speeds. Moreover, it could be speeded up or down and also in a constant speed. The racket movement was started, in average, 25 ms earlier with the ball in the condition 'over' than in the condition 'under', of any ball and its real acceleration. Like the optical flow was the same in both conditions, this response indicated that the influence of the ball direction determined anticipatory mechanisms, especially in the condition which the ball was thrown in favor of the gravity and the cues related to the posture and the environment.

### The role of sensorimotor integration process in movement disorders

The correct execution of a voluntary motor act depends significantly also on peripheral sensory feedback. With this in mind, peripheral pathways convey sensory information to motor cortex. Abnormalities in the peripheral afferent input or in the brain response to sensory input may disrupt the processing of neural networks located in cortical motor areas. Increasing evidence of sensory system involvement in the pathophysiology of Parkinson's disease (PD), dystonia and stroke [45] makes it essential to consider the possible contribution of changes in sensorimotor integration, i.e., the ability to use sensory information properly for assisting neural networks responsible for a motor act execution. Within this context, in this section we review the abnormalities of sensorimotor integration process reported in the most common movement disorders, such as, Parkinson's disease, dystonia and stroke.

#### Parkinson's disease

The currently accepted view on the pathophysiology of PD primarily involves a dysfunction of the basal ganglia-motor cortex circuits. Abnormal firing from the basal ganglia (BG), substantia nigra pars reticulata, and internal segment of globus pallidum, produces functional changes in subcortical and cortical structures, causing cardinal motor features such as, bradykinesia, postural instability, tremor and rigidity

[46]. However, this classical view has been challenged and it has been demonstrated that BG are involved in many functions, such as, somatosensory discrimination, visual perception, spatial working memory and others [47]. PD Patients rely strongly on external sensory information for their movement initiation and execution. Motor act execution depends mostly on a deficient internal cueing mechanism used to discharge successive stages of a movement sequence [48]. When external, visual or auditory cues are provided, substantially improvement of specific features of parkinsonian bradykinesia was noted [49]. With this in mind, defective proprioception may have a role in PD. In line with that, a few experiments on step-tracking motor tasks have showed that PD patients depend more than healthy subjects on ongoing visual information, and without vision, PD patients rely more on kinesthetic input for sensory feedback [50]. Similarly, the study of Klockgether and Dichgans [51] designed to test the influence of visual and kinesthetic information. The authors found that, when the subjects could not see their moving hand, movement accuracy and speed were more severely affected in PD patients than in healthy subjects; moreover, PD patients undershot the movement targets. Keeping this in mind, these findings suggested an impaired peripheral afferent feedback in PD patients.

Another study involving sensorimotor abnormality investigated and demonstrated that PD patients suffer from a deficiency in sensory scaling of kinesthesia. In this study, Demirci et al. [52], tested PD patients using kinesthetic perception to estimate the amplitude of passive angular displacements of the index finger and to scale them as a percentage of a reference stimulus. Two types of stimulus were delivered, either a standard kinesthetic stimulus preceding each test or a visual representation of this one. PD patients undervalued the amplitude of finger perturbations notably more in tasks involving the standard kinesthetic stimulus than in the visual representation of the standard kinesthetic condition. When kinesthesia was used to match a visual target, it was noted that patients perceived distances as shorter. Presupposing that visual perception is normal in PD, however, kinesthesia has got to be reduced. Sensory impairment seems to be a significant mechanism for the pathophysiology of bradykinetic movements.

#### Dystonia

Dystonia is a movement disorder characterized by sustained contractions of agonist and antagonist

muscles leading to abnormal twisting movements and postures. Although dystonia is generally regarded as a pure motor disorder, due to a dysfunction in the cortical-striatal-thalamic-cortical motor loop [53], it is commonly preceded by sensory symptoms, such as, discomfort, pain, or kinaesthetic sensations [54]. Focal hand dystonia is a form of idiopathic adult onset dystonia and tends to be task specific involving repetitive fine movements of the hand such as playing an instrument, writing or typing [55]. Task-specific dystonia of the hand often develops in subjects, whose work involves frequent repetitive movements (e.g., musicians), and who try to achieve perfect and stereotypical, fine movements [56].

The most distinctive sensory phenomenon occurring in dystonia is a tactile or proprioceptive sensory input to the nearby body part that improves abnormal posture. This phenomenon is called the 'sensory trick', i.e., an antagonistic gesture, and can be observed in up to 70% of patients with cervical dystonia [57], but also in other forms of focal dystonia, such as oromandibular dystonia and writer's cramp. The physiological mechanisms underlying sensory tricks are still indefinite, but lately, a PET study in patients with cervical dystonia has demonstrated that sensory tricks can induce a perceptual dysbalance reducing the activation of the supplementary motor area (SMA) and of the primary sensorimotor cortex (SM1) [58]. The additional sensory stimulus can apparently regulate the mistakenly set up link between afferent sensory input and motor parameters, allowing motor commands to be sent more efficiently from the brain. Although elemental sensation is typically normal in dystonic patients, psychophysical studies demonstrated that some specific sensory functions appear to be defective. Dystonic patients demonstrate a reduced perception of the muscle vibration-induced kinaesthetic sensations, i.e., illusory movements [59], indicating a dysfunction in the central mechanisms of processing for afferent signals. Such finding might be related to the reduced cerebral blood flow in response to vibration [60]. A reduction in performance of spatial and temporal discrimination tests was constantly described in patients with focal hand dystonia [61], supporting a role for sensory dysfunction in the pathophysiology of dystonia. In line with that, a nonlinear sensory cortex response to simultaneous tactile stimulation was recently demonstrated by a functional magnetic resonance imaging (fMRI) study in patients with writer's cramp [62]. Undeniably, abnormalities of temporal-spatial processing might cause the impaired force balance observed in writer's cramp [63].

At last, the use of functional imaging techniques has documented in patients with focal hand dystonia probable cortical reorganization of the finger representation on the SM1 (i.e., abnormal finger representation with enlarged and overlapping tactile receptive fields) [64]. Changes in cortical plasticity and damaged tactile discrimination might only be the consequence of co-contraction, as revealed by an experimental study in healthy subjects [65]. On the whole, the earlier clinical and experimental observations are in line with that sensorimotor integration is impaired in focal dystonia, that is, an abnormal sensory input may possibly be a trigger for dystonia or the brain response to sensory input could be abnormal. Functional changes in BG circuits may develop due to striatal lesions or may be induced by overuse and peripheral traumas. The dysfunction might consist for the most part of a deficient central processing (i.e., reduced inhibition) of sensory inputs leading to an excessive and distorted afferent information and causing a fixed input-output divergence in specific neural networks responsible for a motor act execution [66]. In this manner, inappropriate sensory support to ongoing neural networks might result in motor abnormalities such as co-contraction or inappropriate contraction of distant surrounding muscles.

### Stroke

Stroke is defined as a sudden focal neurological deficit due to a cerebrovascular abnormality and their specific deficits seen after stroke depend on the area of the brain affected. Within this context, affected neural networks may disrupt the appropriate sensorimotor integration process and, consequently, lead to changes in the performance of the motor tasks [67]. In this context, the severity of the motor deficits in stroke patients is related to an impairment of the sensorimotor integration process [68]. Such fact is due to the decreased plasticity in affected region while an increase of sensorimotor integration process happens in non-affected regions. Probably, this cortical reorganization pattern is for a larger motor ability of the non-affected limb [69]. However, sensorimotor integration process may improve gradually on affected-region through some kinds of therapy, such as, brain stimulation matched to other types of rehabilitation [70].

Several experiments have demonstrated these specific methods of rehabilitation in hemiparetic stroke patients, e.g., the constraint-induced movement therapy. This technique involves restraint of the intact limb over an extended period, in combina-

tion with a large number of repetitions of task-specific training of the affected limb. Such technique has demonstrated positive outcomes in amount of time and gain of motor ability in affected-limb evidencing that sensory information is being integrated by central nervous system (CNS), favoring the operation of neural networks for the affected-limb. In this manner, an effective motor recovery of stroke patients is associated with a decreased activity in non-affected sensorimotor cortex that will lead to an increase in neural activity of the affected-area [71].

The relearning of rhythmic and coordinated movements of the affected-limb in stroke patients demonstrate that sensorimotor integration process is complex and depends on several kinds of specific models of intervention. Keeping this in mind, 'feedback' is essential for an effective motor control and integration with the environment to perform rhythmic and coordinate movements. Specifically, central neural networks are influenced by sensorimotor feedback to compensate for the changes in the environment through the interaction between neural networks and neuromuscular system [72]. In this manner, it favors the increase in the activation of the affected-area, which leads to the enhancement of the sensorimotor integration process with respective motor recovery of the affected-limb [73]. Within this context, internal mechanisms are associated with other mechanisms available on environment to organize sensory information and to enlarge the motor ability gain. In line with that, the methods of rehabilitation (e.g., motor imagery and mirror therapy) in stroke patients must use different 'feedbacks' associated with the task practice to enlarge the quality of neural adaptation in the affected-region [74].

### Sensorimotor training-induced cortical reorganization

The capacity of reorganization of the sensorimotor cortex of mammalian adult was an uncertain question for many decades. However, today it is known that such changes are possible and occur due to several factors. Diverse experiments demonstrated that training of sensory tasks and behavioral experiences can lead to a solid reorganization on sensorimotor cortex of adult primates [75]. It was suggested by Ramachandan et al [76], that using a mirror, it would be possible to revert to alterations in cortical reorganization observed in amputees with phantom limbs. It was observed when patients watched a hand or arm non-amputated movement in a vertical

parasagittal mirror, an improvement of motor control and a decrease in pain in the phantom limb is observed. Understanding the reorganization of the sensorimotor cortex is essential to create learning and relearning strategies, because through the appropriate interventions, it can possibly promoting an improvement of the quality of life and/or functional recovery.

Studies have demonstrated that functional organization of sensorimotor cortex is dynamic and can change according to the task demands, the context and the peripheral manipulations [77]. An experiment performed in animals and humans demonstrated that somatosensory neural networks allow the learning of sensorimotor tasks or the functional recovery after some lesion through the relearning [78]. Other data demonstrated that M1 has also an intrinsic circuit necessary to support the reorganization, constituted by the horizontal connections, and that it could reflect the synaptic plasticity of these fibers. The plasticity that occurs in SM1 supplies mechanisms to promote the enhancement and also the functional recovery after damage in central and peripheral nervous system [79]. Typically, the adaptive reorganization of the neural connectivity is based on unmasking of previous synaptic connections, on effort of existent synapses and on formation of new synapses.

Experimental research involving Braille-readers subjects and piano players demonstrated an occurrence of use-dependent cortical reorganization. That reorganization characterize, for blind Braille-readers, by increasing motor cortical representation relative to the employed finger in the task compared with the contralateral finger. Moreover, this reorganization pattern was also compared with the cortex of blinds that did not read Braille or of volunteers with normal vision. Furthermore, when those subjects did not perform the reading for a few weeks, it was noted a strong reduction in the size of the employed finger somatotopic representation. In addition, it was observed an augmentation in motor cortical representation of the hand in non piano players, however, the cortical representation returned to the original size when the exercises finished [80].

Intriguing evidence does concern about the increase of the hand area even in piano exercises just imagined by volunteers, without a real execution of the task. That data supports the effectiveness of the mental training performed during a certain period without real training execution. In that way, it was observed that the sensory-motor training plays a potential role in the reorganization of somatosensory and motor cortices [4].

## Final remarks

As this review underlines, we found that the sensorimotor integration process plays a potential role in elementary mechanisms involved in specific goal-directed tasks performed by healthy subjects. In addition, we showed evidence of occurrence of sensorimotor integration abnormalities in patients with Parkinson' disease, dystonia and stroke. Whether these disorders are associated with an abnormal peripheral sensory input or defective central processing is still unclear, but most of the data support a central mechanism. Sensorimotor integration seems to play a significant role in the disturbances of motor control, like movement guide, muscle activation and muscle weakness, typically seen in PD, dystonic and stroke patients. Moreover, it was observed that training strategies that stimulate the existing neural connections in the sensory-motor regions play a potential role on the acquisition of abilities that have as critical factor the coupling of different sensory data which will constitute the basis of elaboration of motor outputs consciously goal-directed.

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### **Integración sensitivomotora: conceptos básicos, anomalías relacionadas con trastornos del movimiento y reorganización cortical inducida por el entrenamiento sensitivomotor**

**Introducción.** La integración sensitivomotora se define como la capacidad del sistema nervioso central para integrar diferentes fuentes de estímulos y, paralelamente, transformar dichas entradas en acciones motoras.

**Objetivos.** Revisar los principios básicos de la integración sensitivomotora, como sus bases neuronales y sus mecanismos elementales implicados en tareas orientadas hacia la consecución de objetivos específicos realizadas por sujetos sanos, y las anomalías descritas en los trastornos del movimiento más frecuentes, como la enfermedad de Parkinson, la distonía y el accidente cerebrovascular, además de los mecanismos relacionados con la reorganización cortical.

**Desarrollo y conclusiones.** Todavía no está claro si estos trastornos se asocian a una entrada sensitiva periférica anormal o a un procesamiento central defectuoso, pero la mayoría de datos respaldan un mecanismo central. Nuestros resultados muestran que el proceso de integración sensitivomotora desempeña un posible papel en los mecanismos elementales implicados en tareas orientadas hacia la consecución de objetivos específicos realizadas por sujetos sanos y en la aparición de anomalías en la mayoría de trastornos del movimiento más frecuentes; asimismo, desempeña un posible papel en la adquisición de habilidades que tienen como factor crítico el acoplamiento de diferentes datos sensitivos que constituirán la base de elaboración de entradas motoras orientadas conscientemente hacia la consecución de objetivos.

**Palabras clave.** Accidente cerebrovascular. Conjunción. Distonía. Enfermedad de Parkinson. Integración sensitivomotora. Movimientos sacádicos. Tiempo hasta el contacto.