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Review Article

The Body Schema: Current Data and Definition

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Abstract

This paper is the second of two about the relationship between the body schema (BS) concept and neurosciences. The first one concerned the history of the body schema concept. Dolto [1] and Gallagher [2] let go the body schema to the neurological and neurophysiological equipment. Since then, body schema has become a very good research field in neurosciences. Body image is an affective concept about the relationship between mind and body. Body schema is a physiological notion with proprioceptive, visual (including peripheral retina which involves movements and brightness vision and is located on the peripheral retina) and vestibular informations. Motor systems are engaged too. Vestibular system is engaged for the postural modifications change the weight of gravity. Interoception and touch are not supposed to interfere with body schema. Neurosciences taught us to take in account a new kind of space to include into the body schema: the peri-personal space. Different regions of the brain are involved in the body schema notion. They are described here.

Keywords: *Body Schema; Neurosciences; Proprioception; Peripheral Vision; Vestibular Information; Peri-Personal Space; Neuron Networks; Cortices; Psychomotricity*

Introduction

Neuroscience has established that body schema is about the automated management of the body's position in space as well as changes in position. They highlighted the existence of a neuro-anatomical substrate at the BS. The cortical areas involved are varied and organized into neural networks. Dolto and Gallagher's clarification turned out to be very fruitful. Let's start with some sketches of definition.

General definitions

Let's start with Fontan [3]:

- "To act effectively it is necessary to have precise knowledge of our bodily capacities engaged in action. This knowledge includes the composition of the different parts of the body, the location of the different body segments in space, the relationships between these body segments or even the physical limits of the body. This information is found at the cerebral level in the form of internal representations providing information on the characteristics of the action that the body performs and on its interaction with the environment.

- It is obvious that, to correctly and accurately generate an action, obtaining information on the state of the body is necessary. An error coming from the state of the body would have a direct impact on the movement carried out. The example of the use of sensory feedback about the body in action (effectors used, position) suggests the existence of an internal representation of the acting body: the body schema [2].
- To act effectively it is necessary to know the position of the body in space as well as its geometry and the relationships between the different body segments involved in the action. This internal representation of moving body segments has been conceptualized as the body schema [4,5].
- The body schema would contain the information about the acting body, such as its position in space, essential to the execution of actions.
- The integration of sensory information from the body and the environment would therefore play an essential role in the construction of the representation of our own body as well as its relations with the environment. To create an accurate representation of the body in space, the body map integrates both sensory information generated by the body in motion via the transmission of sensory inputs - ie vestibular, visual and proprioceptive - and motor information relating to movement. planning, execution and control of movement. The integration of this different information produced during the action would allow the adult to continuously update the body schema.
- When the body interacts with its environment, multiple sensory information will converge towards the central nervous system. This vestibular, visual and proprioceptive information will provide information on the postural changes of the body or even on the modifications related to the environment.
- In summary, the body schema is characterized by a spatial encoding of the body integrating the position and configuration of the body in space, allowing representations of action to integrate the modalities of the body acting to achieve a goal. The body schema is a supra-modal entity that integrates the different sensory information coming from the body - i.e. vestibular, proprioceptive and visual - thus making it possible to create a three-dimensional amodal representation adjusted to its environment. The plasticity of the body schema, as observed during tool use or in motion illusion paradigms, would allow continuous and rapid updating in order to adjust body representations to the multiple changes likely to impact the body. action in a given environment".

In other words, we need real-time sensory information about the position of the different segments of our body in relation to each other. This information can, among other things, ensure a feedback control of the movements carried out to ensure that they are effective. It is this form of spatial representation of the different parts of the body in motion that has been called the body diagram. The latter involves, continuously and in addition to movement planning, the mobilization of the proprioceptive, visual and vestibular sensory systems. The body schema is therefore the result of the coordination of different sensory and motor modalities. It is a sensory-motor concept. Armed with these details, it is now possible to propose a definition of the notion of body schema: BS is a non-subjective physiological function. It is a sensory-motor, three-dimensional, non-conscious, automatic and constantly readjusted representation of the global and/or segmental position of the body and its movements. This representation involves different sensory systems, their coordination and their integration (proprioception, vision, equilibration). Proprioception is, in adults, the main reference. What is called "peri-personal space" is an integral part of the BS.

Interoception, that is to say the sensitivity coming from the respiratory, digestive, cardiac and endocrine systems, cannot be included in a definition of BS because it is too closely linked to the "factory of feelings" [6] and therefore to subjectivity.

Proprioception

For Breedlove., *et al*. [7], proprioception is the perception of the body based on the sensory innervation (proprioceptive) of muscles, tendons and joints, it informs the brain of the position and movements of the body. For Richard and Orsal [8], proprioception, also called deep sensitivity, corresponds to three types of sensory information: position (or posture), movement and force:

- Position information relates to joint angles. This sensory system allows us to feel the position of the different segments of the body in relation to each other and therefore, for example, the position of the segments of the limbs between them and in relation to the body. But it also concerns the position of the neck, the orientation of the trunk as well as the opening of the lower jaw. This form of sensitivity is, according to Richard and Orsal, "weak but can be greatly enhanced by learning".
- Sensitivity to movement, kinesthesia, includes sensations of speed, amplitude and direction all at the same time. Sensory thresholds are lower in proximal than distal joints.
- Sensitivity to force allows us a certain form of muscular resistance but also a feeling of the muscular effort produced to lift a load.

The sensory receptors involved in proprioception are mechanoreceptors (or proprioceptors) located in muscles, tendons and joints. In muscle, these are "sensory endings that wrap around the central region of muscle spindle fibers". The muscle spindle comes into action during the passive stretching of the muscle. In tendons, Golgi tendon organs are sensitive to muscle tension and rather insensitive to passive muscle strain. They are involved in important efforts. They therefore record the intensity of the contraction and provide part of the information that contributes to the precise control of movements. Muscle and tendon receptors therefore play a very important role in controlling contraction. The joints are equipped with many types of receptors: Golgi, Manzoni and Pacini corpuscles. Other types are reduced to simple free endings. Importantly, all of these receptors provide more information about joint movement than the opening angle of the joint. Force receptors appear to be muscle receptors.

Proprioception therefore concerns an internal representation of body segments in motion (or following a movement for position information), an internal representation which was conceptualized under the term body schema by Head and Holmes (1911) [4].

The role of vision

Parson [10] mentions vision as a vital source of information for posture and movement. Gallagher and Cole [2] studied the role of vision in the development of BS. For this, they made reference to the situation of IW, an adult subject, suffering from "sensory neuropathy". This person had no proprioceptive or tactile information below their neck. His motor skills were theoretically unscathed. He had no proprioceptive awareness of the position of his limbs. He therefore could not locate them without seeing them. "Without proprioceptive or tactile information, he could neither know where his limbs are nor control his posture unless he looked at his body with a very strong effort of concentration. Without it, he had no control over his movements. The visual system is therefore an important component of BS.

Gibson [11] proposes the notion of "visual proprioception" to characterize the role of vision in taking in information during active movements. This "visual proprioception" would intervene to process the visual flow taking place dynamically in space. Gallagher and Cole [2] go further and propose that visual proprioception is involved in the non-subjective processing of visual information related to movements appearing in the visual field and not only when it is the subject himself who is moving. "Postural adjustments are made to compensate for changes in visual flow. According to Jouen [12], this ability to process this type of information is present at birth. Gibson's visual proprioception [11] evokes Bullinger's notion of peripheral vision [13]: "Peripheral vision essentially deals with movement. The body's responses to these stimuli are tonic and postural. The displacement of a body segment in the visual field is partly regulated by retinal cues. It is essentially the periphery of the retinas that is solicited. The discovery of a "vehicle" body relies heavily on peripheral visual signals. There is necessarily coordination between vision and proprioception. Proprioception, as an uncoordinated "mechanic" (e.g. when performing a task with eyes closed) to the visual system is obviously a major source of information about - and control of - posture in the here and now. It contributes to the automatic control of posture and movement. But vision plays an undeniable role. The proprioceptive deficit of IW impaired the sensory-motor coordination between vision and proprioception. Control by peripheral vision has replaced proprioception. For IW, the intensity and the success of the concentration necessary to compensate for his proprioceptive deficit by relying on his peripheral vision shows that this last system is, in a non-ill subject, in fact a support for proprioception.

The compensatory nature of peripheral vision in the case of loss of proprioceptive information clearly shows the importance of movement vision in the SC. The case of child development, as we will see later, also supports this idea. Vision, in its peripheral component, is indeed part of the BS.

Balance and the vestibular system

The debates first focused on pathology following the remarks of Bonnier [14]:

- The latter proposes the term "aschematia" to describe a distortion of the representation of the volume, shape and position of the body and its various segments. Schilder [15] recounts that patients with vestibular disorders reported swelling of their neck during numbness or that their extremities widened or that their foot seemed to lengthen. Research from pathology has shown that vestibular disorders can lead to changes in the BS due to misinterpretations of bodily signals, for example postural. Sang., *et al*. [16] as well as Lopez., *et al*. [17] claim that patients with peripheral vestibular disorders mislocate different parts of their body. Borel., *et al*. [18] demonstrated that patients could underestimate their movements as well as the direction of their movements. Schmidt., *et al*. [19] explain that mild and non-invasive electrical stimulation of the vestibular system improves proprioceptive deficits in cases of right hemisphere damage. The patients in question, suffering from visuo-spatial hemineglect, thus prove to be more precise in locating their left upper limb. Vestibular signals could provide sensory information capable of correctly locating the limb by implicating intact structures also involved in the recalibration of body and limb position. And in the subject free from any lesion of the central nervous system?
- The same form of stimulation of the vestibular system used in non-pathological subjects not only alters localization abilities but even creates an illusion of whole-body movement, i.e. a dissociation between perceived and real localization [20]. Bresciani., *et al*. [21] report that vestibular electrical stimulation disrupts the approach movements of a visual target by interfering with the spatial estimation by the subject himself of the position of his hands in the surrounding space.

The pathology therefore clearly shows the involvement of the vestibular system in the SC by misinterpretation of sensory signals. Electrical stimulation of the vestibular system changes the perceived locations of different parts of the body and disrupts movement. In addition, changes in the center of gravity during changes in position require the involvement of the vestibular system. The vestibular system is therefore well engaged in the BS.

Neuroanatomical substrates

- From the outset, it should be noted that there is no cortical zone devoted to equilibration. Vestibular signals reach the vestibular nuclei of the medulla oblongata and are projected onto several multisensory regions of the brain [22]. It is believed, thanks to neuroimaging, that the position of the various body segments rests on the superior parietal lobe. Somatotopic representations of the body could involve the parietal operculum but also the posterior part of the insula. These regions are referred to as the "parieto-insular vestibular cortex". They are located very close to the temporoparietal junction [20,23].
- The vestibular nuclei are the site of a multi-sensory convergence (vision, tact, proprioception). This convergence would seem to "drown out" the vestibular information [24].
- The vestibular nuclei project pathways to the oculomotor nuclei and to the thalamic nuclei involved in somatosensory processing as well as to cortical areas.
- Some of these links provide feedback used to turn the eyes to the left and take into account the proprioceptive signals from the neck during a rotational movement of the head.
- Pathology data, studies on healthy subjects as well as our knowledge of the structures of the central nervous system involved allow us to make proposals on the importance of the vestibular system in CS.

- Paillard [25] argues that gravitational acceleration is a dominant frame of reference that influences visuomotor control of our actions and perceptions. “Gravity signals merge and give coherence to the various frames of reference that underpin action and perception”.
- When a subject is asked to grab a target while their chair is rotating, various forces deflect the hand. The vestibular signals then generated make it possible to correct the trajectory of the latter [26].
- Vestibular signals are used to control our actions and interactions with objects in the environment.
- Vestibular signals contribute to hand location and movement. The convergence that they reflect (their role of multisensory integration) maintains a certain form of perception of the body.
- “The vestibular system provides continuous information to the brain to update body position information as well as to maintain its orientation in the surrounding space” [27].
- The perception of verticality is based on multisensory integration involving the vestibular system. Walking is a set of actions involving this integration.

The vestibular system is based on multiple neuroanatomical bases. Fundamental reference in relation to gravity, it participates in the adaptation of the movements - of the whole body or of the limbs - of approach to the object to be reached even when the body is in motion and is therefore then in the phase of adaptation to changes in the center of gravity.

Adult neuroanatomical substrates: the contribution of neurosciences [3,6]

The neuroanatomical bases of the BS are to be found in the existence and collaboration of three main networks which integrate sensory information coming from the primary somatosensory areas and then converging towards the associative parietal areas: the networks:

- Sensori-motor
- Specialized parietal
- Fronto-parietal.

Sensori-motor: The sensory-motor network [6] is made up of sensory and motor systems aimed at controlling action. “It participates in the kinesthetic processing of information from the members”. The structures involved are the primary and secondary sensory areas and the primary motor cortex with part of the premotor cortex, the supplementary motor area, the cingulate motor area, the basal ganglia and the cerebellum. This set of structures makes it possible to locate a body modification and control movement. It is in fact a round trip between sensory and motor information. The motor cortex (premotor cortex and primary motor cortex) is the place of descending but also ascending information. Connected with the parietal cortex, it receives numerous sensory information. The primary motor cortex “containing a considerable number of corticospinal neurons, both for the proximal and distal muscles, is therefore not a simple center of motor execution but rather an important node which can contribute to the perception of movement. of the limb by receiving and processing the afferent muscular signals […] The representation of the body carried by this network is most certainly a kinesthetic/dynamic postural model of the limb”.

For Fontan [3]: “The involvement of the sensory-motor network in the formation of body representations indicates a coupling between sensory and motor representations. These sensory-motor areas will make it possible to precisely locate the bodily changes perceived thanks to their somatotopic organization”.

For Naito [6]: “Anterior associative parietal areas are responsible for integrating somatic information from different parts of the body to construct a postural model of the whole body”.

In other words, this network participates in the feedback controls of the movements of the four limbs thanks to ascending sensory information. All of the postures of the body are therefore represented at the level of different cortical zones, among other associative ones.

Specialized parietal: The specialized parietal network [6] involves a highly connected posterior parietal cortex with cortical areas processing and integrating sensorimotor information necessary for movement. This multisensory integration activity gives the posterior parietal cortex a role in shaping the body schema. It identifies information from the body to precisely locate the position of the limbs, it creates and constantly updates a coherent representation of the body as a whole but also of the body in contact with the object.

This network plays much the same role as the sensory-motor network except that it is not confined to relying on kinesthesia but integrates information from various sensory modalities. In this way, he can create a complete cortical representation of the body, including its contact with objects.

The fronto-parietal network [3,6] of the right hemisphere is so called because of the close connection between parietal and frontal areas. It appears to "play a major role in shaping the internal representations of the moving body and their conscious access […] It plays an essential role in controlling and supervising the state of the body allowing subjects to consciously access to their bodily representations in order to be able to act. "By monitoring and accumulating bodily information and updating our body's postural model, the fronto-parietal network could carry high-level functions such as recognition and self-awareness. By thus facilitating awareness of representations of the body.

This network is therefore essential for building a conscious cortical representation of the body in motion, which would contribute to the awareness we have of ourselves.

These three neural networks are complementary, the first (sensory-motor) processes ascending kinesthetic information to develop a postural representation of the body in motion, especially of the four limbs. The second (specialized parietal) complements the previous one to include the relationship with the object in the bodily representation. The third allows us some form of self-awareness. We are therefore, in passing from the first to the second and then to the third, faced with an increasing complexity of bodily representation.

Peri-personal space

Brain [28] posits the existence of representations of a space close to the body, the peri-personal space (EPP), and of a distant space, the extra-personal space. Neurophysiological studies have confirmed this distinction. Rizzolatti., *et al*. [29] highlighted the close links between the proprioceptive and visual processing involved in this sector of space.

The EPP is defined as the region of space located close to the body and in which objects can be reached and manipulated. The notion of extra-personal space refers to the space beyond, that which involves exploration by eye movements. The representations of the EPP are central for a sensory guidance of the motor act. Experimentally, after immobilizing one arm, the subjects overuse their other arm and modify its representation. The overused limb is perceived larger after immobilization of the other than before. The BS [30] is therefore closely linked to a functional representation of the EPP.

Experiments with the tool have changed the design of the EPP. Using a tool to act on distant objects, outside of the EPP, enlarges the latter. For Canzoneri., *et al*. [31], the tools can be integrated into the BS because: "after using the tool, the perceived distance between two points along the length of the forearm is significantly greater than the perceived distance between two points located along the width of the forearm […] The perceived length of the limb has therefore increased. According to D'Angelo., *et al*. [30], "the remote space is integrated into the EPP after using the tool".

To obtain this experimental effect, it is necessary to present visual or auditory stimuli to the surroundings close to the body. The function of the EPP is therefore sensory-motor. The information processed does not relate only to the part of the body concerned but also to multisensory representations. The EPP is therefore a sensory-motor system at the interface of the body and its environment. It would serve [32] as a "body boundary allowing adapted reactions thanks to real-time updating and correction of the movement taking into account the concomitant sensory feedback […] It is the action that determines what is coded as near or far".

For de Vignemont and Ianetti [33], two types of PPE can be distinguished: that of the gesture ("cutting carrots") and that of protection ("not touching the hot pan").

"It is plausible to consider the existence of only two EPPs, each having functional and sensory-motor aspects".

For di Pellegrino., *et al*. [34], the representation of the EPP is socially modulated: the presence of a person in the extra-personal space narrows the representation of the EPP, provided this person is judged to be "cooperative". In this situation, the representation of the EPP can go so far as to encompass the extra-personal space in which the person finds himself.

First confined to the space surrounding the hand and the upper limb, it is now recognized as extending well beyond. Noel., *et al*. [32] propose that "the representation of the EPP of the trunk increases in the direction of the front" during walking. This modulation is due to the movements of the whole body and makes it possible to avoid the obstacles that stand in our way.

The representation of the PPE is based on the activity of the multisensory neurons of the fronto-parietal network which includes the premotor cortex and the posterior parietal cortex [30]. These neurons fire upon tactile, visual and/or auditory stimulation presented near a part of the body. For di Pellegrino [34]: "The same neuron that controls hand movements based on skin information can also do so based on visual or auditory information".

Moreover, auditory or visual stimuli in the EPP modify the representation of the hand in the motor cortex. For Noel., *et al*. [32], this phenomenon is possible thanks to the modification of the receptive fields of the neurons of the lower premotor cortex. "The receptive fields of these neurons expand in proportion to the increase in the speed of the approaching stimulus. These neurons are therefore specialized in the mapping of specific sectors of the space surrounding the parts of the body and contribute to the movements of these same parts of the body.

The EPP should not be confused with the space of prehension of which speaks, for example Bullinger (2004). For the latter, the prehension space includes all the points of the space reachable by the hands without moving the whole body. The apprehension of the PPE, for its part, involves the whole body (and not only the upper limbs) and modifies the body representation (enlargement or shrinkage of a part of the body) in the global movement. Moreover, it involves the activation of other sensory modalities in addition to kinesthesia. The EPP is modifiable, flexible if a tool is used. It allows, moreover, the feeling of a certain form of bodily limit. Finally, it is "deformable" in the case of the presence of others. EPP is based on well-defined cerebral structures, particularly on neuronal receptive fields that can be adapted according to movements.

The EPP is a sensory-motor notion which makes it possible to "integrate into the body" the immediate or more distant spatial environment under certain conditions. In this way, the management of the space close to the body is facilitated and anticipations become possible. The representation of the EPP is not the SC but it is associated with it.

The evolution of BS as the child develops

Although the hypothesis has been made, with Meltzoff and Moore [36], of the existence of a primitive SC from an early age, nowadays we think of a construction closely linked to sensory-motor development. Perception is known to influence motor responses. Visual information, for example, affects the child's behavior. But the opposite is also true: the appearance of new motor skills modifies the perception of the environment. In this way, the appropriate behaviors are selected. Perception and action are therefore two intertwined processes. We talk about perception-action coupling. For Assaiante [37], "the early perception-action coupling constitutes the base of the sensory-motor representations essential to exercise intentional, harmonious and adapted motor skills. For Fontan [3]), "the neural bases of perception-action coupling would develop through learning based on sensory-motor experience. This coupling:

- Is functional from birth, its basis being the mirror neuron system [38];
- Allows, in the last step, "to anticipate the consequences of the action, on the basis of an internal representation of the body in action, with the aim of preserving the effectiveness of the gesture" [39]. It's the BS.

The BS of the child does not work like that of the adult. Primacy is first given to vision to the detriment of proprioceptive and vestibular information. Especially when there is a sensory conflict. The immaturity of the parietal and somatosensory zones which manage proprioceptive integration makes them less active before 7 years. This development continues until adolescence. The cerebellum is involved in children - but not in adults [3]. It "establishes and consolidates representations of the body in action. The cerebellum disengages as neurological maturation progresses. In this case, it acts as a learning support structure.

BS relies on strong coordination between the visual and proprioceptive systems. This set of coordinations would only take place around the age of 10. However, the sensory reweighting - that is to say the modulation of the importance given to a particular sensory modality - seems to begin to take place between 4 and 6 years of age: little by little, the proprioceptive and vestibular information increases. The crucial ages, according to Assaiante [39] are "early childhood, the 6/7 year transition and adolescence. For the very young, this means that it is during transitional periods of strong motor acquisition that vision predominates: sitting, standing and walking. Its importance decreases towards 7 years, age of rise in power of the use of the vestibular information.

We therefore note a construction of the BS which gradually passes from a main support on the visual afferents to a firm consideration of the proprioceptive and vestibular afferents. Jerks occur during periods of strong reorganization during which the processing of spatial information must evolve considerably. The primacy of the proprioceptive afferents is only real towards the end of adolescence. At this time, peripheral vision has become a support and the vestibular system intervenes at all levels due to its neurophysiological structure.

As for the peri-personal space, it is estimated that children aged 5 to 7 already have an efficient representation of it, regardless of the size of the tool used in the research [40,41].

The BS, a sensory-motor construction of the first years of childhood, goes through a succession of stages. First supported on - and coordinated with - visual information, he gradually sees the rise in power of the proprioceptive and vestibular systems. It is around 6 - 7 years that proprioception and vestibular come into play. In adolescence, proprioception will take precedence.

Findings and Conclusion

Neurosciences have therefore brought us a clear definition of the concept of BS. Rooted in sensory-motor and spatial coordination, it becomes an access route to the clinical approach. It is consistent with a number of Bullinger's sensory-motor concepts (peripheral vision/proprioception coordination, sensory-motor coordination in general, importance of postures, notion of space, perception-action coupling, etc.). We will make the hypothesis here of a crucial role of the instrumentation of the sensory-motor systems in the development of the BS, the establishment of the instrumentation being accompanied by an elaborate representation of space.

Many populations of patients covered by psychomotricity follow-up should be able to be accompanied as closely as possible to their skills and deficits. Disorders of psychomotor development, "dys", psychopathologies and psychiatric and neurological disabilities (asomatognosia for example), pathologies of aging and old age. Long classified as psychic phenomena, "out of body experiences" involving vestibular particularities as well as phantom limb issues are also BS disorders. It would be important for psychomotor therapists to invest even more in these fields of practice.

It would be, in psychomotricity, appropriate to take into account the existence of the peri-personal space whose neurological foundations have been demonstrated. Similarly, neurosciences showing us that the presence of another, even in the extra-personal space, influences the dimension of the representation of the EPP, it is therefore necessary to take into account the relational aspect, even tonic-emotional.

Motor ideation tasks where research participants are asked to imagine themselves doing a movement or an action are among the most fruitful paradigms. Involving mirror neurons and perception-action coupling, this type of task would benefit from being used more in psychomotricity. For example by developing new assessment tools.

The feelings of deformation (lengthening) of the forearm in the tasks of reaching and grasping an object with a tool are very interesting manifestations of "unusual" bodily experiences. These feelings are perhaps a bridge between certain research themes in neuroscience and certain aspects of body image as it is understood in psychomotricity. Moreover, and this was not the subject of this article, the image of the body is taken into account in a number of bibliographical references cited here. This is a different conception of the image of the body envisaged in psychomotricity [42]. But the neuroscientific characteristics of the image of the body include the perception of the body ("body awareness" and "body perception") of the singular and subjective individual, even its emotional aspect. Perception being the sensation envisaged by the psyche, and CI being subjective and singular, we are not very far from an overlap of the two conceptual fields (neurosciences and psychomotricity).

Moreover, body image disorders are also concerned with the neuroscientific conception of BS insofar as sensory thresholds that are too high or too low, disorders of "self-attribution" and subjectivity originate in sensory functioning and coordination. Understand: BS. The experiences of fragmentation and collapse would also be indirectly linked to it because of their neurological origins: parietal cortex for the first, vestibular system and basal ganglia, including subthalamic nucleus, for the second.

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Conflict of Interest

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