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Journal:	*The World Journal of Biological Psychiatry*
Manuscript ID:	Draft
Manuscript Categories:	Review Article
Date Submitted by the Author:	n/a
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Keywords:	Schizophrenia, Alzheimer's disease, Psychopathology, Autism, Sensory-motor integration

Sensorimotor integration and psychopathology: motor control abnormalities related to psychiatric disorders

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Short title: Sensorimotor integration and psychopathology

Number of words: 4.852

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Abstract

Recent evidences are reviewed to examine relations among sensory, sensorimotor, and cognitive aspects in some important psychiatry disorders. Specifically, the study of psychiatry disorders and its relation with sensorimotor integration process can elucidate how the brain assimilates and combines information and transforms them into motor response. This study reviews the theoretical models in the context of sensorimotor integration and the abnormalities related to sensorimotor integration process reported in the most common psychiatric disorders, such as Alzheimer's disease, autism and squizophrenia. We found that the sensorimotor integration process plays a relevant role in elementary mechanisms involved in occurrence of abnormalities in most common psychiatric disorders, participating in 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. Whether these disorders are associated with an abnormal peripheral sensory input or defective central processing is still unclear, but some studies support a central mechanism. Sensorimotor integration seems to play a significant role in the disturbances of motor control, like deficits in the feedforward mechanism, typically seen in AD, autistic and squizophrenic patients.

KEY-WORDS: Alzheimer's disease, autism, motor control, sensorimotor integration, squizophrenia, Psychopathology

Introduction

Sensorimotor integration is the capacity of the Central Nervous System (CNS) to integrate different sources of stimuli, and to transform such inputs into motor actions (Serrien and Spapé, 2009). In fact, sensorimotor integration is the possibility to combine different sources of sensory stimuli through a unique CNS´s language which transform those stimuli in motor commands (Coynel et al., 2010). The coordination and the development of an internal model are fundamentals aspects of the sensorimotor process (Sarlegna et al., 2009). The coordination of a motor action needs a constant restructuring of different elements of the nervous system. Such reorganization is seen among sub-cortical and cortical sites, neurotransmitters, synapse gaps, neuron´s ramification, and a variety of others micro and macro cosmos in the CNS (Oram et al., 2001; Mueller et al., 2009). Another characteristic involving motor coordination is the integration among the individual (i.e., organism), the environment and the task. The connection between sensitive and perceptive processes from an individual into the environment is the key element in the execution of a motor task. The environment conditions modulate (i.e., positive or negative) the coordination of motor action and, consequently, the motor pattern (Bringoux et al., 2009). Finally, the task to be executed contributes to differentiate degrees of implemented ability. Thus, the cognitive aspects, stimulus exposition, previous experience and the nature of the task (i.e., open or closed tasks) will determine the degree of coupling between the executants and the execution of the motor action (Uc et al., 2009). Particularly, coordination expresses the refinement and detailed control of the motor gesture. Deviations in the coordination pattern are recognized and may represent inadequate motor behaviors which are out of the norm (Caeyenberghs et al., 2009).

Recent researches have pointed out the importance of sensorimotor integration in some neurological disorders (e.g., Parkinson's disease, Dystonia, and Huntington's disease). However, little is known about the relation between sensorimotor integration dysfunction and psychiatry disorders. Some evidences demonstrate that a dysfunction in the integration among diverse sensory information could result in a perceptive distortion. (Li and Lindenberger, 2002; Abbruzzese and

Berardelli, 2003). Recent evidences are reviewed to examine relations among sensory, sensorimotor, and cognitive aspects in some important psychiatry disorders (Delevoye-Turrell et al. 2003). Specifically, the study of psychiatry disorders and its relation with sensorimotor integration process can elucidate how the brain assimilates and combines information and transforms them into motor response. This study reviews the theoretical models in the context of sensorimotor integration and the abnormalities related to sensorimotor integration process reported in the most common psychiatric disorders, such as Alzheimer's disease, autism and squizophrenia. We underline the importance of abnormal sensorimotor integration in the pathophysiology of some psychiatry disorders. 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, A*lzheimer's disease, AD, autism, and squizophrenia* in combination with *sensorimotor integration*. Only papers, such as, critical and systematic reviews, meta-analyses, experimental and clinical reports and book chapters published in English and conducted from 1989 up to 2009 were preferentially reviewed.

The role of theoretical models in sensorimotor integration process

Researchers that study motor control in particular sensorimotor integration, are concerned about establish fundamental elements that were more explanatory and relevant to relationship among subject, task and environment in motor action production (Bruno and Battaglini, 2008). Theoretical models that include such fundamental elements have been proposed. Those models are necessary since they express the main aspects of certain phenomenon, and besides, they reduce its complexity allowing the understanding of its macro properties (Song et al., 2008). The simplification allows the formation of a base that the more complex phenomenon can be understood (Brozović et al., 2007). Over the years, explaining how human beings control and perform movement appeared to be a hard task for scientists, especially, how characterizing the gesture production in terms of measurable dependent variables that describe in detail which mechanisms are involved in movement aspects that play an important role in comprehension of those processes (Bernabucci et al., 2007).

Particularly, in the field of sensorimotor integration, the model becomes necessary since it can selecting elements to be manipulated, and in parallel, in the possession of biological real data retrieved based on essential aspects of the phenomenon, concrete hypotheses can be outlined (Jeka et al., 1997). For instance, models generally include sensory symptoms, perceptive aspects, executive functions, coordination inside the subject and with the environment, motor execution, memory, and feedforward through error correction in order to perform the motor gesture accurately (Page and Matheson, 2009). Evidently, the elements of this theoretical model can be described in a detailed way, approaching each specific stage. For example, the skill of selecting relevant information would be considered an executive function, depending on the interest of the several laboratories; an emphasis may be dedicated to this specific aspect through manipulation of experimental conditions (Cunha et al., 2008). A lot of sensorimotor integration models have a special approach relative to the memory system, since it acts as a part of the comparator system, essential for error correction. In particular, the ability to select, to store and to get back information, i.e., the stages involved in the memory system are often manipulated in terms of the type of memory involved, i.e., either implicit or explicit (Krakauer, 2009).

Thus, the field of motor control was basically divided in three distinct aspects: postural control, gait and voluntary actions (Carver et al., 2006). In regulation of gait and in voluntary actions control, visual information is essential for ensuring the movement performance (Krieghoff et al., 2009). The skill of walking or catching a pen definitely can be performed without stimuli, for instance, either blind subjects or situations when at night a subject try to catch a cup of water at the head of the table represent classically the ability of executing a task without visual information (Magescas et al., 2009). However, taking into account the system integrity in a general sense, vision plays an essential role in production of motor acts. In particular, the sensorimotor integration models consider that light stimulus arising from environment and objects, is the first stage of a widely process called decision making (Puga et al., 2007).

The role of sensorimotor integration process in psychiatric disorders

Abnormalities in the peripheral afferent input or in the brain response to sensory input may interfere with the processing of neural networks in cortical motor areas. Increasing evidence of sensory system involvement in the pathophysiology of certain psychiatric disorders makes it essential to consider the possible contribution of changes in sensorimotor integration, i.e., using sensory information properly for assisting neural networks implementation (Abbruzzese and Berardelli, 2003; Delevoye-Turrell et al. 2003). Therefore, in this section we will discuss the abnormalities related to sensorimotor integration process reported in the most common psychiatric disorders.

Schizophrenia

Schizophrenia is a brain disorder that affects cognitive functioning (Flashman et al., 1996; Chan et al., 2010) and emotional stability (Reske et al, 2007). Schizophrenia is a mental disorder defined by impairment in the perception or expression of reality. It most normally visible as auditory hallucinations, paranoid or bizarre delusions, or disorganized speech and thinking with significant social or occupational dysfunction. Although several studies proposed to investigate these aspects in schizoprenic patients, few studies reported motor behavior characteristics and the nature of the motor abnormality. Investigations in sensorimotor integration have addressed two different directions in schizophrenia research, one that involves the coordination and sequencing of motor action and another that examines the abnormalities in the perception of action while the motor control is intact (Luna et al., 2008). The former is related to negative symptoms and it implies the planning and coordination of motor action. The later is associated with the positive symptoms, i. e., psychotic behaviors, as hallucinations and disillusion. In this case, the patients describe that some external agent control their actions, thoughts or emotions, what some authors call 'passivity' experiences (Frith et al., 2000).

The first findings in schizophrenia demonstrated motor impairments in almost all their schizophrenic patients. It was reported irregular timing and spacing of steps during actions such as gait, as well as reduced efficiency and coordination of fine movements during actions such as handwork (Delevoye-Turrell et al., 2003). Other studies reported deficient motor synchrony as well as generalized incoordination in voluntary motor control (Boks et al., 2000). In the last years, the combination of anticipatory and reactive mechanisms in the generation of potential motor acts has been well understood. Due to its intrinsic time delays, the motor system cannot exclusively depend on reactive mechanisms (Johansson et al., 1994) and, therefore, anticipatory control would be essential for skilled motor performance (Flanagan et al., 1997). Consequenlty, it has been suggested that schizophrenia is a pathology that affects specific predictive mechanisms involved in the anticipatory control of motor actions (Feinberg et al., 1999). Delevoye-Turrell et al. (2003) investigated whether schizophrenia affects the predictive mechanisms required for the scaling, timing, and/or sequencing of motor actions during grip force tasks (i.e., lift, hit and resist an object). The investigators found that schizophrenic patients were impaired in the smooth execution as much the lift as the hit tasks however not in the performance of the resist task. Such findings were interpreted as a specific deficit in the sequencing of motor actions rather than with an overall problem in the predictive control of movement. These results showed an abnormality in the integration of sensory information into motor action, especially during the motor coordination and motor sequencing (Walker, 1981; Walker and Green, 1982; Manschreck et al., 1981).

Another feature presented by schizophrenic patients are the self-generated actions involving central processes of sensorimotor integration that supervise sensory inputs to insure that motor outputs are congruent with our intentions (Fourneret et al., 2002). This mechanism acts automatically in normal conditions but becomes conscious whenever a mismatch happens during the performance of action between probable and existing sensorimotor reafferences. It is now acknowledged in the current literature that sensorimotor processes as well as the ability to forecast the consequences of our own actions involve an action forward model based on efference copies. Previous studies proposed that positive symptoms expressed by schizophrenic patients, such as delusions of control or thought insertions, arise because of a dysfunction in the action forward model, and mainly, because of a lack of awareness of certain aspects of motor control derived from such an internal model (Frith et al., 2000). Neurophsysiological studies have demonstrated an abnormal functional integration of brain processes (Simons et al., 2006; Stephan et al., 2009). These authors hypothesize that this abnormal functional integration is involved in the generation of positive symptoms that reflect a difficulty discriminating between external information and information that was imagined. Reuter et al. (2007) investigated experimental relative roles of volitional action initiation and the inhibition of reflexive behavior in an oculomotor task. They observed that schizophrenic patients have a deficit in initiating volitional action. These results are in agreement with the hypothesis of the previous authors and it confirms and abnormal functional integration involving central processes in schizophrenia.

Alzheimer's disease (AD)

Alzheimer's disease (AD), also called Alzheimer disease, Senile Dementia of the Alzheimer Type (SDAT), is the most common form of dementia. This irremediable, degenerative, and fatal disease presents cognitive disturbance, represented by profound memory impairment. The AD development demonstrates that some forms of memory are affected while others remain relatively intact. In early stages the patients have the ability to consciously and directly recall or recognize recently processed information, i.e. explicit memory. While in later stages these patients present impairment in the implicit memory (i.e, the knowledge is expressed through performance or behavior, rather than conscious recall, such as information acquired during skill learning, habit formation, classical conditioning, emotional learning, and priming) (Machado et al., 2009). Specifically, the investigation of sensorimotor integration process in AD focuses in the later stages, when the impairment of the implicit memory implies in a motor control or motor ability alteration. This alteration is related to a deficit in the integration of cognitive information into a movement plan (William et al., 2006). In line with that, Ghilard et al. (2000) have investigated the visuomotor integration in patients with AD, and these studies had concluded that AD patients used the visual information differently for motor control, and it includes programming and executing the movement.

One consequence of the deficiencies in the integration of visual and cognitive information into movement is the decline of motor accuracy. It is well know that the enhancement of accuracy of visual targets oriented-movements depends on feedforward mechanisms that guide the movement into distant targets; while visual feedback (FB) conduct the movement when the subject is near the target (Jagacinski, 1989). Feedforward commands are based on different parameters of memory, such as, spatial relations related to visuomotor integration which is updated by sensory information. For instance, movements performed without visual FB show systematic directional biases depending on the initial hand position with respect to body mid-line. These errors represent a range effect reflecting prior experience: the error-free area includes habitual location of the hand in daily tasks and practice in spaces away from it produces new biases in previously error-free regions (Ghilard et al., 1995). See the hand prior to movement is required to update internal representation of the starting point in the workspace and to plan movement direction.

Otherwise, representation in memory of the hand's usual location in the workspace is used, leading to directional bias. Ghilard et al. (1999) ask whether memory deficits in Alzheimer's disease (AD) interfere with movement planning and execution. Nine AD patients and nine age-matched controls moved a cursor to targets without seeing their limb. Starting and target positions were always visible on a screen, while, during movement, cursor position was either visible or blanked. It was found that patients' paths demonstrated discontinuous segments and prolonged movement time; movement inaccuracy, which increased without visual feedback, correlated significantly with scores of disease severity, working memory and attention. Another evidence of sensorimotor integration conflicts comes from recent findings which demonstrated that the integration of eye and hand information may be impaired in AD patients.

Autism spectrum disorder (ASD)

In the same way that Schizophrenia and AD, ASD is a complex disorder characterized by a marked impairment in sensorimotor integration process. Impairment in social interaction, restricted, stereotyped and repetitive behavior, and hypersensitivity to certain sounds are some symptoms present in ASD (Kohen-Raz et al., 1992; Gepner et al., 1995; Molloy et al., 2003). A disruption in neural development affects functional connectivity and, consequently, the capacity to coordinate activity across many brain regions to produce complex behavior (Dapretto et al., 2006). Abnormal connectivity of brain regions may have a huge impact on the work of the multimodal association cortex. Its contribution to adaptive behaviors typically depends strongly on the integration and interdependency of different role in complex and widely distributed brain systems. A multisensory integration deficit could cause impairments in higher order cognitive and adaptive behaviors and affect other systems that are dependent on distributed brain systems, such as those that perform sensorimotor transformations.

There are many existent theories which attempt to explain the multiple behavioral impairments in ASD. One recent theory suggests that a dysfunction in a specific functional system, the mirror neuron system, underlies the behavioral impairments in ASD (Oberman et al., 2005; Williams et al., 2001). The theory of an impaired functioning on mirror neuron systems appears as a path for testing models of functional connectivity deficits in autism, and for determining whether some neural circuits are selectively affected in this illness. Recent studies have demonstrated evidences which links this theory and the dysfunction in the mirror neuron system to the behavioral deficits in autism (Nishitani et al., 2004; Oberman et al., 2005; Theoret et al., 2005). EEG and fMRI studies demonstrated that during the observation and execution of complex actions, children with autism were not able to activate in a feed-forward manner the target muscles that are consecutively involved in the specific motor task (Hauk et al., 2004; Hauk and Pulvermuller, 2004; Cattaneo et al., 2007). For example, when normal individuals activate ingestive actions, such as grasping a piece of food, this anticipatory activity is lacking in children with autism; this may explain why these patients have difficulties in coding the action intention of others.

Others researchers investigated the role of mirrors neuron systems in the emotion expressions in children with ASD. An fMRI study verified the capacity to imitate facial emotion expressions in high functioning ASD subjects compared with healthy control subjects (Dapretto et al., 2006). This study provided strong evidence in favor of a deficit of the mirror mechanism in ASD. Interestingly, the researchers observed a weaker activation in the inferior frontal gyrus (IFG) in children with ASD than in normally developing children. It was observed a stronger activity in face motor areas (i.e., primary motor and premotor areas) of ASD children during the imitation task. Moreover, they did not find difference between-group in these regions. The ASD children demonstrated a greater activity in right visual and left anterior parietal areas than the normally developing children. These findings suggested that although both groups executed the imitation task as requested, the pattern of neural strategies adopted by normally developing children and those with ASD are quite different. Normally developing children can rely on a mirroring neural mechanism located in the right hemisphere interacting with the limbic system via the insula according to the meaning of the emotion provided by imitated action is directly felt and hence understood. In contrast, this mirroring mechanism is seemingly not engaged in children with ASD, who must then adopt an alternative strategy of increased visual and motor attention whereby the internally felt emotional significance of the imitated facial expression is probably not experienced.

Moreover, different from classically developing subjects, children with ASD tend not to imitate other subjects when they view their facial expressions (Avikainen et al., 2003). Such fact is possibly attributable to a dysfunction in the mirror mechanism to superimpose another person's movements on one's own. In this manner, the observation of an action done by another subject seems to interrupt the motor system of a typically developing observer, in contrast to children with

ASD. This finding suggests that in ASD children, the mirror neuron system is silent during action observation, and in addition, the immediate experiential understanding of the intentions of others is absent.

Final remarks

As this review underlines, we found that the sensorimotor integration process plays a relevant role in elementary mechanisms involved in occurrence of abnormalities in most common psychiatric disorders, participating in 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. Whether these disorders are associated with an abnormal peripheral sensory input or defective central processing is still unclear, but some studies support a central mechanism. Sensorimotor integration seems to play a significant role in the disturbances of motor control, like deficits in the feedforward mechanism, typically seen in AD, autistic and schizophrenic patients.

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