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Review

The Role of Cognition in Balance Control

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Abstract

Balance is the ability to move and/or preserve a particular position while not falling under external force. Human balance is a complex process of integration and coordination of the sensory, motor, and biomechanical components, which is influenced by intrinsic and exogenous factors. One inherent factor that is hypothesized to have an impact on balance is cognition. However, studies about cognition's role in balance control are still limited, and study literature is needed to gain a better understanding. Cognition is involved in various thinking processes. Attention, memory, visuospatial, and executive functions are among the cognitive areas integrated with information processing in the processing of information, followed by a reaction that aims to preserve body balance and prevent falls. Cognition limitation has been linked to decreased function associated with gait alterations, mobility limitation, and increased risk of falling. Cognitive function impairments such as executive function (EF) limitations are thought to increase the risk of losing. Injury to the cerebral cortex, basal ganglia, and cerebellum can also affect the cognitive function in balance. The role of cognition in maintaining physical balance is critical. Deficits in cognitive function caused by diseases or injuries will impact bodily balance control.

Keywords
Balance; cognition; risk of falling

1. Introduction

Balance defined a state of equilibrium, an ability to move or maintain a position without falling. Human balance is the ability to sustain specific postures such as sitting, standing, shifting between postures, and not falling while being subjected to external disturbance. Maintaining balance involves coordination between sensory, motor, and biomechanical components of the body, resulting in integrated movement between muscles and joints [1-3].

Intrinsic and extrinsic factors also influence balance. The inability to maintain balance caused by intrinsic and extrinsic factors will cause instability. Outside factors include external and environmental conditions such as lighting, uneven ground surface, unsuitable shoes/footwear, and walking aids. Intrinsic factors include cognition, age, pathological conditions, drugs, and decreased physical conditions. A previous study showed that individual cognition, especially in older people, caused this group to have a double risk of falling compared to healthy individuals [1, 4].

Cognition is an internal mental expression characterized as a thought and an idea. The cognition process combines many cognitive domains, such as attention, memory, visuospatial, and executive processes, that integrated into processing information. This information subsequentlyprocessed into a reaction to keep the body balanced and prevent falls [5]. Currently, there is an understood that changes in balance are associated with various cognitive domains. However, there hasn't been much research that explores how cognition and balance are related. A previous study shows a correlation between cognition processes and balance in adult and elderly patients [6]. Therefore, this literature review aims to define the importance of cognition in balance control.

2. Methods

For our research on the role of cognition in balance control, we conducted a comprehensive literature search using electronic databases such as PubMed, Scopus, and Google Scholar. Our search strategy involved combining relevant keywords to capture various of articles exploring the link between cognition and balance control. These keywords include "cognition," "balance control," "cognitive function," "postural control," "executive functions," "attention," "memory," "visuospatial skills," "information processing," "reaction time," "falls," "cognitive limitations," "neurocognition," "neuromotor control," and "cognitive-motor interactions." We identified relevant articles from the search results to review each topic comprehensively. All abstracts were carefully assessed and chosen based on their perceived relevance to the subject. While we did not include a detailed description of every published article on each topic, we aimed to gather appropriate articles that would contribute to an informative review aligning with our stated objectives.

3. Results and Discussion

3.1 Biomechanics and Physiology of Balance

Human balance is a complex multi-dimensional process that includes sensory, motor, and biomechanical elements [2, 3]. Balance is achieved by a complex interaction between physiological mechanisms and the interpretation of central sensory input based on the body's postural expectations, movement goals, and priorities. Body schemas play a crucial role in balance regulation, particularly in adapting reflex modulation, estimating state, making predictions, learning, and linking cognitive and motor functions [7]. To mantain balanced in a posture, the body's center of gravity (COG) must remain vertically above the base support [2, 3]. When the COG moved, a quick return establishes a solid foundation of support beneath the COG, or additional external support is required to stop someone from falling. The definition of balance changes when a person moves more quickly because the momentum of their bodily movement must also be considered [8, 9].

The angular deviation of the COG from vertical gravity can used to define a person's state of balance. The COG swing is defined as the angle formed by crossing the first line at the midpoint of the base of the support with the second line extending vertically from the center of the base (Figure 1) [8, 9]. The system of the balance must determine the position of the COG relative to gravity and the base of the support and then coordinate movement to correct for COG deviation. This movement is necessary to counteract the effects of gravity and the motor motions made while standing and walking. From a clinical perspective, separating the motor and sensory processes of balance suggests that the patient may have a balance impairment due to one or a combination of the following two reasons [8, 10]:

(1) The position of the COG relative to the support's base is not accurately sensed, and
(2) The automatic movement required to bring the COG into balance is not well coordinated or executed at the right moment.

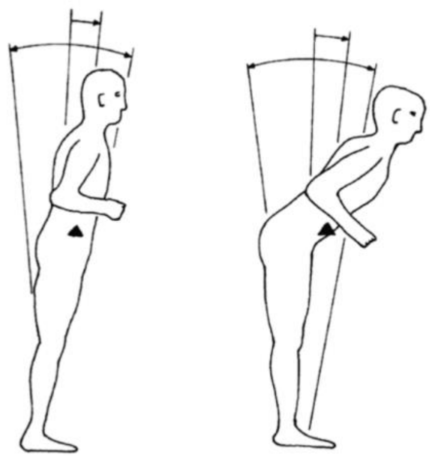

Figure 1 The COG swing angle and its relationship to the boundary cone stability.

Sensing the relative position of the COG to gravity and the "base of support" requires a combination of visual, vestibular, and somatosensory inputs (tactile, internal pressure, joint receptors, and muscle proprioceptors) [11, 12]. These three senses can provide inaccurate information in maintaining balance control in pathological conditions [13, 14]. Visual input is the most dominant sense of balance in providing information about orientation and movement, especially in unstable base conditions. The visual senses give the orientation of the eyes and head relative to surrounding objects [11, 13].

When visual and somatosensory inputs actively work, the vestibular plays a modest role in maintaining COG [14, 15]. The vestibular system does not provide information about orientation to external objects but instead measures the head's gravitational, linear, and angular acceleration relative to the inertial space. However, vestibular input is critical in balance when visual and somatosensory inputs are absent or do not function normally. The primary role of the vestibular is to independently control the position of the head and eyes and the direction of gaze. Precision control of the head, eyes, and gaze is essential in many complex motor activities, such as running, kicking, or catching a moving ball [14-16].

Sensory input from the somatosensory system provides information about relationship between body parts and support base [11, 12]. Under normal baseline circumstances, somatosensory input is derived from contact with pressure and movement between the foot and the base to maintain balance. The COG swing is highly modest when a person is standing on solid and flat ground. However, combining these three senses may not always provide accurate information about COG under all conditions. One or more of these senses can provide incorrect or inaccurate information in maintaining balance control [13, 15].

When a person is standing straight, the COG placed in the lower abdomen. The ankle, knee, and hip strategies represent the three basic postural systems in the human body that maintain balance against anterior and posterior responses. The more prevalent stepping technique is characterized by an asymmetric load and moving base support fixed on COM [17]. The clinical implications of postural disorders are how patients respond to external disturbances: (1) how well the patient's sensory and motor systems react to specific stimuli, (2) how well the patient's nervous system is prepared to adapt to distal disturbances, and (3) how well the patient learns and uses planned, and coordinated motor patterns [18].

Two essential motor controls are involved in controlling the multisegmented balance of the body against gravity and the environment, notably muscle synergy patterns and movement strategies. Small movements in body segments to maintain posture induce very little muscular response. At the same time, more significant displacements of the center of mass (COM) cause reactions powerful enough to position the body in a specific direction to restore the COG. The sensory characteristics and responses created by the CNS determine the movement of the COG, which are related to expectations, concerns, experiences, contextual settings, and preprogrammed muscle activation, generating patterns called "synergies" [19]. In a more comprehensive approach, the balance movement systems are explicated within Table 1.

Table 1 Balance Movement Systems.

Properties	Movement Systems		
	Reflex	Automatic	Volunteer
Mediation pathway	Spinal cord	Brainstem and subcortex	Brainstem and cortex

Activation mode	External stimuli	External stimuli	Internal and external stimuli
Respons	Local and highly stereotyped	Coordinated in the muscles of the legs and body but can adapt	Unlimited
Role in postural control	Regulate muscle strength	Coordinate movement between joints	Cause a purposeful movement
Response time	40 ms*	100 ms*	Varied, 150+ ms*

* ms = Milisecond

Two types of voluntary movement impact balance. The first is movement, which involves manipulating external objects, significantly impacting the balance. The second is voluntary movement that does not involve an external object, which can alter posture but has only a minimal impact on the position of the COG, directly or indirectly.18 When a person is free-standing, automatic postural motions involving external objects will begin before voluntary arm movements to anticipate balance problems and provide a solid basis [12, 20].

3.2 Ascending Spinal Tract Pathways of the Balance System

The transmission of ascending sensory signals is pivotal in facilitating conscious awareness regarding the spatial positioning of the body or limbs. Furthermore, this process enables the nervous system to compare the anticipated and actual sensory outcomes of movement, as illustrated in Figure 2. This, in turn, permits the adjustment of motor commands and the modulation of reflex pathways to align with the demands of posture and response objectives. The primary route for conveying proprioceptive and exteroceptive information involves the dorsal column medial lemniscal pathway, spinoreticular tracts, and posterior and anterior spinocerebellar tracts [21].

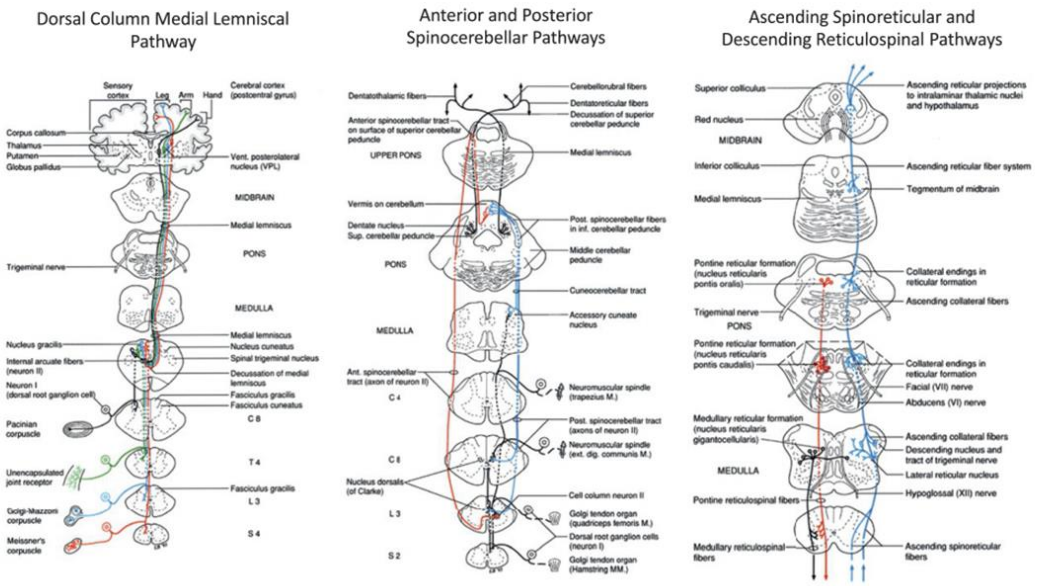

Figure 2 The ascending spinal tract of the balance system.

The dorsal column medial lemniscal pathway is the fastest path for transmitting proprioceptive and cutaneous signals. Sensoric inputs start from the nerve branches of muscle spindles (specifically Ia and II afferents), cutaneous, and joint receptors. Then, it travels through the ipsilateral posterior white columns (fasciculus gracilis and fasciculus cuneatus). Then, they synapse in the internal arcuate fibers within the nucleus gracilis or cuneatus at the medullary level. Next, these fibers cross over (decussate) and run through the medial lemniscus to reach the contralateral thalamus's somatosensory region, specifically Hassler's ventro-caudal (Vc) thalamus. Thalamocortical projections stemming from muscle spindle afferents predominantly target Brodmann's area 3a, located near the base of the central sulcus in the primary somatosensory cortex. Meanwhile, cutaneous afferents project to area 3b in the primary sensorimotor cortex [21, 22].

In the spinoreticular tract, axons originating from proprioceptive afferents, specifically Ia, II, and Ib fibers, synapse with cells in the posterior horn of the spinal cord. Then, these nerve fibers primarily ascend through the anterolateral section of the ipsilateral spinal cord. Some axons also have extensive branching connections throughout the pontomedullary reticular formation, including the nucleus reticularis pontis caudalis and oral and the nucleus reticularis gigantocellularis. These regions play a pivotal role in controlling anticipatory and reactive postural adjustments, as well as regulating functions related to postural tone and locomotion [21, 22].

Proprioceptive and exteroceptive signals from the lower limb to the cerebellum are transmitted by both the posterior and anterior spinocerebellar. The posterior spinocerebellar tract originates from large cells in the dorsal nucleus of Clarke. These cells receive direct monosynaptic input from axon collaterals of muscle spindles (groups Ia and II), Golgi tendon organs (Ib), or pressure receptors. Cutaneous and proprioceptive inputs are separated and organized somatotopically. This organization maintained to its termination in the cerebellum. The ascending fibers from the dorsal nucleus travel up ipsilaterally through the posterolateral region of the lateral funiculus and then pass through the inferior cerebellar peduncle. They ultimately terminate as mossy fibers in the rostral and caudal parts of the cerebellar vermis, specifically in lobules I–IV, pyramids, and paramedian lobule, which collectively form the paleocerebellum. It's worth noting that the dorsal nucleus of Clarke is not present above the level of the eighth cervical vertebra (C8). Therefore, some uncrossed Ia and Ib afferent fibers terminate on cells within the accessory cuneate nucleus in the medulla and ascend through the cuneocerebellar tract to reach the cerebellar cortex lobule V. It is important to remember that the posterior spinocerebellar tract and the cuneocerebellar tract are not influenced by spinal processing or descending motor commands [21, 23].

The cells in the anterior spinocerebellar tract originate from Rexed's laminae V-VII, and the cells in the anterior tract receive combined input from both proprioceptive and cutaneous afferents. Additionally, these cells receive collateral projections from descending pathways, including the corticospinal and vestibulospinal systems, which allows supraspinal modulation of ascending activity based on the specific task and postural requirements. Axons within the anterior spinocerebellar tract cross to the opposite side of the spinal cord at the level of the anterior commissural fibers. Subsequently, they ascend on the contralateral side along the anterolateral funiculus, then pass through the superior cerebellar peduncle, and ultimately terminate in the anterior cerebellar vermis on either the contralateral or ipsilateral side. These terminations occur within lobules I–IV. Collateral branches of these fibers also terminate in the regions of the dorsal and medial accessory olivary nuclei [21, 23].

3.3 Descending Spinal Tract Pathways of the Balance System

The descending motoric pathways that contribute to the balance system are the vestibulospinal tract, reticulospinal tract, and lateral and anterior corticospinal tracts, as shown in Figure 3.

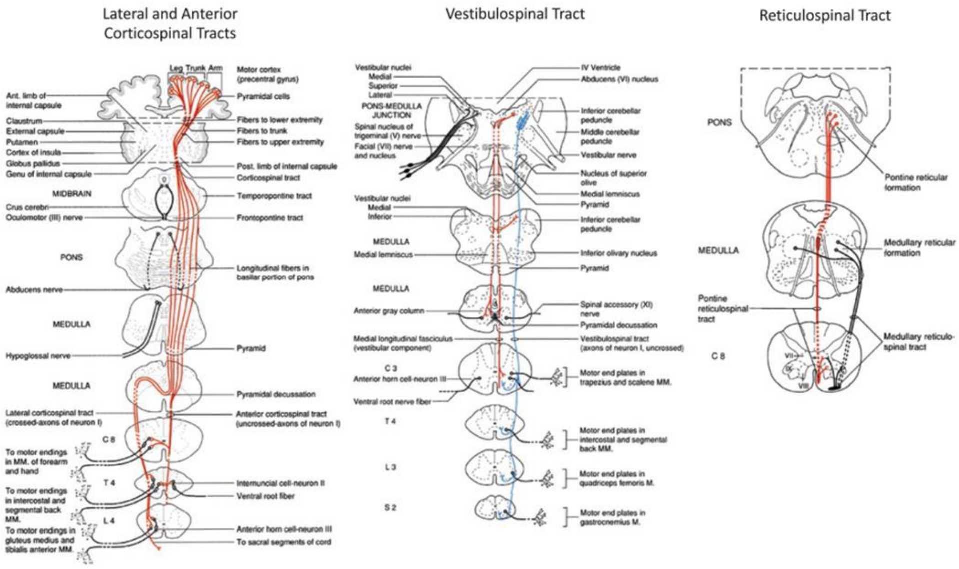

Figure 3 The descending spinal tract of the balance system.

The vestibulospinal tract consists of the medial and lateral tract. The lateral vestibulospinal tract is the larger of the two tracts, primarily composed of axons of neurons in the lateral vestibular nucleus, also known as Dieter's. These fibers descend ipsilaterally within the ventrolateral columns and send branches that innervate various spinal cord levels. This arrangement allows them to modulate the activity of spinal motoneurons across different segments effectively. The primary sites where vestibulospinal projections terminate are interneurons located in Rexed's laminae VII and VIII. As a result, this pathway indirectly influences spinal motoneuron activity through di- or polysynaptic connections. Rexed's lamina VII is also a significant location for terminating proprioceptive afferents and descending projections originating from reticulospinal and corticospinal pathways. Therefore, the vestibulospinal pathways play an essential role in modulating the excitability of reflex responses in reaction to anticipated or externally induced postural displacements [21, 22].

The lateral (medullary) reticulospinal tract arises from the axons of neurons in the nucleus reticularis gigantocellularis. In contrast, the medial (pontine) reticulospinal tract arises from the nucleus reticularis pontis, specifically from its pars oralis and pars caudalis. Axons of the medial reticulospinal neurons originate in the pontine reticular formation. They initially descend bilaterally through the medullary tegmental field, then continue their course ipsilaterally through the ventral funiculus of the spinal cord. Axons of the lateral reticulospinal formation also descend bilaterally (although the ipsilateral tract is predominant), just lateral to the medial longitudinal fasciculus, before entering the spinal cord. Some join with the pontine fibers that comprise the medial reticulospinal tract, while others proceed through the ventrolateral funiculus, forming the lateral reticulospinal tract. A subset of reticulospinal neurons establish monosynaptic connections with alpha and gamma motoneurons in the spinal cord's ventral horn (lamina IX). Most of these neurons, however, terminate on premotor interneurons located in the intermediate zone of the spinal cord, specifically in laminae VII and VIII. This arrangement of parallel inputs to alpha and gamma motoneurons equips the reticulospinal system with the capability to adjust muscle stretch sensitivity in alignment with the requirements of a given task [21, 22].

The corticospinal tract primarily originates from the primary motor cortex and premotor area. However, this tract also receives input from the somatosensory cortex, cingulate gyrus, and parietal lobe. On its descent, the fibers running in this tract pass through corona radiata and internal capsule, cerebral peduncles, pons, and upper medulla. The decussation of the fibers occurs in the lower medulla, where approximately 85 to 90% of the fibers cross, forming the lateral corticospinal tract. Within the spinal cord, the lateral corticospinal tract descends through the lateral funiculus. It establishes connections at each spinal level, with lower motor neurons responsible for controlling the extremities' gross and fine motor movements. Some fibers do not cross over (non-decussating) and continue on the same side within the spinal cord as the anterior corticospinal tract. The anterior corticospinal tract controls neck, shoulder, and trunk muscles [21, 24].

3.4 Cognition System

Cognition refers to the mental capabilities or thinking skills that allow a person to perceive, acquire, understand, and respond to information from their environment. In a broad sense, cognition means information processing. Cognition denotes a ‘relatively high level of information processing of specific information including thinking, memory, perception, motivation, skilled movements and language’ [25, 26]. The primary purpose of cognition function is to effectively handle sensory input (tactile, visual, and auditory), convert it, process it, and store it before using it for interneuron connections. This allows a person to make decisions based on the sensory input. In the cognition process, perception, attention, memory, language, visuospatial ability, and executive function (i.e., functions of planning, organizing, and implementing) are all domains of cognitive function [27].

From the brainstem to the spinal cord, the gait process connected to postural reflexes, including head-eye coordination, body, and muscle tone. The reticulospinal pathways of the lateral section of the mesopontine tegmentum and spinal locomotor tissue are principally responsible for this process. Cognitive function based on body parts and movements is necessitated when walking in an unfamiliar area. Through reciprocal connections between the brainstem and the cerebral cortex, cognitive information produced in the temporoparietal association cortex coordinates with motor cortical areas, basal ganglia, and cerebellum to regulate cognitive processes in controlling balance. The primary signal pathway of postural control is described in Figure 4 [28]. Damage to the cerebral cortex, basal ganglia, and cerebellum causes cognitive function impairments that influence body balance control, resulting in falls [27].

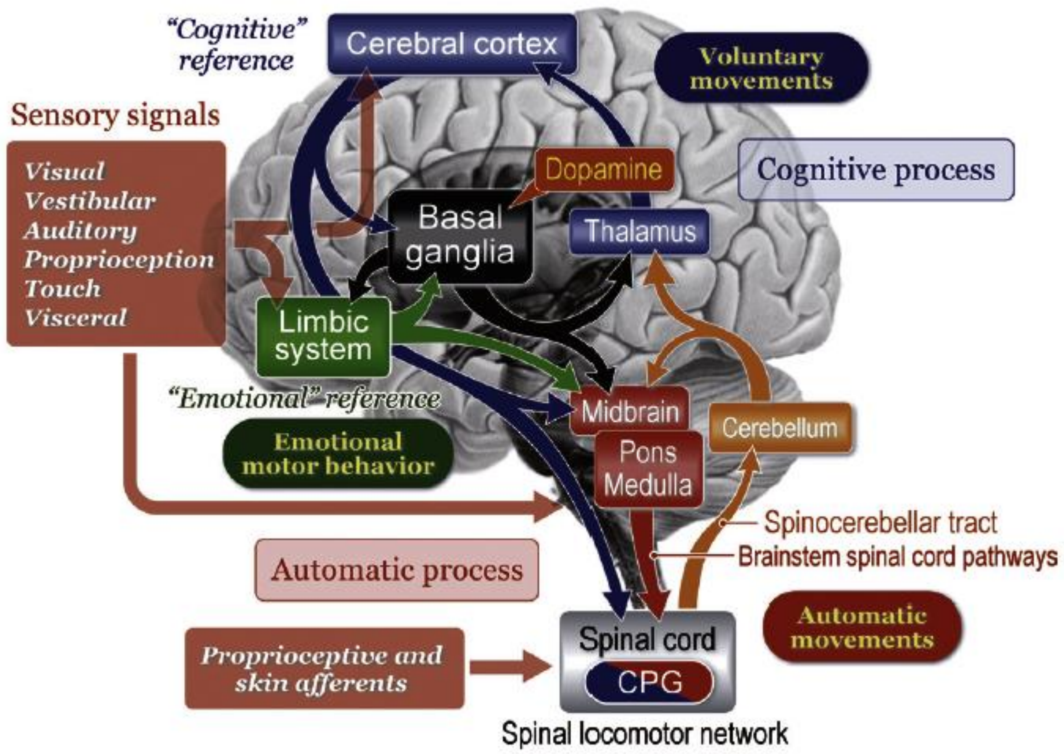

Figure 4 The primary signaling pathways in postural control.

Perception. Perception can broadly described as the capacity to recognize the stimuli and sensations that a person experiences. The process of perception formation can be described as follows [29]:

1. The selection process is the process through which a stimulus translated into a valuable experience by the human senses.
2. Organizational processes: selecting the information received and organizing it by finding meaningful patterns. This corporate stage accomplished by classifying data.
3. Interpretation process: After categorizing the chosen inputs into predictable, structured patterns, the brain attempts to connect these patterns by giving meaning to the various things.

Attention. Attention is one of the critical domains in the process of thinking and learning [30]. Attention is required to focus and disregard distracting stimuli. Ordinary people can reach and maintain an alert status. The ability to remember and understand what is happening around him, Selective visual attention capacity helps a person have goal-directed behavior by receiving signals and stimulating the behavioral inhibition and activation systems [31]. Previous studies showed that attention formed from an anatomically specific system that can divided into three parts according to alerting, orienting, and executive functions [32, 33].

Alerting is a condition in which a person can achieve and maintain an alert status. The frontal and parietal lobes of the brain's right hemisphere are related to the alerting system. Due to the distribution of norepinephrine from the brain's locus ceruleus in both lobes, a continuous and alert activity will stimulate both lobes. The act of selecting the incoming signal, which may take the form of a visual sensor, is known as orientation (visual orienting). The parietal and frontal lobes of the brain are involved in orientation. The Executive Network is an execution process that involve resolving several conflicts that develop throughout the attention process. Executive attention is also a conflict resolution skill [32, 33].

Memory. An individual's capacity for storing information that can recalled later is known as memory. The ability to consciously store information for adaptive usage is known as working memory. Data from all sensory modalities and verbal and nonverbal information can be included [34]. Based on the period, memory categorized into short-term, intermediate, and long-term. Whereas, based on the type of information stored, it is divided into declarative memory and non-declarative memory [35]:

a. Declarative memory is essentially the memory of various integrated thought details, such as the memory of significant experiences, which include environmental memory, time relationship memory, experience-causing memory, experience-meaning memory, and memory of a person still existing in the mind.
b. Non-declarative memory is frequently linked to motor activity of the body, such as automatic memory for all skills developed for hitting a tennis ball, such as (1) seeing the ball, (2) calculating the relationship and speed of the ball to the racket, and (3) inferring rapid movements of the body, arms, and racket needed to hit the ball.

New memory coded during the consolidation process into many different types of information. Further information and old information compared for similarities and differences. Thus, in consolidation, new memories are not solely stored in the brain but alongside existing memories of the same type. This is necessary if one wants to be able to "search" the memory storage at a later time to find the required information. Short-term memory needs to be frequently triggered to cause the chemical, physical, and structural alterations at the synapses that lead to long-term memory consolidation. In sensory disturbances, the dynamic function of the brain will temporarily prevent consolidation [35, 36].

Visual and spatial processing. Visuospatial ability refers to a person's capacity to identify visual and spatial relationships between objects. Visuospatial ability is the ability to imagine objects to understand the differences and similarities between objects. This ability processes visual stimuli, understands space and objects, and visualizes images and scenarios. Such various cognition abilities as learning navigation and attention orientation are included in this category [37].

Executive Function. Executive function in humans includes several abilities, such as flexibility, anticipation, problem-solving, decision-making, and self-regulation. Cognition flexibility is the ability to appropriately adjust one's behavior in response to new and unexpected environmental conditions. This ability is essential for adaptation and survival [38].

According to Luria, Human cognition anticipation defined as "action, decision, or behavior based on predictions (implicit or explicit)" [39]. Problem-solving is the human ability to solve problems in achieving goals [40]. The ability to make rational decisions by forming judgments and considering all relevant options is called decision-making [41]. Conversely, self-regulation is a complex concept that includes the mechanisms for controlling one's emotions, motivation, cognition, social interaction, and physical conduct. To achieve one's goals, emotional regulation (ER), one of the SR components that defined as "extrinsic and intrinsic processes," is in charge of observing, assessing, and altering emotional reactions [42].

3.5 Anatomical Correlation Between Cognition and Balance

Balance is known to be significantly influenced by several different brain regions. The cerebellum, basal ganglia, and thalamus are a few of these structures, and the hippocampus and inferior parietal cortex are also involved in balancing [6]. Adults with prefrontal cortex disorders have been shown to have balance and mobility issues. The prefrontal cortex is a region of the brain that controls executive functions. Falls risk is thought to be influenced by cognitive function impairments, such as executive function (EF) limitation. The three components of administrative control of most significant interest to the present study are working memory (i.e., storing information in the mind long enough to use it), cognitive flexibility (i.e., changing perspectives by shifting attention), and inhibition (i.e., selectively attending to one stimulus while ignoring another) [43]. Altered gait, restricted mobility, and a higher incidence of falls have all been linked to diminished executive function [44].

Signals from the visual cortex, vestibular cortex, and primary sensory cortex (S1) that enter the central nervous system integrated starting from the level of the cerebral cortex. Meanwhile, the body schema formed in the temporoparietal cortex, including the vestibular and posteroparietal cortex. The body schema is then transmitted to the auxiliary motor area (SMA) and premotor area (PM) to produce motor programs [45].

Purposeful behavior always accompanied by automatic processes of postural control, including balance adjustments and regulation of muscle tone. The motor cortex's areas collaborate with the basal ganglia and the cerebellum to ensure proper motor programming. Motor programming in SMA/PM can triggered by signals from the prefrontal cortex (plans and intentions), which can include deliberate movement and linked to postural control. Then, a motor program is transmitted to M1 to achieve goal-directed skilled movement [45].

The cerebellum regulates cognition processing and posture-gait control by acting on the cerebral cortex via thalamocortical projections and the brainstem. This process could facilitated by information from the cerebral cortex via the cortical-ponto-cerebellar pathway and sensory feedback from the cerebellum via the spinocerebellar tract. The basal ganglia also contribute to every process of gamma-aminobutyric acid (GABA)-ergic projection to the cerebral cortex and brainstem. Dopaminergic neurons regulate the degree of GABAergic influence on the basal ganglia in the midbrain [45].

Through the cortico-vestibular and vestibulospinal pathways, the vestibular cortex used to maintain a vertical posture. Anticipatory postural adjustments can achieved using postural control programs by the cortico-reticular and reticulospinal pathways. The midbrain locomotor region or mesencephalic locomotor region (MLR) in the mesopontine tegmentum, the subthalamic locomotor region (SLR), and the cerebellar locomotor region (CLR) in the cerebellum have all identified as significant structures influencing gait posture in animals. If there is a lesion in the MLR, stimulation of the SLR will trigger locomotor activity. Hence, the connection of the SLR to the MLR is likely essential for maintaining proper posture and gait [28, 45]. Anatomically, cognition's role in balance control can be seen in Figure 5 [28].

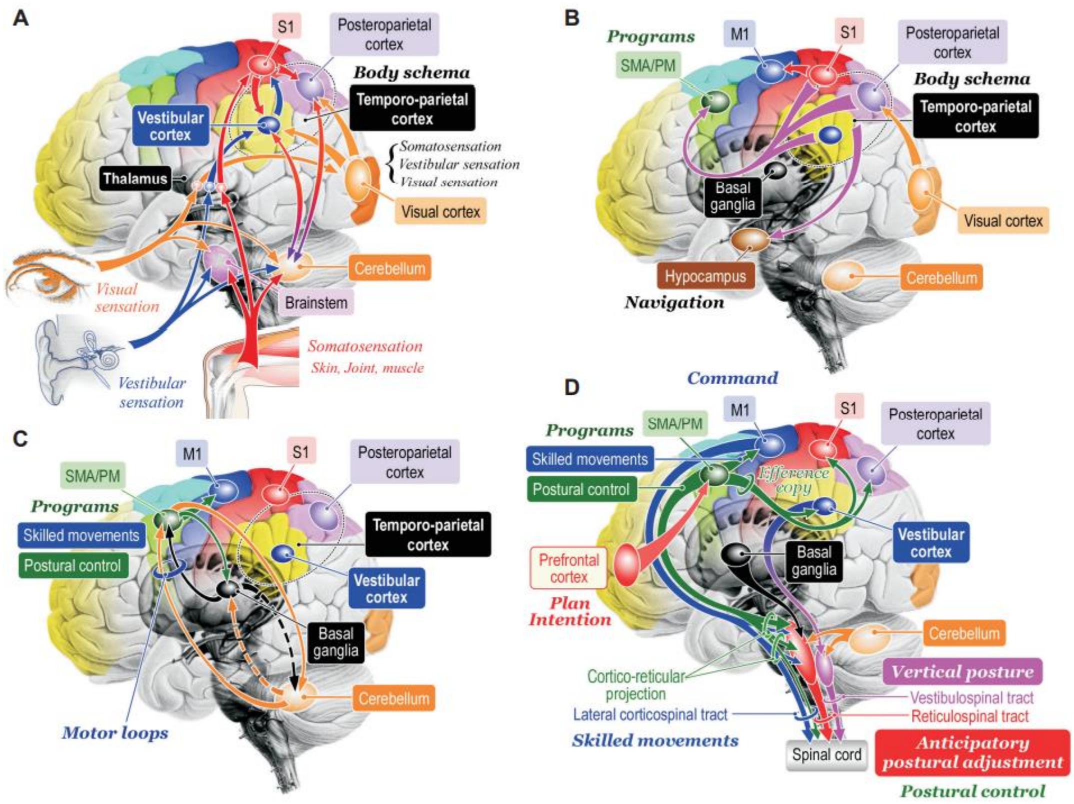

Figure 5 Cognitive control of posture and gait hypotheses. A: Cognition of bodily information. B: Transmission of the bodily information. C: Motor programming. D: Postural control by corticofugal projections to the brainstem and spinal cord.

3.6 Cognition System the Role of Cognition in Balance Control

Cognition is essential in maintaining body balance because balance results from various systems' complex integration and coordination. Almost all cognitive components, such as perception, attention, memory, visual and spatial processing, and executive function (i.e., flexibility, anticipation, decision-making, and problem-solving), have a role in balance processes.

Stimuli, both internal and external, frequently impact the process of sustaining equilibrium. Individuals will categorize and process the sensory information that is acquired into perceptions. The role of attention is to choose which sensory input from various sources should be prioritized using the DAS and VAS. The selected sensors will be identified to choose the best strategy [45].

Attention, an individual's information-processing capacity, is essential for balance [46]. Studies show that cognition factors are important in controlling stability during activities such as standing and walking. Studies using the dual-task paradigm to examine the effect of attention and balance control when performing secondary tasks show that attentional function contributes significantly to balance disorders [47].

The cerebral cortex and limbic system receive multisensory signals from the visual, auditory, somatosensory (proprioceptive), and visceral receptors, creating cognition and emotional references that lead to voluntary movement or passionate motor action. Multiple purposes are served by sensory signals from internal and external visceral stimuli, for example, in cognition processes such as producing working memory to control future behavior. Sensory signals also detect and correct postural instability by acting on the cerebral cortex, cerebellum, and brainstem [28, 45].

Voluntary movement originates from motor commands from the cerebral cortex to the brain stem and spinal cord. On the other hand, emotions can contribute to emotional motor behavior produced by projections from the limbic hypothalamus to the brainstem, such as the "fight or flight" reaction. Purposeful behavior is always accompanied by automatic processes of postural control, including balance adjustments and regulation of muscle tone. This process is elicited by sequential activation of neurons in the brainstem and spinal cord. The basic locomotor motor patterns are generated by a spinal locomotor network called central pattern generators (CPG). However, to learn motor skills or behave in new circumstances, subjects need a cognitive function for posture-gait control that depends on cognition and spatial localization of objects in the environment.

Vertical posture is supported by perceptions formed by visual, somatosensory, and vestibular information. This upright posture is often disturbed in pathological conditions such as "pusher syndrome" after stroke and "Pisa syndrome" in severe Parkinson's disease. Stroke patients with pusher syndrome actively push on the ipsilateral side and tend to fall to the present or contralateral side (left side for patients whose strength is on the right) [45]. Postural stability is also often affected in cases of sarcopenia, where there is a decline in muscle strength and mass. It has been documented that in patients with especially severe sarcopenia, the decline in muscle strength is an independent risk factor for postural instability. Therefore, postural instability in sarcopenic older adults is associated with a higher risk of falls [48-50]. Meanwhile, regarding the role of executive function in balance, the presence of deficits in cognition flexibility is associated with various pathologies such as autism, schizophrenia, Parkinson's disease, Alzheimer's disease, and attention disorders [37].

4. Conclusions

Attention, memory, visuospatial, and executive functions are among the areas of cognitive function that are integrated with processing information, followed by a reaction that aims to preserve body balance and prevent falls.

The temporoparietal association cortex produces cognitive information that helps to maintain an upright posture and motor development. The motor cortical region controls optimal anticipatory posture adjustments, ensuring that movement is appropriate for the situation. Through the reciprocal interaction between the brain stem and the cerebral cortex, the basal ganglia and cerebellum will influence cognition processes that control balance. Cognitive function impairments will impact bodily balance control due to injury to the cerebral cortex, basal ganglia, and cerebellum, leading to falls.

Therefore, after acknowledging the importance of cognitive function in the balance system, we suggest that early screening and mental state assessment be performed in the population so that patients with potential cognitive function deficits can be monitored closely for possible balance problems. In addition, screening of sarcopenia should be performed widely in older adults, and patients with this condition are suggested to undergo muscle strength and balance training to prevent the risk of falling.

Author Contributions

Na and No were involved in planning and drafted the manuscript, Na designed the figure and table. Na, No, TP and FA worked on the manuscript. All authors discussed the results and commented on the manuscript.

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Competing Interests

All authors declare that they have no conflict of interests.

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