ISSN: 2694-166X
Scientific Journal
Biology & Life Sciences
DOI: 10.33552/SJBLS.2024.03.000572
Iris Publishers

Review Article

The Integration of the Sensorimotor System in Elderly Individuals: An Update

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Received Date: May 08, 2024

Published Date: May 16, 2024

Summary

This update is aimed at the sensorimotor system: concepts, anatomy, relationship between the visual, somatosensory and vestibular systems in a context aimed at the elderly population. The sensorimotor system has great integration with such systems related to the ability to capture sensory information and take it to the central nervous system. Consequently, motor responses are generated both to destroy movements and to seek protection mechanisms that tend to reduce the risk of falls for the elderly. The presence of internal, external and socioeconomic factors can affect the competence of the sensory system in capturing sensory information. Such conditions can compromise the quality of life, prognosis and physical functionality of the elderly, making them less active and participative in their own lives. In this study, due importance is given to the sensorimotor system, presenting the complexity that exists in its function of capturing information, conducting neuromotor mechanisms and providing the biomechanical dynamism necessary for the senile body to position itself favorably in space.

Keywords: Aging; balance; visual; proprioception; sensorimotor

Introduction

As people age, they face several physiological transformations that interfere with their socio-behavioral dynamics related to the physical challenges they face. Trials have shown that approximately 30% of individuals over 65 years of age experience a fall at least once a year and in 50% of them, the episode recurs (Tinetti) falls are the main cause of injury in adults over 65 years of age. The presence of intrinsic and extrinsic factors begins to be decisive in this process, in which the search for quality of life and reducing the risk of falls are the main objectives for survival. Extrinsic factors can be represented by the conditions of the physical location, such as the presence of slippery floors (smooth or wet), carpets, inadequate lighting, stairs, switches out of reach, and use of inappropriate footwear [1,2]. Intrinsic characteristics are the individualized characteristics of each patient and their physiological conditions associated with aging (musculoskeletal, cardiac, digestive and urinary disorders, disorders of the nervous, visual, auditory and cognitive systems), as well as medication used by them [3,4]. Detecting obstacles, sending information to the nervous system, processing them, and choosing the best motor response is a skill that the elderly need to constantly develop (Lord et al.). The somatosensory system is one of the systems closely linked to the vestibular and visual systems, in which in this triad they complement each other functionally to act on balance and dynamic stability. This is relevant in the elderly, considering they constantly fight against the intrinsic and extrinsic factors that cause falls [5]. Highlighting the importance of the topic on sensorimotor systems in an elderly population, the objective of this update is to gather relevant information regarding the sensorimotor system. Furthermore, showing the relationship between the vestibular, visual, and somatosensory systems to allow the elderly to achieve balance and reduce the risk of falls.

Sensory Systems

Concept and afferent pathways of the Visual System

Studies already carried out a few years ago [6] show the impact of aging on functional physical activity, quality of life, frailty and physiological functions. Changes in the visual system also have a major impact on the elderly and are associated with mortality [7]. Recent studies carried out by Marmamula et al. [8] show that adequate screening for vision loss and adequate provision of services make all the difference in healthy aging. The visual system is considered one of the most complex sensory systems related to postural control due to its complexity and mechanisms involved [9,10]. Initially, the eye captures the light, which travels through the entire ocular environment until it reaches the retina where the image is projected inverted (Fishman, 1973). All structures along this route work so that light can be captured as efficiently as possible. While the stroma and corneal epithelium are transparent (Maurice, 1970) to allow better passage of light, the pupil acts as a regulator of the amount of light. Upon arriving at the retina, the light stimulus encounters the photoreceptors. In humans, Prasad and Galetta [11] state that there are three types of cones, responsible for detecting specific wavelengths, and a type of rod, which is more effective for night vision. The information processed will depend on the amount of humidity and the variation in wavelength so that the electrochemical components can be generated.

The optic tract is made up of temporal fibers originating from the retina of the ipsilateral eye with nasal fibers originating from the retina of the contralateral eye. It promotes the crossing of fibers in the optic chisma, being considered a point of discussion for the axons of the optic nerve. This chiasm, located in most individuals above the pituitary gland [12,13], provides information from these ganglion cells. After that, an image formed by each eye's retina, from the same visual field, can be unified. So, the route passes through anatomical structures such as: tracts, lateral geniculate nucleus, and optic radiations. The information is transmitted until it reaches the occipital lobe in the striate cortex for being processed [11]. The fascicles originating from the parietal radiations are directed to the most superior portion of the striate cortex. In contrast, the temporal fascicles reach the most inferior portion of the striate cortex, according to Prasad and Galetta [11]. Finally, the participation of the association cortices is actived so that complex visual processing can be finalized. Currently, studies focused on virtual reality [14], the relationship between visual and symbolic modalities [15,16], have served as essential support for the field focused on anatomical knowledge to improve the understanding how the human body behaves. Studies related to technology and computational approaches have facilitated a better understanding of human anatomy and visuomotor representations [17].

Definition, anatomy and reflexes of the Vestibular System

The Vestibular System is important in reducing the risk of falls in the elderly based on the functionality of their vestibular organs. They are located in the inner ear, which can detect the linear and rotational acceleration of the head and its positions, according to the Earth's gravitational field, being strictly related to the sensation of movement [18]. A unique feature of the vestibular system about the others is that the same central neurons receive direct information from the afferents of the 8th nerve. It can also project directly to the motor centers that control vestibular motor reflexes, according to Cullen [19]. Vestibular structures such as the semicircular canals and otolith organs constitute the labyrinth and they are important collectors of sensory information. The semicircular canals, made up of three: horizontal, anterior, and posterior, consist of three connected ducts filled with endolymph [20], a fluid that is quite similar in properties to water. According to these authors, this fluid flow agitates according to our rotational movement and excites hair cells (located within a gelatinous dome, according to Khan and Chang [21]) through the mechano-electrical transduction system [22]. It is through this process causes depolarization and in the opposite direction, hyperpolarization [21,23]. The signals generated are captured by the vestibular nucleus complex (VNC) located in the brain stem through the VIII cranial nerve (vestibulocochlear nerve), according to Carleton and Carpenter [24]. In this study, Muller [25] explained the process of rotational information. Three coordinates are taken into consideration by the semicircular canals:

a) Terrestrial reference considered stationary, without displacement.

b) Reference of the canal connected to the head that rotates around an origin and rotational vector and

c) Displacement of the endolymph that circulates inside the duct.

This acceleration of the fluid in reference 3 about reference 1 was initially described by Valentinuzzi [26] decades ago through mathematical ways and concepts.

Over the years, scholars improved both the mathematical concepts for the dynamics in question, these models starting from a single duct model [27] until the emergence of the first three-dimensional concept between the three channels [28], inspiration for what is known today. The otolith organs, made up of the saccule and utricle, in turn, detect the linear acceleration of sensory information. While the utricles detect change in a horizontal direction, the saccules detect vertical acceleration, including gravitational action [21,23]. In both, calcium carbonate crystals are contained which, to encode information. When accelerated, they cause a deflection of the hair cells that are fixed adjacent to the epithelial tissue [23]. Still regarding head movements, the vestibular system is connected to the vestibulo- ocular reflex (VOR) and vestibulo-spinal reflex (VSR). While the VSR acts to control the body's postural stability, the VOR has a fundamental role in ocular control, keeping the image stabilized on the retina, occurring simultaneously during rotational and linear movements [29]. The adaptation or modification process for this reflex happens quickly, through the use of corrective lenses or gradually, through the loss of hair cells due to aging [30]. Therefore, a vestibular system in its normal functionality provides important sensory information about the direction and orientation of the head and body. It is related to the relationship between them and the space in which they are part [31]. According to a study carried out by Ertl and Boegle [18], in recent years, studies have shown galvanic [32] or caloric vestibular stimulation, in addition to movement platforms. Currently, imaging techniques are used for vestibular research, presenting advantages and disadvantages.

Definition, receptors and pathways of the Somatosensory System

Through tactile, proprioceptive and even temperature-related sensory information (according to Pasluosta et al., [33]), the somatosensory system actively contributes to that, associated with the visual and vestibular system. Together, they can improve their functional activities with greater motor control efficiency. However, considering the high complexity of these systems and their great connection, it is hard to separate them to study. [34,35]. Considering the sensory receptors related to the somatosensory system, we can quote: mechanoreceptors, which are represented by Meissner's corpuscles (responsible for detecting skin stretching and vibration), Merkel and Ruffini cells (sensitive to touch and pressure), Pacinian corpuscle (perceptible to touch and vibration). The presence of free endings is also important for the detection of temperature, pain, pressure, touch and proprioceptors. They can be represented by muscle spindles and Golgi Tendon Organs that detect the length and state of muscle tension, respectively [33]. All of them act as encoders of information about the perceptions of objects and parts of our body. According to Wang et al. [36], the somatosensory system has three functions: exteroceptive capacity (perceiving stimuli outside our body), interoceptive (within our body), and proprioceptive capacity (related to body position and balance).

The endings of muscle spindles can be further divided into primary spindle afferents, or type Ia fibers, and secondary spindle afferents, or type II fibers, which innervate the muscle spindles [37,38]. They branch upon entering the spindle and take on the innervation of several intrafusal muscle fibers. In passive movements, the length and speed of muscle will influence the activation of the response of these fibers. In dynamic movements, primary fibers will be more sensitive to activation than secondary axis fibers [39]. Gamma motor fibers also act in the contraction of muscle fibers, acting in the input of muscle spindles [40]. While the afferents related to the Golgi Tendon Organ, being classified as slowly adapting units, are more sensitive to tendon tension (as mentioned previously) and classified as Ib [41,42], they also present some sensitivity in the muscle stretching [43]. Joint receptor afferents are activated according to the pressure exerted on the joint, as well as joint movements and the twitch of muscles inserted in it. They are: Ruffini Corpuscles, Pacinian Corpuscles and the Golgi Organs themselves located in the ligaments [44].

These four types of low-threshold mechanoreceptors (Merkel cells, Ruffini termination, Meissner corpuscle and Pacinian corpuscle) can be classified according to their receptive fields (superficial, type I, or deep, type 2) and based in the speed of adaptation (slow or fast), according to studies carried out by Wang et al. [36]. In addition to proprioceptive receptors, tactile receptors that together convert mechanical deformations into neural information are innervated by afferent nerve fibers. The majority of them are myelinated fibers for greater agility and speed in conduction due to myelin sheaths (Group I proprioceptive fibers, speed: 60-100m/s and proprioceptive fibers Group II + tactile A β fibers, speed: 30-80m/s) with the exception of tactile C fibers, according to Delhaye et al. [45]. After all this information is captured, action potentials (AP) are generated [46] through rapid depolarizations and repolarizations in the cell membrane. The generation of nerve impulse that follows through the afferent pathways until reaching the cerebral cortex will be responsible for the process of somatosensory decoding [38]. Therefore, the frequency, time and intensity of the stimulus are coded according to the profile of each receptor [47,48] (Poulos et al., 1984). After this, an efferent response causes activation of alpha motoneurons and their respective muscle fibers. It may be either a reflex spinal response or a voluntary motor response, when submitted to subcortical or cortical areas [49].

Connection between Sensory Systems in the elderly population

Zheng et al. [50] states that with age, the ability to maintain static and dynamic balance are strictly linked to the somatosensory system and tend to decrease, becoming even more difficult to control, resulting in an increased risk of falls, regardless of the associated pathologies. In 1999, Klein presented a study on the involvement of the visual system in the aging process being the most commonly affected in the elderly population. More recent studies carried out by Riva et al., Gschwind et al., Kim et al. and Zheng et al. [50-53], present the importance of such a system, where the responsibility for the perception of physical space, the distance between bodies and objects were relevant in their research. Ersin et al. [54] states that in order to achieve balance, the somatosensory and vestibular systems are closely interconnected. When the somatosensory system is disturbed, the parts of the vestibular system such as posterior SSC, the saccule and inferior vestibular nerve are more affected due to any instability or deficiency presented, more significantly than the superior vestibular nerve.

Kim et al. (2014) carried out their research to investigate the influence of the visual system by proposing an exercise program in which one group of participants were blindfolded and another group was not. They concluded through specific tests that after 4 weeks of training there were significant changes in the group carried out with their eyes closed. These authors, in agreement with Tossavainen [55], state that when the visual system is blocked, the proprioceptive system and the vestibular system act together to provoke a motor response and more effective postural control. Hence the importance of understanding the connectivity between these three systems can act to provide support among them, in the case of expected physiological deficiencies resulting from the aging process. However, even considering all this importance, there are still scientific uncertainties regarding the best type of exercise to be performed to reduce the risk of falls in the elderly population, according to Gine-Garriga et al. and Gobbo et al. [56,57]. Riva et al. [51], when proposing an intervention focused on High-frequency Proprioceptive Training – HPT, the objective was to evaluate the increase in proprioceptive control and the contribution of the visual system to this tool. They analyzed that HPT significantly improved the unique postural stability of elderly people compared to other activities, such as treadmills. They also compared participants who did HPT and who did not perform any physical activity during the research. As a result, the values achieved were considered ($p < 0.001$) for postural control and proprioceptive control for interventional group. Researchers such as Bacsi and Colebatch, Kristinsdottir et al. [58,59] and Lord et al. state that individuals point to greater credibility in the efficiency of proprioceptors and cutaneous receptors for maintaining postural control and balance when thinking about carrying out functional activities related to daily life. Experiments reveal that the functional proportions between systems vary according to external stimuli and environmental conditions, as well as neurological conditions. The sensory capacity will actively respond to reduce the imbalance and possible risks that individual can face. All these systems contribute in a dynamic and variable mechanism to try solving these matters [60].

Impact of Postural Control on the Elderly

Postural Control is related to the motor response provoked through the transmission of sensory information (Barela, 1997) provided by the following systems: visual, vestibular and somatosensory (Nashner et al., 1989; Collins and De Luca, 1993; Morasso, 1999; Redfern et al. al., 2001) [60]. All this connectivity causes motor control to act towards an adequate repositioning of body segments through balance, biomechanical dynamism and postural orientation [61]. Recent studies show that elderly people with high-frequency hearing loss were associated with a greater loss of postural control in dual or single task conditions [62]. In a similar result, Bruce et al. [63], found greater difficulties in performing the dual task in elderly people with hearing loss, compared to those considered normal. It was analyzed when they combining a task with postural control. This postural control is very important for the elderly population. It is through the physiological interaction with the external environment that elderly people have safe conditions to carry out their daily activities with reduced risk of falls. Therefore, it is considered an interaction between the neural system and musculoskeletal activities in which the limbs are organized, aligned and oriented in space [58].

For postural control to occur, three systems are connected: the visual, vestibular and somatosensory systems so that this action is carried out in the most coordinated and controlled way possible [64]. The visual system's basic function is to guide the position and movement of the head to capture the necessary information from environment. Sasaki et al. [65] state that this system can cause a reduction of up to 50% in body sway. The relationship between the somatosensory system and postural control is quite complex. There is the involvement of muscle spindles, intrafusal proprioceptors and coactivation between muscles related to the coactivation between plantar flexors and dorsiflexors [66]. In turn, the vestibular system is sensitive to deviations in head orientation due to information provided through the semicircular canals (rotational movements) and the otolith organs (tilting movements) [67]. The somatosensory system, on the other hand, is related to receptors distributed throughout the body, and can be grouped into four groups, according to Mochizuki and Amadio [68]: touch, temperature, pain and proprioception. Therefore, the sensory information necessary for this postural control is provided by the neuromuscular spindles, Golgi Tendinous Organs, and other receptors located deep within the tissues, at the tip of the fingers and joints [69].

The ability to maintain postural balance is related to the control of gravitational force, inertia and muscles that act to maintain the body when it is at rest and in dynamic work, a moment when its center of gravity is displaced [70]. The Center of Gravity is the location of the weighted midpoint of our entire body mass, while the Center of Pressure (CoP) is the field of pressure that the body exerts on a support surface (Caron et al., 1997) [71] and it is due to the variation in the CoP oscillation that the Center of Mass moves. Recent studies show that for elderly people to have postural control, they need to have good conditioning of muscles such as extensors of the head, thighs, trunk, legs and feet [72-75]. The impairment of these antigravity muscles has been associated with postural imbalance [73, 76]. In this context, weakness of the flexor muscles would have a less negative impact on the control of postural balance than the extensors. In order to obtain evaluative data among the elderly and the correlation between postural balance and the risk of falls, some instruments and parameters are usually considered. Posturography, a tool used to study postural balance through force platforms, obtains data related to oscillations in different clinical contexts, especially in the elderly [77].

Although this tool is important for analyzing and finding differences between young people and the elderly, elderly individuals who are affected by the effects of aging are still unclear [78]. One of them is the use of measures extracted from the Center of Pressure (CoP) analysis in association with its dynamic measures, as mentioned by Tallon et al. [79]. Authors such as Gerdhem et al. (2005) state that a well-reported fall is a great source for understanding where the fall is coming from. There are some indicators to analyze if elderly people have greater or lesses risks of falls (Baloh et al., 1994). They are: lateral balance indicators such as the speed of the medio-lateral (ML) movement of the center of pressure (CoP), lateral balance indicators such as the amplitude of the ML movement of the CoP, among others. Average speed and elliptical area are important to evaluate the effect of learning on orthostatic postural control, according to Mello et al. (2010). Benjuya et al. [80] carried out studies comparing elderly individuals who were more and less prone to falls with a wide and narrow base. In addition, opening or closing their eyes. They concluded that there was a significant difference between elderly people who fall and those who do not fall in a position with a narrow base. Considering their eyes open, elderly people more prone to falls showed an increase in CoP length, as well as CoP speed and CoP movement in a medio-lateral direction. Moreover, with their eyes closed, this same group also had significant increases related to CoP, in length, speed, elliptical area and balance. Authors such as Winter et al. [81] argue that postural control is passive and independent of sensory afferent information. These authors state that the biomechanics of the ankle controls the anteroposterior displacement. It can be supported by inverted- pendulum model. This model states that the signals of the center of mass (CM) and CoP are connected with the acceleration of the CM and the difference between the center of pressure and the center of mass. Other authors believe that compensatory postural adjustments are anticipated by sensory feedback signals [82,83] processed by the Central Nervous System through the activation of the muscles of the lower limbs and trunk.

Sensorimotor Variability in the elderly population

Concept of Sensorimotor Variability

The sensory inputs captured by sensory receptors, the processing of information directed to motor planning, and the capacity for motor response, suffer interference and disturbances that affect the best motor response [84]. In other words, the imprecision and the large number of stimuli captured by the receptors make this signal “noisy”, leading to uncertainty in the real information offered. In addition, the motor response also suffers interference during its journey to the motor action. This process is called Sensorimotor Variability. Being, therefore, the sum of sensory variability, motor variability, and the physiological mechanisms that interconnect them [85]. In sensory information combined to detect the position of an object or lower limb, for example, the Central Nervous System, requests combined information from the visual system and proprioceptive system (depth estimation), according to van Beers et al. (1996, 1999, 2002) to optimize information integration. Regarding motor responses, Harris and Wolpert (1998) state that motor actions are directed toward the goals of reducing motor variability, through more specific and directed movements. Putting it in another way, when the individual has a motor objective to be accomplished, there are countless possibilities for achieving it. The execution is successful through stereotyped movements or speed profiles without falls (Fitts, 1954). As the years go by and the aging process sets in, this physiological ability tends to become more weakened, potentially compromising the elderly person’s daily life. Lin & Faisal [86] believe that it is worth designing studies presenting the connection between aging, sensory variability, and changes in gait dynamics. They also concluded that with advancing age, proprioceptive variability increased significantly by 56% in the older intervention group and that this negatively affected sensorimotor variability. All in all, the ability of an elderly person to overcome an obstacle without major risks is harder. This is in common agreement with Horak (2006) and Shaffer and Harrison [49] who state that impaired proprioception, due to aging, also affects postural control and balance.

Conclusion

The aging process is a common way for people to be impacted when time influences the body in different aspects, such as physiological, anatomical, and metabolic issues. The risk of falls is not only related to the minimal process of falling but to the serious consequences that can affect the quality of life and expectations regarding treatments that the elderly face. Integrating the sensorimotor system, we can consider the relationship between the visual, somatosensory, and vestibular systems. This connection can improve older people’s ability to deal with many physical risks. Furthermore, the importance of sensorimotor training in the elderly is perceived as an intervention to reduce the risk of falls in the elderly. In addition, helping to guide new related studies, it can provide scientific support to professionals who like to work with sensorimotor system to improve elderly’s outcomes.

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Citation: Ivelize Freire*. The Integration of the Sensorimotor System in Elderly Individuals: An Update. Sci J Biol & Life Sci. 3(5): 2024. SJBLS.MS.ID.000572. DOI: 10.33552/SJBLS.2024.03.000572