Topical Review: Vision and Gait in Older Adults: A Clinician’s Perspective
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ABSTRACT
Gait is an important human function, and vision is the dominant sensory input used during gait. Vision aids pathfinding decisions and provide ongoing sensory feedback to maintain appropriate balance and prevent falls. Eye care providers who wish to effectively address the impact of vision impairment on the risk of falling will customize their management plan based on specific impairments. This article provides an overview of normal sensory integration as it applies to gait, with an emphasis on vision. It also presents an evidence-based review of visual dysfunctions that cause falls, as well as strategies to reduce falls in adults with visual impairment, with emphasis on patients over age 65.

EXECUTIVE SUMMARY
Gait, or the manner of walking, is an important human function. Vision is the dominant sensory input used during gait. Vision is used to make pathfinding decisions, and provide ongoing sensory feedback to maintain appropriate balance and prevent falls. Individuals with vision impairment are at a greater risk of falling. Eye care providers who wish to effectively address patients’ fall risk will understand the impact of vision on gait, recognize those at risk of falling due to impaired vision, and customize their management plan based on specific impairments.

The aims of this article are to provide: (1) An overview of normal sensory integration to inform gait, with an emphasis on vision; (2) An evidence-based review of visual dysfunctions that cause falls; and (3) Strategies to reduce falls in older adults with visual impairment. In this article the term “older adults” references people over age 65.

BACKGROUND
The human gait cycle moves the body forward efficiently through a complex interaction of gravity and coordinated muscle contractions around joints of the body. Successful walking during normal environmental demands requires constant sensory input to modify this motor plan. While motor impairments are a common cause of gait instability, this review will focus on the sensory systems, rather than motor, and their role during gait.

There are two categories of sensory data. When planning a task, like stepping up onto a train, the sensory information gathered in anticipation is called feedforward; feedback is the use of sensation during motion, such as the sensory response after being jostled in a crowd.

Since falls are a leading risk of death and disability in older adults [ranging in age from over 50 to over 65 depending upon the authors], falls have been studied extensively to determine risk factors and remediating interventions. Not only are falls more frequent with age, but...
the severity of injuries increases. Dysfunction in any of the sensory systems leads to falls in older adults, including visual impairment. Clinicians working with high risk populations, such as older adults or adults with visual impairment, offer hope for fall and injury prevention.

The four main systems contributing sensory information to guide gait are described next: somatosensory, vestibular, perception/cognition, and vision. To start, an overview of each system (including an expansive review of the subcategories of vision) is provided, followed by a brief review of relevant anatomy and physiology to provide a foundation for understanding general effects of sensory impairment on gait, and finally a description of the effect on gait of impairment of the system.

### Somatosensory Overview

Highly specialized sensory endings in the skin, muscles and joints respond to different stimuli and coordinate with motor information and other senses in the cerebellum and cortex. These coordinated sensory and motor interaction produces ideal movement that is purposeful and appropriate to the task.

### Relevant Anatomy and Physiology

There are two main somatosensory pathways in the spinal cord: the dorsal column carrying highly detailed discriminative mechanical information, such as joint position, and the spinothalamic tracts carrying noxious inputs interpreted as painful. A third pathway, the spinocerebellar tract, monitors body position during motions at an unconscious level, contributing to slight motor changes that help guide goal-oriented movements. Sensory information from these proprioceptors is used to engage specific muscles to maintain postural control. This allows muscle recruitment to remain upright, even during unexpected changes in the ground. The somatosensory system is generally the first to be activated during gait. For example, proprioceptors in the feet, ankles, knees, and hips continuously provide information during joint position changes. Further, neck proprioception are essential for accurate head position placement, and as a result, proper visual alignment.

### Effect of Impairment on Gait

Impairments of the somatosensory system delay reflex mechanisms that produce normal rhythmic gait, as well as rapid adaptations during changing ground surfaces. Loss of neck proprioception often produces vertigo due to vestibular and visual mismatch.

### Vestibular Overview

The vestibular system provides information about the exact position of the head. Vestibular impairments increase fall risk due to inappropriate balance reactions, dizziness and reduced gait confidence.

### Relevant Anatomy and Physiology

Hair cells within the vestibular apparatus of the inner ear depolarize in response to head motions and convey information to the vestibular nuclei via cranial nerve VIII. These neural signals coordinate head and eye movement for stable vision, as well as participate in descending pathways for reflexive balance control while making additional blood pressure adjustments during positional changes. The four vestibular nuclei in the medulla and pons give rise to both ascending and descending tracts; ascending tracts carrying input to the medial longitudinal fasciculus for eye motion control, while descending pathways coordinate sensory information for motor response.

### Effect of Impairment on Gait

Loss of accurate, continuous information regarding head position through vestibulo-ocular reflex abnormalities increases fall risk. Oversensitivity to head motions is linked to excessive and inappropriate balance
reactions, while vestibular hypofunction is linked to injurious falls in part because of inadequate protective reflexes.

Perception and Cognition
Overview
Definitions of cognition and perception are essential. Perception refers to the neurological processing of sensory data from various areas of the body. Cognition in this article refers to the use of attention, memory and executive function to generate measurable behavior for walking. Attention to the environment is necessary for adjustments to gait patterns. Past experiences create movement habits and inform perception (e.g. is the floor slippery or just shiny?). Finally, executive function integrates all incoming internal and external factors to provide the foundation for movement. Together, perception and cognition link the subconscious aspects of balance together to determine the body’s reaction.

Relevant Anatomy and Physiology
Sensory input from each of the systems arrives at the primary sensory cortex for that sense. Then the association cortices coordinate input from various senses prior to generating appropriate behavioral responses.

Effect of Impairment on Gait
Misinterpretation of sensory data can easily lead to loss of balance, such as missing a low contrast curb and tripping, or being overly sensitive to visual motion in the periphery that triggers balance reactions such as the vestibulospinal reflex. Individuals with cognitive impairments often display these and other behaviors, placing them at higher risk for falls and do not respond to traditional fall prevention training.

Vision
The following sections provide an overview of key vision functions and describe their contribution to maintaining balance during gait. The visual system contributes to gait by providing information for ongoing route planning, as well as feedback for proper gait maintenance. Identifying and locating potential obstacles requires good peripheral awareness. Adequate visual acuity, contrast sensitivity and visual processing add detail about the obstacle for further decisions. Monocular and binocular depth cues further determine their precise locations. Eye movements ensure that the visual system is attending to the correct target. All these aspects of vision work together with other systems of balance to maintain an upright posture and smooth gait, across varying environments, without falling. However, if any aspect of the system is compromised, there is an increased risk for falling. The next sections detail each of the specific components of the visual system that contribute to postural control during gait.

Visual Acuity
Overview
Visual acuity contributes primarily to feed-forward motor planning of route finding and obstacle negotiation. Central visual acuity is specifically used to locate obstacles, maintain walking strategy and step negotiation.

Anatomic Pathway/Relevant Physiology
Visual acuity is the smallest object an individual can discriminate at a given distance, typically recorded as a Snellen fraction. The macula has a high concentration of retinal cones (particularly dense in the fovea) used to perceive small forms. Foveal cones communicate high spatial frequency information to retinal parvocellular ganglion cells, forming the parvocellular pathway. This parvocellular pathway passes through layers 3-6 of the lateral geniculate nucleus (LGN), before projecting to layer 4 of visual cortex. This visual information eventually joins with other sensory information in various cortical areas to produce the percept of an object, which can then be accessed by other systems, for example association centers...
that could inform the body that the object is an obstacle to be avoided.48

**Effect of Impairment on Gait**

It is difficult to describe the effect on gait of decreased visual acuity alone. Further, decreased visual acuity variably affects gait among individuals, with some people able to ambulate through their environment without tripping on items, or running into objects, despite reduction in visual acuity.49-51 Others with self-reported poor vision restrict behavior due to fear of falling52 or alter gait strategies with associated increase in fall risk.3,49 Further, inappropriate spectacle correction used while walking can impose incorrect refractive blur and alter gait,53 thus increasing potential of falling.54

**Peripheral Vision and Visual Field Overview**

The peripheral visual field is used for both locating obstacles and sensing movement in the environment, essential information in feedback and feedforward postural control. Perceived visual movement provides both feedforward information when we note the speed of objects approaching; and feedback regarding our own gait speed and body position as the world moves past. Peripheral field awareness during feed forward pathfinding uses past experience. Variations stimulate the brain to change fixation and foveate details of the potential obstacle.

**Anatomic Pathway/Relevant Physiology**

Cells in the peripheral retina are quite different than in the fovea, and this difference impacts visual function, primarily because much of the retina, except for the fovea, is dominated by rods. Rods, themselves, are less sensitive to high spatial frequency information. In addition, ganglion cells have much larger receptive fields in the periphery due to a huge convergence of rods onto amacrine/ganglion cells forming the magnocellular pathway. The combined effect is a decrease in visual acuity with greater eccentricity from the fovea. However, peripheral vision under scotopic conditions is enhanced, which contributes to improved mobility in low light. The magnocellular ganglion cells that exist primarily in peripheral retina project to the first two layers of the LGN. Both parvocellular and magnocellular input from layers 1 and 2 of the LGN projects to the extrastriate cortex V5 area for motion sensing, though the magnocellular input is stronger. The result is that peripheral retinal cells will perceive large objects, or moving objects that could be in the movement path,47 to infer where the body is in space and how quickly it is moving.

**Effect of Impairment on Gait**

Visual field loss is independently associated with reduced postural stability,55-57 impacted gait,10 and increased falls.50 Visual field loss will affect gait differently depending on the location of loss.58

**Contrast Sensitivity Overview**

Contrast perception works in conjunction with other visual functions, visual acuity in particular. High contrast sensitivity allows for ideal obstacle discrimination during visual scanning of the environment. Together with past knowledge, contrast perception is used in feed forward gait planning. Reduced contrast sensitivity leads to postural instability9 and increased risk of falling.59,60

**Anatomic Pathway/Relevant Physiology**

Contrast in the visual system is the difference between the luminance of an object as compared to other objects within the field of view. Reduction in visual contrast can produce functional challenges. Letters on this page, typically black on a white background, create higher contrast, compared to the lower contrast of a series of gray concrete steps at the local park, where the area lighting provides shadows that variably distinguish between the steps. Contrast sensitivity can be measured by assessing the ability of an individual to see...
ocular alignment. Depth perception is involved in route finding and obstacle negotiation, and has an important role in body stabilization. Stereopsis is prevalent at distance and though the impact of stereopsis on gait has not been extensively studied, there is some evidence of its importance during movement. One study showed that subjects with monocular viewing had impaired gait. Stereopsis and binocular vision are important for feed forward motor planning.

Anatomic Pathway/Relevant Physiology
Retinal disparity contributes to stereopsis when an object stimulates corresponding points on the retina that are disparate to the fovea. These retinal cells then advance monocularly, and the retinotopic corresponding points from both eyes are ultimately put back together in the extrastriate cortex in multiple areas including V2, V4, and V5. The neurophysiology of this process is complex and not fully understood, however, there is evidence that binocular disparity while moving is coordinated in V6 and MST.

Effect of Impairment on Gait
Optimal contrast sensitivity function requires intact retinal cells, but also requires clear media and optimal retinal focus. Loss of contrast sensitivity is particularly significant during complex gait tasks such as navigating stairs and curbs. Poorer contrast is associated with an increased fear of falling, increased risk of falls in the elderly, and increased falls and injuries in patients with age related macular degeneration and visual impairment.

Binocular Vision/Stereopsis Overview
The eyes are intentionally separated in space to provide for binocular viewing. Binocular vision is important to create an enlarged visual field, for binocular summation where vision with both eyes is better than one, to facilitate vergent eye movements, and perhaps most importantly, to provide for stereoscopic viewing. While monocular individuals will still experience cues to depth such as relative size, linear perspective and motion parallax, stereopsis is the strongest cue, particularly at near. Stereopsis requires good retinal disparity, which in turn requires good retinal function as well as appropriate optotypes in decreasing amount of contrast. The ability to perceive varying levels of contrast is due mainly to the receptive field of the ganglion cells. Ganglion cells have a center-surround design, where light falling on the center will cause the cell to behave differently than if light falls on the surround. For optimal contrast perception, the light falling on the center of a cell’s receptive field would be in direct contrast to the light falling on the surround, thereby evoking an optimally excited cell. There is naturally a decreased contrast sensitivity at larger spatial frequencies because the receptive field falls entirely within a single grating. Similarly, there is a limit to the ganglion cell receptive field based on the cellular size of cones, which contribute to limitations of contrast sensitivity at higher spatial frequencies.

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to verify movement in the peripheral vision.\textsuperscript{48} Eye movements are particularly important for gaze stabilization while moving\textsuperscript{56} through the vestibulo-ocular reflex, allowing visual imagery to stay clear with head movement.

**Anatomic Pathway/Relevant Physiology**

Eye movements have three main purposes: (1) to maintain visual stability during movement (2) to maintain foveal fixation of objects, including for stereopsis, and (3) to shift visual attention. Sensory pathways are dictated by each of these functions. Most of the sensory processing for eye movements takes place in V5, as well as the frontal eye fields and supplementary eye fields.\textsuperscript{48}

Motor planning for eye movements starts in many supranuclear regions in the brain, which innervate premotor nuclei in the brainstem. The superior colliculus, along with other cortical areas, provides input to the premotor nuclei regarding the desired eye movement.

**Effect of Impairment on Gait**

Stable fixation creates the foundation for reliable vision. Slower eye movements such as smooth pursuits disrupt balance and delay timely movement strategies,\textsuperscript{70} while saccades improve postural stability.\textsuperscript{71,72} In particular, unstable gaze associated with older age negatively affects balance\textsuperscript{73} by impairing visual stability.

**Normal Interactions of Systems**

Purposeful human movement requires coordination of motor and sensory information. A real-world example follows (see figure 1). Walking on uneven sand at the beach requires visual information interpreted through past experiences of other irregular surfaces and your accurate egocentric location. Understanding of your body's size and how much space you take up is also essential for pathfinding. Using eye movements and visual acuity, you first scan the environment for the best walking path to your destination to avoid obstacles, or spot running kids and sunbathers. As you begin walking, accurate perception of a contrasting surface illuminated on the sand identifies a shadow. Is it a rock or a hole? Using both eyes together, you can more accurately anticipate the object's depth and avoid stepping into the hole built by an industrious child.

Suddenly your ankle joint proprioceptors fire, telling you the surface just changed orientation.

![Figure 1. Walking on the Beach: a real-world example of sensory integration for normal gait. (Reproduced with permission from Jamie Graham.)(/content/100/vdr/7-2/100.png)](image)
from horizontal to diagonal, soft to hard. You have stepped on a buried rock. As you look down, your vestibulospinal reflex is triggered by rapid changes in head position and engages leg and trunk muscles to adjust your foot position.

As you continue to your destination, your vestibulo-ocular reflex will be working to make sure that eye movements are appropriate to keep your fixation on the path ahead to clearly see a friend seated on a nearby towel. Your auditory perception begins to localize a sound overhead. Using vestibular and proprioceptive input to ensure accurate placement of your head towards that region of sky, you direct your fovea to the area, then recognize a drone. As your journey ends, the parking lot on one side of your peripheral vision and the horizon on the other provide feedback to coordinate body orientation and your relationship to upright before you bend down to join your friend.

Visual Impairment and Gait

The key vision functions described individually above work together to produce normal vision for gait. An evidence-based summary of visual impairments and their role in fall risk is offered next for the clinician.

Impairment in vision increases risk for gait dysfunction and falls by one or more of these methods: reducing feed-forward input for motor planning, impacting gait speed and stability; or loss of visual feedback for efficient localization and navigation.

Decreased visual acuity will impair an individual’s ability to perceive small objects, which could cause someone to trip over an obstacle in the gait path. However, in someone with intact peripheral field, such as in the case of macular disease, the vision eccentric to the macula should be able to identify large obstacles to inform the gait path. It is possible that the effect of decreased visual acuity on increased gait errors could be the combined effect with decreased contrast sensitivity and decreased binocular vision, as it is very difficult to parse these impairments apart. It is also possible that the effect of decreased visual acuity on gait errors is due to psychological impacts. If one knows that they cannot see what they are trying to view, they may question their ability to move safely through their environment. This could be the cause of effects such as altered walking speed, increased fear of falling, and a general sense of discomfort with perception of visual information.

Decreased peripheral vision has been shown to cause significant effects on gait, perhaps more so than reduced visual acuity, even in mild disease. This is likely because reduced peripheral vision, with intact central visual field, causes a loss of feedforward planning. In this situation, larger obstacles just outside of the central visual field may be missed. Diminished information used to infer body position may further impair feedback during gait. People with impaired peripheral vision may have reduced binocular vision, depending on the extent of peripheral vision loss, though contrast sensitivity would remain unaffected in this situation.

Impaired contrast sensitivity is rare in isolation, but it can occur in situations of reduced media clarity, such as corneal disease or cataract. It has been shown that patients with reduced contrast sensitivity despite minimally impaired visual acuity have impaired gait that improves after cataract surgery.

Inoue et al found that older adults who experienced falls had fewer eye movements during gait than those without falls, however, these subjects reported unimpaired vision. It is not known how visual impairment impacts eye movements and gait.

Role of the Optometrist

There is a need for optometrists to participate in the assessment and management of patients who may have gait dysfunction, including:

1. Comprehensive vision exam includes screening for fall risk.

Routine screening for gait dysfunction is ideal for all older adults. A query of fall
history or gait dysfunction provides useful information regarding future risk. Falls in the past six months are highly predictive of future falls. For older adults at risk for falling, incorporate contrast sensitivity in a comprehensive exam. Contrast sensitivity can be measured both monocularly and binocularly.

2. **Appropriate refractive correction to minimize falls.** Multifocal lenses can increase falls among patients who are already higher risk for falling. For these patients, consider multifocal lenses for seated tasks only, and prescribe distance vision only glasses for ambulation.

3. **Appropriate Rehabilitative Strategies Involving Prism.** Beyond classical considerations of prism to enhance binocular vision and stereopsis, there is evidence that yoked prisms can have an influence on gait that may ultimately reduce the risk of falling.

4. **Ocular disease management to minimize visual disruption of gait.** Many ocular diseases impact visual functions important for gait. For example, macular disease has been shown to negatively impact gait through compromised visual acuity, contrast sensitivity, and binocular vision. Ideal management of disease can decrease fall risk through optimized maintenance of visual function.

5. **Considering comorbidities that impact other sensory systems.** Recognize that adults at risk of eye disease are also at risk of conditions that can affect their peripheral sensations and cognition, either due to age alone or as a comorbidity (such as diabetes) that may impair gait. Falls are the leading cause of traumatic brain injury in the elderly. Additionally, brain injury in the elderly is associated with increased mortality and the optometrist is advised to perform detailed neurological assessment. Additionally, fear of falling, even without obvious disease or dysfunction is a comorbid condition correlated with gait dysfunction.

6. **Develop a network of allied health professionals for patient referrals.** Interprofessional management of adults with gait dysfunction and visual impairment is both crucial and highly rewarding. Nurturing relationships with like-minded local clinicians improves care quality and builds your practice. When communicating use shared language to enhance collaboration.

**CONCLUSIONS**

Vision is an important contributor to normal gait, along with vestibular, somatosensory, and cognition/perception systems. Visual dysfunction contributes to gait dysfunction, and in severe cases, may cause falls. Optometrists knowledgeable about the impact of visual dysfunctions on gait can reduce the patient’s fall risk through optimal patient management, including referral to other providers to address gait concerns. Finally, optometrists cognizant of language used to describe visual dysfunction to non-vision care providers, can more effectively tailor communications to the appropriate audience.

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