A MODEL OF FALLS RISK IN OLDER ADULTS

by

Gregory Joseph Genna

Bachelor of Music, Ball State University, 2005

Master of Arts, University of Pittsburgh, 2009

Doctor of Audiology, University of Pittsburgh, 2010

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This dissertation was presented

by

Gregory Joseph Genna

It was defended on

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and approved by

Barbara Vento, PhD, Associate Professor, Department of Communication Science and Disorders

James Coyle, PhD, Professor, Department of Communication Science and Disorders

Susan Whitney, PhD, Professor, Department of Physical Therapy

Robert Turner, PhD, Professor (ret.), Department of Communication Disorders, Louisiana State University

Dissertation Advisor: Catherine Palmer, PhD, Associate Professor, Department of Communication Science and Disorders

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Gregory Joseph Genna, BM, MA, AuD

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Falls are a significant problem in older adults, with 1/3 of people over the age of 65 falling in a given year. Age-related changes in the systems involved with balance lead to increased reaction time to postural perturbations, decreased postural control, and changes in gait, all resulting in an increased risk of falling. Other factors that can lead to imbalance outside of the primary balance systems increase the risk of falls. Previous research focused on producing a clinically-relevant tool for fall risk assessment; a theoretical falls risk model has yet to be produced. Risk factors were identified from literature review and recommendations from multiple clinical practice guidelines in the area of falls risk. Using data from the National Health and Nutrition Examination Survey, a Poisson regression was performed to determine which risk factors are significant predictors of reported problems with falls in older, community-dwelling adults. An additional Poisson analysis was performed, including interaction terms to see if any risk factors combined to increase the falls risk. Analysis showed that including interaction terms was a significantly better fit in the Poisson model than with the terms omitted. The most predictive risk factor for a reported problem with falls is asking the patient if they have problems with their balance. Many other risk factors will cause a feeling of imbalance, so the primary risk factor for falls is likely having a feeling of imbalance. Additional research is needed on intervention for falls risk and identifying threshold values for when risk factors will likely lead to imbalance.

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1.0 EFFECTS OF AGE ON POSTURE AND STABILITY

The risk of falling increases with age, dramatically rising after the age of 60. According to the Centers for Disease Control and Prevention, about one third of older adults will suffer a fall that results in injury (most common injuries are hip fractures and head injuries), and of those injured, one third will not survive one year past injury (2006). The World Health Organization defines a fall as “an event which results in a person coming to rest inadvertently on the ground or floor or other lower level” (2017). In 2000, falls cost the US healthcare industry $19 billion, the majority going towards treatment for nonfatal falls and account for more than half of emergency room visits for older adults (Centers for Disease Control and Prevention, 2006). Many older adults, whether they have fallen or not, live in fear of being injured in a fall, which decreases their ability to live independently and take care of themselves. Normal everyday tasks, such as cooking, bathing, dressing, or cleaning cannot be performed due to the fear of falling, which can lead to earlier dependence on caregivers or earlier admittance into an assisted living facility. Even in older adults who have not suffered a fall, fear of falling increases the risk of falling (Vellas, Wayne, Romero, Baumgartner, & Garry, 1997) and can be equally debilitating. With the increasing average age of the US population and increased life spans, these numbers are likely to increase.

In normal aging, systems involved in balance lose sensitivity and discrimination ability. Vision, somatosensation, and vestibular sensation work together as primary balance systems to facilitate balance and stability, but they all lose sensitivity with age to some degree. Redundancy exists between these systems, but they cannot fully compensate for sensory loss. The motor system loses speed, strength, and resiliency as well. With these changes, not only does an older adult have difficulty detecting a balance perturbation, they require more time to react to the fall, to arrest or compensate for the perturbation, and are less likely to effectively react to a fall. The peripheral changes are compounded by increased central processing time for detecting or planning a response to the fall. As will be discussed, changes in both sensory processing and cognitive processes (such as attention) add together to increase fall reaction time to an even greater extent. Because of the changes in detection and reaction time, older adults use different strategies for fall arrest than younger adults, which can be seen primarily beginning in the seventh decade of life. Older adults and young adults appear to be very different when reacting to a balance perturbation due to these changes in fall arrest strategies. Older adults are much stiffer and adopt strategies that utilize larger muscle groups, while young adults can use small, more precise muscle movements, and are more flexible in terms of adapting to a perturbation. Many of the adaptations that older adults use to remain stable are really maladaptations, which themselves increase the likelihood of fall-related injuries.

1.1 AGE-RELATED CHANGES IN THE BALANCE SYSTEMS

Both sensory and motor systems involved with balance decline in function with aging. Pathology may increase the amount of decline, but even in the healthy aging population, losses are still seen. Decreases in sensory and motor systems related to normal aging are gradual enough that the aging person develops adaptations as the systems change, but only to a point. Compounding the difficulties faced by one system decreasing in function is the cumulative effects of decreases in multiple systems. For multisensory functions, such as balance, declines across the primary sensory systems involved (vestibular, somatosensory, and vision) can interfere with any compensatory strategies that might be utilized in the case of a pathological loss in one modality when the others are intact, such as with vision loss or a vestibular pathology. Motor systems also suffer from a decrease in strength and reaction time, compounding the issue of responding to sensory information. Decreases in both sensory and motor systems occur at both the peripheral and central level, with changes in the end organ and peripheral nerves, as well as in the central nervous system (CNS). As the brain changes with age, the sensitivity and reaction time of the systems also will be affected. The combination of decreased sensory sensitivity, decreased motoric speed and strength, and increased central reaction time substantially increase the risk of falling in the normal aging population when compared to normal younger people. Pathologies in any of these systems (peripherally or centrally) will increase the already greater risk of falling. The prevalence of pathologies that may affect any of these systems also increases with age, increasing the likelihood that an older person will have some additional reduction in balance function.

1.1.1 Vestibular function

Table 1. Summary of changes in vestibular function seen during aging.

Study	**Findings**	**Age range of subject group**	**Implications**
Fife and Baloh 1993	Decreased VOR in elderly compared to young	> 75 years	Correlated to increased sway
Kristendottir, Frannson, & Magnusson 2001	Subclinical VOR asymmetry	66-88 years	Linked to fall risk (Kristendottir, Nordell, et al., 2001)
Tian, Crane, Wiest, & Demer 2002	Linear VOR asymmetry	56-75 years	Linked to fall risk
Baloh, Enrietto, Jacobson, & Lin 2001	Changes in VOR time constant and decreased gain	> 75 years	Linked to fall risk

Decreases in vestibular function are seen in normal aging (see Table 1). Johnsson (1971) showed that normal aging subjects had decreases in the vestibulo-ocular reflex (VOR) when compared to normal young people, although he did not report any changes in falls risk related to these differences. Fife and Baloh (1993) also showed reduced VOR and correlated these decreases to increases in postural sway and disequilibrium. Many subjects had subclinical asymmetries on caloric testing, suggesting that some of the balance problems that these subjects are experiencing may have been a result of differential changes between sides. They also found nearly one-third of the subjects had a clinically relevant balance finding on testing. Kristinsdottir, Fransson, and Magnusson (2001) also found that about one-third of older adults without a balance complaint had an asymmetrical VOR. This asymmetry also was seen in the linear VOR (Tian, Crane, Wiest, & Demer, 2002). Since both the linear and angular VOR are affected, these results suggest some widespread change in the vestibular system that affects both the semicircular canals and the otolith organs, changes in the neural component of the vestibular system, or some combination of both.

In a longitudinal study over five years, decreases were seen in VOR time constant to step changes and decreases in gain across frequencies with age (Baloh, Enrietto, Jacobson, & Lin, 2001). These changes were not associated with any report of balance complaint. Abnormalities and asymmetries in the VOR have been linked to falls and fractures in the elderly population (Jacobson, McCaslin, Grantham, & Piker, 2008; Kristinsdottir, Jarnlo, & Magnusson, 2000; Kristinsdottir, Nordell, et al., 2001), although the largest covariates of falls and overall balance function in patients with a vestibular diagnosis is self-perceived handicap, manifesting during functional balance tests (Whitney, Wrisley, Brown, & Furman, 2004). Only a weak correlation exists between balance impairment and perceived handicap, as measured by the Dizziness Handicap Inventory (Gill-Body, Beninato, & Krebs, 2000).

Testing considerations must be taken into account when connecting vestibular function with falls risk. Normative data for widely used clinical measures, such as videonystagmography (VNG) and rotary chair testing, have been developed for site-of-lesion diagnostics for patients complaining about dizziness. Other anatomical variables, such as size and shape of the ear canal and other mastoid structures, can influence the results of testing independent of vestibular function. A larger caloric response, for instance, does not necessarily mean greater vestibular function. The included age range in these studies must also be considered when interpreting the results. A large spread of ages may not accurately capture the changes related to aging in the vestibular system. Illing, Choy, Nitz, and Nolan (2010) found that changes in the vestibular system seem to take place in the seventh decade of life, as the number of subjects with decreased or asymmetrical VOR was negligible until that decade. Wolfson et al. (1992) showed that nominal changes occur from 70 to 85 in a large group of subjects, suggesting that any age-related changes to the vestibular system occur at a younger age, or that additional changes may be undetectable using current methods.

Changes in the vestibular system appear to take effect most strongly after age 60 is reached, which may be a logical lower cutoff for future studies. The previously referenced studies suggest that changes in the vestibular system or any balance impairments after the age of 70 appear to be more likely due to pathology as opposed to normal aging processes.

Pathological changes can exacerbate any age-related changes in the vestibular system. The prevalence of pathologies that can affect vestibular function also increases with age, including (but not limited to) benign paroxysmal positional vertigo (Katsarkas, 1994), hemiplegic migraine (Gori et al., 2012), cerebellar ataxia (Safe, Cooper, & Windsor, 1992), and autoimmune diseases (Goronzy & Weyand, 2012). Some of these disorders, such as cerebellar ataxia, may be the effects of a traumatic occurrence (such as stroke), affecting widespread systems, while others can be isolated to just the vestibular system (BPPV).

Table 2. Summary of degenerative changes of the vestibular epithelia

Study	**Abnormalities**	**Presence of pathology**
Richter 1980	Decreases in number of hair cells in all vestibular organs, decreases in Scarpa’s ganglion, dendritic recession	None reported
Johnsson 1971	Decreases in number of hair cells in all vestibular organs, decreases in Scarpa’s ganglion	None reported
Tsuju et al. 2000a	Decreases in type I hair cells in semicircular canal ampulae	Aminoglycoside toxicity
Tsuju et al. 2000b	Decreases in type II hair cells and Scarpa’s ganglion cells	Meniere’s disease

Much of the age-related changes seen in balance can be attributed to degenerative processes within the vestibular organs and nerves (see Table 2). Richter (1980) showed degenerative changes in both the vestibular sensory epithelia and Scarpa's ganglion. The number of vestibular hair cells is reduced in all vestibular organs in the ears of older individuals and appears to be roughly equal across ears and individual organs within and between subjects, suggesting that there is some degenerative process common among all organs when pathology is absent. A decrease in Scarpa's ganglion cells also was observed along with signs of dendritic recession, although changes in Scarpa's ganglion appear after changes in the vestibular end organ. Loss of vestibular hair cells may precipitate the loss of ganglion cells, as fewer ganglion cells can be utilized with fewer functioning hair cells in a use it or lose it fashion. Johnsson (1971) also noted similar findings, although neither study accounted for the increase of pathology affecting the vestibular system in their findings. A decreasing number of sensory and neural cells seen in a histopathological study may be related to aging, but unless pathology is controlled for, reported decreases may be more dramatic than what is normally seen in the aging process. Tsuji et al. showed that Meniere's disease and aminoglycoside ototoxicity do have differential degenerative effects, with selective destruction of type I and type II hair cells depending on the pathology and the end organ. More type I hair cell destruction is seen in the ampulae of the semicircular canals with aminoglycoside ototoxicity, while more type II hair cell and Scarpa's ganglion loss is seen in Meniere's disease (2000a, 2000b), suggesting that pathology affects different parts of the vestibular system. There did not appear to be any differences related to sex in either study, suggesting that any differences seen in balance function between males and females are not related to the integrity of the vestibular system, but instead to differences in changes in other systems.

1.1.2 Vision

As with most sensory systems, changes in visual function can be related to aging. Among the normal aging population, estimates range from 2.6 to 4.8 percent of people over the age of 70 exhibit some level of visual impairment, defined as visual acuity of 20/60 to 20/400 in the best corrected condition in the better eye (Buch, Vinding, & Nielsen, 2001; Congdon et al., 2004; Dineen, Bourne, Ali, Huq, & Johnson, 2003; Foran, Wang, & Mitchell, 2003; Gunnlaugsdottir, Arnarsson, & Jonasson, 2008), with the leading causes of visual impairment being age-related macular degeneration (AMD), untreated cataracts, and uncorrected refractive errors. These numbers increase dramatically over the age of 75, with 31.9 percent of patients in a nursing home showing some level of visual impairment (Sainz-Gomez et al., 2010). With the addition of pathology, such as type II diabetes, the incidence increases as 37.2 percent of persons with diabetes taking insulin showed diabetic-related visual impairment (Moss, Klein, & Klein, 1994). The number of older adults affected by visual impairment is large amount of the population of older adults, and with the increasing age of the population, especially in the United States, this subpopulation is going to grow rapidly. Among the major causes of visual impairment, many of the problems have potential for being corrected, as cataracts and refractive error are easily corrected through use of prosthetic lenses or through medical intervention, but the rates of treatment are fairly low and need to increase, especially among rural and poorer populations (VanNewkirk, Weih, McCarty, & Taylor, 2001).

1.1.3 Proprioception and somatosensation

Along with vision and vestibular sensation, age-related decreases in somatosensation and proprioception abilities, especially in the limbs, contribute to the increased risk of falls in the older population. Changes in proprioception can be linked to morphological changes in mechanoreceptors in the muscles, joints, and tendons, as well as diminished numbers of mechanoreceptors (Aydog, Korkusuz, Doral, Tetik, & Demirel, 2006; Rosant, Nagel, & Perot, 2007), along with losses in distal sensory fibers (Shaffer & Harrison, 2007). These changes lead to deficits in proprioception in the upper limbs and wrist (Adamo, Alexander, & Brown, 2009; Adamo, Martin, & Brown, 2007; Wright, Adamo, & Brown, 2011), trunk (Abrahamova, Mancini, Hlavacka, & Chiari, 2009), and legs (Hurley, Rees, & Newham, 1998; Madhavan & Shields, 2005; Rosant et al., 2007). Changes in proprioception of the hips and ankles are among the greatest predictors of falls in older adults (Abrahamova et al., 2009; Allet, Kim, Ashton-Miller, De Mott, & Richardson, 2012; Hurley et al., 1998). Lower back pain can intensify the decreases in proprioception as sensory resources are used to respond to the pain, diverting them away from proprioception in the back, an important cue for postural control (Brumagne, Cordo, & Verschueren, 2004). However, other studies suggest that peripheral sensation is a more important sensory input for fall prediction (Lord, Clark, & Webster, 1991a; Lord & Ward, 1994). Peripheral sensation and proprioception are closely linked, as decreased sensation in the limbs normally accompanies decreases in proprioception. The previously discussed studies agree that changes in various sensations in the limbs will increase the risk of falls.

Decreases in somatosensation also are affected by central function, which leads to problems in sensorimotor integration. Transcranial magnetic stimulation shows differences in long latency motor potentials (both inhibitory and excitatory), but not in shorter latency potentials, suggesting that decreases in proprioception are associated with decreases in the ability of remaining proprioceptive inputs to influence excitability in the motor cortex over longer intervals (Degardin et al., 2011). This is evident during balance activities, as older subjects have much more difficulty using proprioceptive information from the ankles but still retain the ability to utilize information from finger contact with a fixed plate (Reginella, Redfern, & Furman, 1999). Older adults can use proprioceptive and somatosensory inputs when they are available but decreases in the senses decrease their availability. Evidence shows that some of these changes may be avoided or decreased with physical activity, showing that increased physical activity in older adults is correlated with lesser degrees of decrease in proprioception (Adamo et al., 2009; Goble, Coxon, Wenderoth, Van Impe, & Swinnen, 2009).

1.1.4 Musculoskeletal function

Sensory systems change with normal aging, both at the peripheral and central level, and the motor system mirrors these changes. In normal aging, 25 percent of muscle volume (sarcopenia), 10 percent of fiber length, and 10 percent of tendon stiffness can be lost (Narici & Maganaris, 2006). Type 2, or fast-twitch, muscle fibers are predominantly affected. Muscle fiber length and tendon stiffness appear to be recoverable with resistance training, although length-tension properties of muscles appear to be unaffected by training. In addition to morphological changes in muscle fiber, nerve conduction velocity shows a slight decrease correlated with age, likely due to changes in the peripheral nervous system, effectively delaying central commands to the muscle fibers (Colin, 1997; Letz & Gerr, 1994). Compensation for changes in muscles and the peripheral nervous system is likely to be central and manifested in changes in motor control mechanisms, although no testable model of motor control change has been proposed. Generally, central changes of the motor control mechanism are suspected and implicated when changes in peripheral factors are not sufficient to explain changes in performance. While there is currently no evidence against a change in central motor control, other factors, such as sensory integration with motor systems, may play a part in changes seen in motor control.

Adaptations in the balance system do not effectively compensate for changes in motor control. Because of this, it is speculated that some of these changes are less adaptations and more likely the results of normal degeneration in the central motor control system. Nonpathological changes in motor control at the central level have been suggested to significantly decreases stability and increases the risk of falls in older adults (Nolan, Nitz, Choy, & Illing, 2010), especially as task complexity is increased (Light & Spirduso, 1990). Nolan et al. showed that these changes appear in the seventh decade in life, manifesting as deficits in several motor control tests involving balance and postural stability. Older adults are also less likely to improve motor control with training, as Pratt, Chasteen, and Abrams (1994) showed that young adults can produce correct ballistic submovements during a task much more effectively than older adults and were better able to improve with practice than the older adults. Changes in motor learning with aging may suggest changes in the motor control system, but overall changes in plasticity and learning ability could account for some, if not all, of the proposed central motor control changes. Older adults may lose the ability to effectively learn how to use the altered peripheral system, manifesting in these apparent central changes.

Slowing of movement and a decreased ability to learn new movements in older adults may come from some level of weakness in the periphery or degeneration in the central system, but some evidence suggests that changes in motor control are a deliberate strategy, representing a quantitatively different mechanism or strategy for motor control in older adults. Morgan et al.

(1994), using a drawing task, suggested that when time differences are accounted for, changes in strategy in older adults reflect an increased preference for caution in movement. These changes may reflect a self-knowledge of an increase in the error rate, but ironically, older adults still exhibit a higher error rate than younger adults even with slower, more cautions movements. Young adults show a speed-accuracy trade-off, but older adults do not show this trade-off, even with immediate feedback (Hines, 1979). Feedback regarding the speed and accuracy of each trial increased both reaction time and error rate in older adults, suggesting that older adults are unable to effectively use feedback due to changes in sensorimotor integration or deficits in other cognitive processes involved in movement, such as attention or sensory stream switching. In balance tasks, however, there is evidence that older adults are able to use feedback at least as effectively as young adults. Reginella et al. (1999) used finger contact on a fixed plate during a posture task and showed that, while older adults swayed more than young adults, both groups decreased sway with finger contact. No statistical interaction was found between age and finger contact, suggesting that older adults were as able as young adults to utilize contact to remain stable and may use a similar (or the same) strategy to remain stable. The difference between Reginella et al.'s findings and the results of Hines may be due to the type of feedback. Reginella et al. used a continuous feedback paradigm, while Hines used a discreet feedback paradigm. A continuous, short latency feedback, like that used by Reginella et al., may be easier to integrate immediately into use, especially as the type of feedback is most likely more familiar and meaningful for the subjects. Hines provided the feedback following the task, as opposed to dynamically during the task. This may have resulted in increased difficulty in integrating the feedback into improving or changing the performance of the task. Reginella et al. integrated the feedback directly into the task, allowing immediate changes in performing the task. The timeframe of providing performance feedback may be critical for balance tasks, as well as other tasks outside of balance and posture. For postural control, Collins, De Luca, Burrows, and Lipsitz (1995) showed that increases in sway seen in older adults may be the result of closed-loop (with feedback) postural control strategies having a greater delay before being utilized, suggesting that older adults take longer to utilize any feedback.

Changes in motor planning also can be seen in older adults, suggesting that the initial processes of preparing a movement contribute to changes in motor control in this population. Motor event-related potentials showed that older adults have a lack of effector-specific activation, instead recruiting frontal areas for motor planning, which is a significantly different strategy than used by young adults during motor planning stages (Sterr & Dean, 2008). During the motor planning stage, there is no apparent differentiation of effector in processing, initiating movements from any part of the body in the same way, suggesting a lack of specificity in motor planning in older adults. Lack of effector differentiation at this stage puts the onus for segment-specific processing later down the processing line, forcing these stages to compensate for the initial planning. It is unknown what the recruited frontal areas are involved with, but event-related peaks over these areas suggest increased activation at the expense of other areas, which may be more effective. Variability and irregularities in limb movements can be attributed to lack of (or at least less effective) movement planning in the initial stages of an arm-aiming task (Yan, Thomas, & Stelmach, 1998). Older subjects also showed less ability to change movements after initiation. The authors attributed this to an increased preference for using visual feedback during this task. While studies suggest that older subjects may in fact be more dependent on visual feedback due to changes in proprioception and peripheral sensation, Yan et al. do not consider changes in the motor control system that have been previously discussed, instead focusing on peripheral function.

1.1.5 Conclusion

Changes in sensory and motor systems occur with normal aging and appear to cause major changes in perception and movement throughout the lifespan, but especially by the seventh decade of life. Changes manifest as decreases in sensitivity and discrimination, slowed reaction time, and increased error rate regardless of more careful planning or effort towards the target task. Many changes in the systems cannot be fully attributed to the periphery, with evidence showing drastic changes in the areas of the CNS responsible for processing the detection, discrimination, processing, and planning for the systems. Simply restoring sensitivity to sensory systems (or strength to motor systems) will not return the systems to normal function, as central processes need to be addressed as well. Novel strategies are developed to compensate for peripheral and central changes, producing quantitatively different planning and performance strategies in older adults when compared to young adults. Many of these changes come with normal aging, but the addition of pathology to any of these systems (which become more likely with age) can dramatically reduce the function in a very short amount of time, perhaps preventing compensation strategies from being developed in a normal fashion. In the cases of normal and pathological sensory and motor loss, interventions can help to improve function, but only to a certain degree.

Degeneration in the systems involved in balance and posture drastically change how older adults react to changes in posture and falls. Vestibular, visual, and somatosensory decreases make an older adult require a more drastic perturbation to detect a change in posture, and changes in motor control and musculature make reacting to a postural change and arresting a fall slower and more difficult. Changes in strategies, such as the switch to a hip-dominant strategy for maintaining posture, or changes in side-stepping in response to a sideways impulse, are developed to compensate for systematic changes. When one system decreases more rapidly than others (such as in the case of pathology), the other systems, already decreased themselves, must use their remaining resources to compensate. Inherent redundancy in the balance system facilitates compensation across senses, but even in the most ideal situation, functional decreases are apparent when one (or more) senses are compromised. The changes in balance reflexes and responses with age are a result of the changes in sensation and motor control and must be addressed in any intervention designed to facilitate balance and reduce the risk of falls in the elderly population, in response to normal or pathological aging.

1.2 COGNITIVE FACTORS IN BALANCE AND POSTURE

Changes in reaction time precipitate adaptations in postural responses to perturbations during both normal upright stance and locomotion. Loss of vestibular sensation can be compensated for in most, but not all, situations, although some of these adaptations may cause more problems than they solve. Not all the adaptations seen in balance in elderly individuals can be accounted for solely by physical changes related to aging. Sensory systems lose sensitivity and the musculoskeletal system weakens, but some postural changes seen with age are a result of changes in central processing, including changes in motor planning, attention, executive control, resource allocation, memory, and other cognitive processes.

1.2.1 Cognitive resources and postural precedence

Table 3. Summary of dual-task results. VOR – vestibulo-ocular reflex

Study	**Primary Task**	**Secondary Task**	**Results**
Talkowski et al. (2005)	Rotational chair VOR testing	Visual reaction time	VOR decreased with the addition of visual task
Teasdale et al. (1993)	Auditory reaction time	Increased eccentric postural position	Reaction time increased with amount of eccentricity
Muller et al. (2004)	Auditory reaction time	Platform perturbation w/ or w/o visual cue	Reaction time increased without visual cue, and when auditory stimulus was temporally closest to perturbation
Redfern et al. (2002)	Auditory and visual reaction time	Platform perturbations	Auditory more influenced by visual, not affected when presented > 250 ms after perturbation; posture not affected
Furman et al. (2003)	Auditory reaction time	Rotational chair	Reaction time increases during rotation; increased VOR phase lead
Donker et al. (2007)	Standing with eyes closed	Word reversal	Increased sway irregularity
Ojha et al. (2009)	Auditory reaction time	Ascending stairs	Reaction time increased with walking, greater in older subjects
Lajoie et al. (1996)	Auditory reaction time	Sitting, standing, and walking	Reaction time increased while walking
Brown, McKenzie, & Doan (2005)	Verbal reaction time	Walking, obstacle crossing	Reaction time increased during obstacle crossing – more at precrossing in young subjects, more during crossing for older
Bisson et al. (2011)	Unipedal stance	Verbal reaction time	Increased mediolateral and anterior-posterior sway, mediolateral greater with hip and ankle fatigue

Several investigations delving into the role of cognitive resources involved in balance and posture have focused on resource allocation. Results between the studies vary, but the general outcome is that the human brain has a finite amount of resources to devote to cognitive activities, such as attention, language, movement, problem solving, memory retrieval, and other tasks, as well as balance. Results also vary depending on which tasks are considered primary and secondary, which determines where the subject is instructed to pay the most attention to (see Table 3). The terms primary and secondary are used loosely between articles, so for the purposes of uniformity, primary will be used to denote the task in which performance is measured, while secondary is the task added to provoke changes in the primary task performance. Some authors also measure performance changes on both the primary and secondary tasks, further blurring the definitions.

With age, changes can be seen in both the amount of resources available and the resources required for performing these tasks. Reactions, such as the VOR, have classically been considered to be subcortical, but Talkowski, Redfern, Jennings, and Furman (2005) showed that cognitive resources are in fact involved in the production of the VOR, specifically suggesting that appropriating cognitive resources for non-balance tasks can decrease postural stability and the ability to react to a perturbation. Changes in the VOR were seen during a dual tasking paradigm with greater changes seen during more complex tasks, suggesting that cognitive resources are required for multisensory integration involved in balance and balance-related tasks. The investigators also showed greater decrements in patients with compensated unilateral lesions, suggesting cognitive resources play an important role in the maintenance of VOR compensation which may occur at the level of the cerebellum. This suggests that patients with compromised vestibular systems utilize more cognitive resources for balance-related functions.

The vestibulospinal reflex (VSR) is thought to be a subcortical reflex, and while the activation of the reflex does appear to be subcortical, some level of cortical-level planning seems to be required to effectively arrest a fall. Teasdale, Bard, LaRue, and Fleury (1993) showed increases in auditory reaction time when the task was accompanied by changes in posture and stability. Subjects stood on a platform that was either flat or tilted, with visual information either concordant or discordant with the platform position. The more demanding situations required more cognitive resources due to the need for corrective action to be taken, effectively slowing down auditory reaction time even more. Petersen, Rosenberg, Petersen, and Nielsen (2009) also showed greater amplitudes in motor evoked potentials (MEP) when elicited with transcranial magnetic stimulation (TMS) prior to EMG responses during a postural perturbation when compared to resting state. The anticipatory cortical response represents a level of motor planning occurring in the cortex. Quant, Adkin, Staines, Maki, and McIlroy (2000) showed physiological evidence of higher-level motor planning involved in the fall response and the VSR using the anticipatory cortical response, showing decreases in the N1 potential along with increases in EMG magnitudes when a visual tracking task was paired with a postural disturbance compared to the postural disturbance alone. This is in agreement with Dietz, Quintern, and Berger (1984), who showed that the N1 represents somatosensory activation during a balance disturbance.

During simple balance tasks, though, there appears to be very little interference (Muller, Jennings, Redfern, & Furman, 2004), suggesting that at some point in difficulty, postural control and balance shift from a relatively involuntary, background task, to the forefront of concern. This does contradict previous findings from dual tasking studies, although Muller et al. did find that the task interference increased with increased task difficulty. Muller et al. suggest that there is a processing bottleneck in the response-selection mechanism, but when the tasks are simple enough, the tasks only interfere for a very brief period, not enough to cause any significant difference in performance. Simple balance and reaction time tasks appear to be easy enough to avoid any significant dual task interference. Muller et al.'s results suggest that, when maintaining balance is relatively simple, few cognitive resources are dedicated to maintaining balance, but once something makes balance more difficult (perturbations, increased sway, irregular footing, etc.), cognitive resources and attention are suddenly diverted to balance from other tasks. This postural prioritization occurs when the postural stimulus increases demand on selective attention. In effect, other sensory information not related to stability must be inhibited and ignored to focus solely on reacting to some postural stimulus. Decreases in sensory systems related to motion detection will increase the amount of perturbation required to initiate postural prioritization. Among other changes, decreases in sensory inhibition abilities in elderly individuals will affect reaction time and postural response to the perturbations (Mendelson, Redfern, Nebes, & Richard Jennings, 2010). Older subjects showed decreased sensory and motor inhibition abilities, which were correlated with decreases in postural control during conditions with eyes open in the light but not in the dark. The elderly subjects also performed more poorly on tasks involving switching attention between sensory channels with more resources required for the switch and a greater cognitive cost associated with the switch. Frailty also increases the difficulties in inhibition and raises the costs for switching sensory channels, increasing the risk of falling in the frail elderly (Kang et al., 2009). Changes in sensory inhibition appear to be exaggerated in patients with vestibular disorders, although there is some evidence that patients can reduce these deficits through training and therapy (Mohammad, Whitney, Sparto, Jennings, & Furman, 2010).

Inhibitory processes appear to be important for processing multiple streams of sensory data, especially for the elderly. Some of the changes in sensory channel switching may be related to changes in inhibition abilities in older adults. Mendelson et al. (2010) correlated decreased motor and sensory inhibition with increased postural sway in older adults, also suggesting that the cost of sensory channel switching is much greater in older adults than in younger adults for balance tasks. Selective attention is especially important for maintaining balance while standing or walking as our sensory systems are constantly bombarded with stimuli. Increases in cognitive resources required for maintaining balance and inhibiting irrelevant information makes the cost of distraction much higher for older adults, as devoting needed resources away from posture or gait to another task can lead to instability or falls.

Changes in executive function and working memory have been connected to fall risk (Liu-Ambrose, Ahamed, Graf, Feldman, & Robinovitch, 2008), suggesting that decreases in perceptual judgment and decision-making skills along with memory of one's limits of stability may contribute to the risk of fall related injuries. By not being able to effectively tap into one's experiences during postural control tasks, those with these cognitive decreases cannot accurately estimate the limits of stability while standing, putting themselves in risky postural situations more often. Functional imaging studies also show decreased activation of areas associated with response inhibition and selective attention in subjects who show greater risk of falling (Nagamatsu, Hsu, Handy, & Liu-Ambrose, 2011). These results have led some to suggest that therapies targeting cognitive function may be of benefit to those at risk of falling (Segev-Jacubovski et al., 2011), although cognitive function only accounts for a small amount of variance in fall risk (Liu-Ambrose et al., 2010). Decreases in executive function and working memory often occur with other cognitive changes, so isolating the effects of an individual mental process on balance is difficult.

There remains a question of how effective targeting cognitive function can be to reduce fall risk, as cognitive factors only account for a small amount of variance. Targeting cognitive function alone for therapy is likely not the most effective use of therapy for patients with balance problems. Indeed, Mohammad et al. did not include cognitive therapy in their intervention and showed improvement in sensory inhibition and sensory stream switching, suggesting that therapy targeting falls risk has some cognitive benefits, even if cognitive function is not specifically targeted.

1.2.2 Changes in attention and attentional demand

Using dual-task paradigms, evidence shows that the proportion of cognitive resources used for maintaining balance increases with age, leaving fewer resources available to perform other tasks. This, along with lack of sensory inhibition, may contribute to the difficulties in sensory channel switching seen with age and may be responsible for some of the maladaptive strategies for maintaining balance seen in older subjects. Because of both decreases in available resources and difficulties in attentional channel switching, older subjects may adopt a form of hypervigilance towards their balance, directing as many resources as possible toward remaining steady and balanced. Changes in attention towards balance will change postural responses with greater attention showing less sway and more regularity during upright stance. When distracted by a secondary stimulus, sway irregularity increases, although the source of focus (internal versus external) also has an effect, with internal focus of attention being less effective in maintaining postural regularity (Donker, Roerdink, Greven, & Beek, 2007). When presented with multiple sensory inputs, older adults adopt more stringent sensory selection than younger subjects, increasing their reaction time to visual or auditory stimulus while performing a balance task (Redfern, Muller, Jennings, & Furman, 2002). Not only do older adults have limited attentional resources to devote to sensory inputs, they appear to prioritize these resources into maintaining balance above any sort of secondary task, such as the simple reaction time tasks used above. Using more demanding non-balance tasks, however, appear to force attention away from balance, and performance on postural tasks decreases, as shown by Shumway-Cook and Woollacott (2000). They showed that older adults had a small decrement in postural tasks while performing an auditory choice reaction time task, but their performance decreased more when they were performing a multisensory task, and performance decreased even more dramatically when somatosensation and vision were removed as cues for balance. No changes were seen in younger subjects. This suggests that attentional resources are prioritized for balance, but when expected cues are cut out, older adults are much worse at effectively compensating for a lack of expected sensory information than younger adults. Older adults may rely more on an internal focus for maintaining balance. Decreases in sensation may eliminate the usefulness of external focus (such as visual or vestibular cues), so older adults must rely more on an internal focus, which is inherently less effective for maintaining posture.

More dramatic changes can be seen in dual tasking procedures performed during ambulation. Ojha, Kern, Lin, and Winstein (2009) and Lajoie, Teasdale, Bard, and Fleury (1996) showed that performance on both gait and the secondary task (simple reaction time) decreased in older adults during dual tasking while walking on a flat surface, and even more dramatically during stair ambulation. Stride length and gait speed were both shorter for older adults and both decreased with the addition of a dual task. Differences in attention between younger and older adults are seen during obstacle crossing, with younger adults devoting more attention during precrossing, while older adults use more attentional resources throughout the entire crossing process (Brown, McKenzie, & Doan, 2005). General fatigue does not appear to change attentional demands. In a dual task paradigm, reaction time did not increase in older or younger subjects after tiring, although sway did increase (Bisson, McEwen, Lajoie, & Bilodeau, 2011). With the addition of a vestibular pathology to the normal aging processes, even more attention is required for postural tasks. In subjects with compensated unilateral vestibular lesions, dual tasking decrements were greater than age matched controls (Talkowski et al., 2005).

1.2.3 Conclusion

Cognitive resources decrease during the normal aging process, but so does the ability to effectively use remaining resources. Changes in sensory switching and attentional resources in older adults result in decreases in postural control and the ability to multitask during a postural task. Older adults require a greater proportion of cognitive resources to devote to balance, which stands in opposition to the classical belief that postural and balance reflexes occur primarily at the level of the brainstem and cerebellum. Dual tasking has shown that there is a great amount of cognitive influence on balance and vestibular reflexes like the VOR. Classical models of the VOR and other vestibular reflexes place the pathways subcortically, with little to no influence from higher brain regions, but this research contradicts these models. Current models involving cortical influence on vestibular reflexes suggest that cognitive influences can be used to alter vestibular reflexes, especially in cases of pathology or other abnormalities in the vestibular system. These models, along with changes seen in the vestibular reflexes with age, suggest pathways for intervention including the use of cognitive or other therapy modalities to elicit more useful adaptations for losses in systems involved in balance. Techniques to divert cognitive resources to balance and posture when needed may be warranted for older adults at risk of falling as a part of therapy. Even though cognitive therapy by itself may not reduce the risk of falls, including the basic principles during falls risk reduction intervention may increase the intervention’s effectiveness. There is already some evidence for this, as Booth, Hood, and Kearney (2016) performed a meta-analysis showing that adding a cognitive training aspect to an exercise program designed to reduce falls (addressing motor control and cognitive balance function) decreased falls risk more than in controls who received therapy only addressing motor control.

1.3 BALANCE REFLEXES AND AGE-RELATED CHANGES

Previously explored changes in sensory, motor, and cognitive performance with balance and stability necessitate some level of adaptation to maintain stability as the systems do not function ideally. Certain patterns of adaptation tend to be seen across patients, although many of them can be considered maladaptive as they may increase the risk of falling and decrease stability. The increase in reaction time associated with decreased sensory sensitivity and decreased muscular strength means that an older person who is unstable will have less time to correct for the instability, less speed and strength to correct with, and consequently may not be able to react effectively in time to prevent injury from an ensuing fall. DeGoede, Ashton-Miller, and Schultz (2003) investigated the differences in strategies between elderly fallers with and without fall-related injuries. They showed that the arresting method utilized by the faller can be changed to decrease impact forces, the major cause of injury during falling. Mobility skills such as static balance, walking, and stair descent performance appear to be an important predictor of fall-related injuries and can be addressed through therapy (Woolley, Czaja, & Drury, 1997). Any compensation strategy must address the relative strength and contributions of the sensory systems involved in postural control. Due to changes in one or more systems involved in balance, therapeutic goals should be set to utilize the most sensitive and fastest systems that remain intact. In older adults, the sensory systems may have some level of degradation, so some combination of compensatory strategies need to be utilized. Pathology of any of the systems will necessarily increase the demand on the intact systems to compensate for any missing information. Compensatory strategies, whether self-correcting or learned through intervention, must address these issues to be effective in arresting or lessening the impact of a fall.

1.3.1 Reaction time and postural perturbations

Reaction time to postural perturbations is an important predictor of falls in the elderly population. Nolan et al. (2010) showed that reaction time to postural perturbations decreases significantly by the seventh decade of life. EMG recordings show increased latency of response to an unpredictable passive fall, showing that increases in reaction time appear to be at the level of activation of postural control muscles (Bisdorff et al., 1999). Reaction times increase continuously across life, changing from 0.5 to 1.6 ms/year depending on the choice paradigm (Fozard, Vercryssen, Reynolds, Hancock, & Quilter, 1994; Lajoie et al., 1996). Dykiert, Der, Starr, and Deary (2012) performed a meta-analysis on reaction time, showing speed differences between young, middle age, and older subjects, with speed decreasing with age and greater variability in the older subjects. Some of these changes may be attributed to the decreased ability of skeletal muscles to quickly generate changes in tension. The change is also a direct function of task difficulty, suggesting that greater mediation of the task in the CNS additionally affects the reaction time. Lewis and Brown showed slower muscle activation in addition to increased reaction time in elderly subjects, although this result cannot on its own show whether the slowing is coming centrally, peripherally, or some combination of the two. Dykiert et al. and Bisdorff et al. suggest an interaction effect. Errors also increase with age even as reaction time increases, possibly due to increased relative demand of central resources with age. With postural perturbations, not only does reaction time increase with age, but the type of reaction also changes. Tucker, Kavanagh, Barrett, and Morrison (2008) showed that elderly men are much more rigid in their movement strategies for dealing with postural perturbation in both static and dynamic paradigms as compared to the more fluid, flexible reactions of younger men. Rigidity can be defined as inflexibility in movements, resulting in less smooth or jerky movements. In the case of posture, postural rigidity will result in sudden, jerky corrections during a postural perturbation. A more rigid strategy decreases the degrees of freedom for postural compensation, decreasing the resources available for compensation which are necessary for falls that can happen in any direction. These changes and maladaptations have been shown in a number of other postural reaction strategies during both gait and standing posture (Cao, Ashton-Miller, Schultz, & Alexander, 1997; Patla et al., 1993). Cao et al. showed that even with increased time allowed for the reaction, older adults were not able to perform a sudden turn during gait as successfully as younger subjects. This suggests that motor control and postural control changes that occur in elderly adults are not only a result of slowing of muscular activation, as changes occurring only from slowed or weaker muscle activation would affect only the rate or strength of the correction as opposed to what is seen, which is a fundamental change in ability and accuracy.

As discussed above, Era, Jokela, and Heikkinen (1986) showed that motor reaction time decreases independently of motor speed, suggesting that changes in reaction time are not directly due to musculoskeletal changes but also involve changes in central level processing of motor commands. In their analysis, cognitive performance was one of the most important covariates of motor speed within the age groups (young, middle age, and elderly), with differences seen at all levels of complexity. Vibration sensitivity also correlated strongly with motor performance, suggesting a link between sensory function and motor abilities. What may mediate this connection was not discussed. Narici and Maganaris (2006) suggest that changes in motor reaction time are not just due to changes in the musculoskeletal system but involve slowing of neurological processing for motor control. Training can help to reduce the anatomical effects of senile scarponia (muscle loss associated with aging), but reductions in muscle performance appear to be unaffected, suggesting an existing strategy to limit muscular activity. Welford (1984) suggests that joint stiffness (defined as reduction in motion and/or range of motion of a joint) increases reaction time, which may at least partially account for Tucker et al.'s finding of more rigid postural control in the elderly, but also points to preference differences for increases in reaction time, such as caution and an increased desire to be correct. Even with these preferences, error rates still increase with age (Lajoie et al., 1996). These results suggest that changes in reaction time cannot solely be due to changes in sensory, motor, or nervous systems, but as a combination of degeneration and weakness in all three, causing a change that is greater than the sum of its parts.

1.3.2 Compensation for decreases in sensation and strength

Changes are seen in not just reaction time for postural perturbations in elderly adults, but also in compensation strategies used for fall prevention and stability maintenance. The older adult adopts a much stiffer and rigid upper body, while younger people stabilize their upper bodies independently of their lower bodies which provides more stability and adaptability for dealing with the perturbation (G. Wu, 1998). Decreases in ankle strength and proprioception also can cause older adults to adopt a hip-dominant strategy to remain stable, as opposed to an ankle strategy used by younger people (Berger, Chuzel, Buisson, & Rougier, 2005a). Ankle strength for both dorsi- and plantarflexion are critical for compensating for sway, especially if adopting a rigid strategy for posture maintenance, but ankle weakness is seen at a significantly greater rate in older fallers than non-fallers (LaRoche, Cremin, Greenleaf, & Croce, 2010). In addition to reduction in ankle strength and flexibility, Mickle, Munro, Lord, Menz, and Steele (2009) and Menz, Morris, and Lord (2006) saw decreases in toe plantar flexor strength in older adults, especially those with hallux valgus deformities, which was linked to a greater probability of suffering a fall. Larger muscles and greater neuromuscular energy are utilized when using a hip-dominant strategy to compensate for decreases in sensitivity and strength elsewhere. This also can be a consequence of increased detection and reaction time as greater strength and energy are required to compensate when the corrective action is taken further into the perturbation. Older people who are at greater risk for falls demonstrate increased sway during unperturbed upright stance with greater neuromuscular activation during corrective movements than non-fallers (Berger, Chuzel, Buisson, & Rougier, 2005b). Previously discussed studies also see increased muscular activation and increased joint stiffness in older adults who are at greater risk for falls.

Neuromuscular activation appears to be fundamentally different between age ranges. Benjuya, Melzer, and Kaplanski (2004) showed that older adults adopt a strategy of contracting muscles around the ankle during sway and postural perturbations, unlike young adults, who use a more flexible control strategy during sway. Increased sway shows a loading-unloading strategy for postural control, which increases both the amplitude and frequency of the sway during upright stance. Increasing muscular activity to compensate for sway and postural instability is seen during gait, even during demanding walking tasks in people at risk for falling (Fraser, Li, DeMont, & Penhune, 2007). The increase in muscular activity is evidence that poor balancers can successfully compensate for distraction and increase their balance abilities, but no statement is made as to whether the increase in muscular activity is a beneficial adaptation which results in increased balance ability. Even if it is shown that generalized increase of muscular activity during normal postural activity helps to increase stability in those with balance disorders, the increase in muscular activity also limits the amount of resources available to correct for a perturbation and decreases the degrees of freedom for arresting a fall.

Decreased sensitivity in the vestibular system can account for some of the changes seen in postural strategies used by older adults. This can be seen in the relative contributions of vision, somatosensation, and vestibular sensation for postural control. Older adults appear to rely mostly on visual information to remain stable. Altering or eliminating visual inputs can produce a great amount of instability. While vision does change with age, except in the case of pathology, it remains relatively intact, especially compared to changes in the vestibular or somatosensory systems. Peripheral vision appears to be especially important for stability, as instability occurred when peripheral vision was occluded and only foveal vision remained (Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989). When older adults must rely solely on vestibular input, they tend to be the most unstable. Compensatory strategies for loss of vestibular input can allow a person with total bilateral vestibular weakness to appear and behave normally in most situations. Upon further testing, the elimination of visual and proprioceptive inputs will cause instability as vision and proprioception are used to establish a perception of verticality (Baloh et al., 2001). In normal adults, the vestibular system (specifically the otolith organs) is used to detect gravity and establish verticality, but in patients with vestibular weakness, other cues are needed to establish vertical. With the elimination of a reference for vertical, most perturbations will cause instability, as shown by Macpherson, Everaert, Stapley, and Ting (2007). Abnormal perceptions of visual and postural verticality can be seen in patients with vestibular pathology, forcing them to rely on other cues to remain stable (Bisdorff, Wolsley, Anastasopoulos, Bronstein, & Gresty, 1996).

Patients with vestibular weakness appear to use the sternocleidomastoid (SCM) stretch reflex in combination with vision in order to keep their head upright and stable, although the latency for activation is greater for subjects with vestibular pathology or weakness than in subjects with normal vestibular systems (Kanaya, Gresty, Bronstein, Buckwell, & Day, 1995). The stretch reflex can compensate for vestibular weakness, but cannot totally replace vestibular input, as the stretch reflex determines head position relative to the body, not the environment. In the case of vestibular weakness, a combination of the stretch reflex, proprioception, and vision is required to maintain vertical.

1.4 CONCLUSION

Changes in vestibular reflexes and balance cannot be attributed solely to decreases in one singular system. Age related decreases in peripheral sensory receptors, musculature, or changes in the nervous system (peripheral or central) all contribute to increased latency of reaction to posture perturbation, longer response times, and the increased risk of falls. Measurable decreases in cognition in older adults have been directly linked to changes in strategies related to arresting falls, suggesting that there is cortical control over balance reflexes, which is in opposition to the classical model of vestibular reflexes. Some investigators believe that rehabilitation strategies targeting cognitive interventions can help older people who are at a higher fall risk, although the evidence for this is lacking.

These changes affect how older people react to postural perturbations. Adaptations in the responses to falls come about through various levels of compensation for sensory or muscular weakness. Most of these adaptations come about through redundancies in the balance system, utilizing the multisensory processes involved in postural control. Such adaptations, such as utilizing the stretch reflexes in the cervical muscles to detect head movement, can supplement decreased sensation in other sensory systems, although these adaptations cannot fully compensate for sensory losses. These result in functional changes in the fall response. The combination of increased latency of fall detection and slower motor response leads to the need for intervention aimed at earlier fall detection, or faster motor response.

Many of the noted changes in balance systems in older adults occur as a part of the normal aging process. No specific pathology is needed to see these decrements in the systems. Most of these changes occur concurrently, so older adults are being exposed to many changes to their overall balance system at once. In addition to the changes in the primary balance senses, other anatomical and physiological changes occur which, while not directly affecting the primary balance systems, can lead to decreased postural control and an increased risk of falls. Each individual factor can increase falls risk, but the combination of changes can lead to serious risk.

2.0 RISK FACTORS FOR FALLS IN OLDER ADULTS

Any age-related change in the balance systems can lead to an increased risk of falls in older adults, but there also exists other factors and conditions outside of the primary balance systems that can increase falls risk. Falls risk assessment relies on two different approaches for assessment in older adults. One approach is to assess body structures related to risk factors for falls. The presence of impairments results in increased risk for falls when compared to otherwise healthy older adults. The second approach is to look at function, assessing the patient's performance on one or more balance tasks, such as navigating an obstacle course or sitting and standing. Functional testing is used as predictive measures of falls, providing either a yes/no result for risk of future falls, or a percentage risk for falls. Impairment is linked to increased odds of falling, which is generally quantified using odds ratios or relative risk. Functional testing is normally evaluated based on its predictive abilities for a future fall. Both approaches have their benefits and shortcomings, but combining the two can help to overcome some, but not all, shortcomings.

2.1 CLINICAL GUIDELINES FOR FALLS RISK ASSESSMENT

To evaluate the risk of falls in older adults, a comprehensive falls risk assessment protocol is needed to assess various risk factors. Table 4 lists several Clinical Practice Guidelines (CPG) developed by various stakeholder organizations. The CPGs are designed to review the evidence for falls risk assessment in community-dwelling older adults and provide guidelines for assessment and intervention. Only the assessment piece of each guideline was evaluated for the purpose of this review.

Table 4. List of clinical practice guidelines (CPG) for fall risk assessment and fall prevention for community dwelling older adults. CPGs focusing on older adults in a health care facility (such as hospital or nursing care) were not included. CPGs will be referred to by the corresponding acronyms.

Guideline	Source
American Physical Therapy Association (APTA)	Avin et al. (2015)
French Society of Geriatrics and Gerontology (FSGG)	Beauchet et al. (2011)
American Geriatrics Society and British Geriatrics Society (AGS-BGS)	Kenny et al. (2010)
National Institute for Health Care Excellence (NICE) (UK)	Longson et al. (2013)
Health Promotion Board (Singapore) (HPB)	Shyamala et al. (2015)
American Academy of Neurology (AAN)	Thurman, Stevens, and Rao (2008)
Royal London Medical School (RLMS)	Feder, Cryer, Donovan, and Carter (2000)

2.1.1 Clinical practice guideline scope

Each CPG varies in scope. For example, the AAN focuses mainly on neurological examination, while the AGS-BGS and FSGG include multiple systems and domains in their recommendations. In general, the CPGs address factors that increase the odds of falling. The domains addressed by each CPG are presented in Table 5. CPGs also vary by specificity of evaluation recommendations.

The range spans from a review and combination of multiple CPGs (APTA), specific evaluation recommendations (FSGG, AGS-BGS), to recommendations that a falls risk assessment should be considered without including any specific recommendations for what should be assessed (RLMS).

2.1.1.1 Screening recommendations Differences in screening recommendations would drastically change the number of patients recommended to undergo a full falls risk evaluation. The AAN's screening recommendations include any number of conditions related directly or indirectly to balance function as well as screening all patients over the age of 65. Four of the CPGs (APTA, FSGG, AGS-BGS, NICE) use previous falls as criteria for falls risk assessment. The FSGG uses this exclusively, while the other three CPGs include gait or balance problems in their recommendations. Most of the CPGs include specific tests in their screening recommendations, relying instead on either patient report or previous diagnosis of gait or balance disorder. The FSGG recommends the Timed Up and Go (TUG), but that is the only specific test recommended.

2.1.1.2 Domains evaluated In addition to the areas previously explored (vestibular, vision, somatosensation, motor control, and cognitive function), each CPG also recommends additional evaluation of systems not directly involved with but impacting balance and postural function. The lists vary, but generally include neurological symptoms, cardiac symptoms, depression, osteoporosis, and joint mobility/range of motion. There is also emphasis on footwear, environmental factors, and activities of daily living (ADLs). The APTA also includes urinary incontinence as a risk factor. Psychological conditions, such as depression, are also recommended to be screened for by the AGS/BGS CPG, although no course of action is recommended.

2.1.2 Shortcomings of CPGs

Most CPGs related to preventing falls in community-dwelling older adults include recommendations for screening and evaluation for falls risk. These recommendations range from specific tests to vague recommendations that testing should be performed. Most CPGs recommend full evaluation for any patients who report an injurious fall or multiple falls, but the FSGG's screening recommendations stop there. Most of the other CPGs also add obvious gait or balance issues as a prerequisite for a full falls risk evaluation. The AAN includes other conditions, such as stroke or peripheral neuropathy, to its inclusion list for full evaluation, but it also recommends that any patient over the age of 65 receive a full evaluation for falls risk. The CPGs recommend testing either only those with obvious balance or gait dysfunction or every adult over the age of 65. There does not appear to be a middle ground in the CPGs. Many patients without obvious dysfunction will be missed when using the more conservative guidelines, such as the FSGG; many more than necessary will be tested when using the more liberal guidelines, such as the AAN. While the purpose of a screening is not to comprehensively determine fall risk, additional factors should be utilized to capture more older adults at risk while not burdening the testers with many unnecessary evaluations.

The CPGs lack specificity in evaluation recommendations, which is typical for guidelines. Many domains are recommended for evaluation, but few tests are recommended by name. The clinician is required to create a protocol of tests to address the areas described in the guidelines. While CPGs generally do not spell out specific protocols for testing, more guidance into the depth of the testing in each domain would be warranted to increase the strength of the recommendations. For example, the APTA recommends evaluation of neurological, cognitive, and cardiac function. There are no recommendations for the scope of any of these evaluations. Should screening instruments be used with the intent of referring for a full evaluation should it be warranted, or should a full evaluation be performed from the start? What areas of each system should be tested? This lack of clarity on the depth of evaluations decreases the usefulness of the CPGs by making the development of a falls risk protocol more difficult for clinicians and less uniform across clinics. The FSGG recommends the Mini Mental State Examination (MMSE) for screening of cognitive function, but most other CPGs do not include anything specific. The FSGG also does not provide any guidance for cognitive assessment beyond this recommendation. The CPGs do not provide a threshold for inclusion of any of the risk factors. The presence of metabolic disorders or osteoporosis are considered risk factors, but no statement beyond this is included. There are no allowances for controlled versus uncontrolled conditions or mild versus severe symptoms. The mere presence of a disorder may be enough for one clinician to consider it a risk factor, while another may not consider a mild or controlled condition to be enough to warrant intervention.

The CPGs recommend a test model that is heavily weighted towards an impairment-based model of falls in older adults. The logic is that the presence of certain impairments increases the likelihood of falls (risk factors that are covered by multiple CPGs are listed in Table 6), and the more impairments present, the greater the risk. Increased odds of falling with a particular impairment generally are reported using odds ratio or relative risk statistics. While logical, very few studies look at more than one risk factor at a time, so the quantitative cumulative effect of multiple risk factors cannot be factored into the CPGs.

Table 5. Summary of CPG assessment recommendations and risk factors.

Guideline	Screening Recommendations	Domains evaluated	Specific Tests Recommended	Notes
APTA	Report of multiple falls, or report of one fall and observed balance or gait impairment	Meds review, med hx, osteoporosis, depression, cardiac disease, strength, balance, gait, activities of daily living, footwear, environmental hazards, cognition, neurological function, cardiac function, vision, urinary incontinence	None	
FSGG	2 or more falls in last year	Age >80, female gender, traumatic fractures, med review (including polypharmacy, psychoactive drugs, cardiovascular drugs, and anticholinergic drugs), gait/balance disorders, impaired strength of lower limbs, BMI <21, osteoarthritis of lower limbs/spine, foot anomalies, loss of sensation in lower limbs, visual acuity, depressive symptoms, cognitive declines, cardiac symptoms, neurological symptoms, vestibular symptoms, metabolic disorders, environmental factors	Timed Up and Go >20s, one leg stand <5s, MMSE, Codex, mini-Geriatric Depression Scale, Romberg	
AGS-BGS	2 or more falls in last year, presents with acute fall, or difficulty with gait or balance	Gait and balance, med hx, cognitive dysfunction, hx of falls, visual acuity, neurological impairments, muscle strength, heart rate and rhythm, postural hypotension, feet and footwear, environmental hazards	None	Includes flowchart for assessment
NICE	Report of recurrent falls, seeking medical attention due to fall, or demonstrate gait/balance abnormalities	Cognitive impairment, continence problems, falls hx, footwear, health problems, meds, postural instability, mobility problems, balance problems, syncope syndrome, visual impairment, osteoporosis, muscle weakness, neurology, cardiovascular	None	Include research questions
HPB	All older adults asked about falls, gait and balance problems	None specified	None	
AAN	Hx of falls, or stroke, dementia, gait or mobility problems, Parkinsonism, peripheral neuropathy, use of assistive device, or other condition w/ lower extremity sensorineural loss; age >65, vision deficit, arthritis, arthralgia, depression, polypharmacy, restricted activities of daily living	Neurological exam emphasizing balance and gait, lower extremity strength, sensation, and coordination, and cognitive status. May use standardized assessment	For screening: Timed Up and Go (low specificity) or Get up and go, Tinetti	
RLMS	None	None specified	None	

2.2 RISK FACTORS

Table 6. Risk factors for falls. Included are risk factors identified by at least 2 CPGs (table 5) and at least one reference with relative risk or odds ratio for falls when compared to older adults without the listed condition. MMSE – Mini Mental State Examination. OR – odds ratio. RR – risk ratio (denoted by *)

Risk Factor	Disorder or Test Used	OR/RR	Reference
Vestibular Function	Unilateral	5.17	Agrawal et al. 2013
	Bilateral	10.2	Ward et al. 2013
	Otolith	*1.55	Menant et al. 2012
Somatosensation	Lower Extremity Pain - 1 to 2 sites	3.61	Volpato et al., 2006
	Lower Extremity Pain - 3 to 4 sites	5.58	
Vision	Acuity	2.02	Agrawal et al. 2013
	Strabismus	1.28	
	Esotropia	1.3	
	Exotropia	1.27	
	Amblyopia	1.12	
	Diplopia	1.36	
	Disorders of binocular vision	1.27	
	Nystagmus	1.32	
Musculoskeletal function	Grip Strength	1.02	Agrawal et al. 2013
	Lower Limb Weakness	1.75	Speechley et al. 2005
	Gait disturbances	*1.01-1.41	Verghese et al. 2009
Cognitive Function	MMSE Total score (<24)	1.64	Ramirez et al. 2010
	Orientation to place	2.01	
	Attention and calculation	1.77	
	Visual Construction	1.9	
Osteoporosis	Thoracic Kyphosis	1.2	Arnold et al. 2005
	Lower Limb Arthritis	*1.22	Sturnieks et al. 2004
Cardiovascular Function	Orthostatic Hypotension	1.71	Heitterachi et al. 2002
		2.54	van der Velde et al. 2007
Urinary Incontinence	Frail older women	4.9	Lee et al. 2011
Previous Falls		3.85	Sai et al. 2010
Medications	> 4	1.2	Kron et al. 2003
	Antipsychotic	1.8	
	Antianxiety	1.2	
	Antidepressant	1.3	
	Hypnotic	1.1	

2.2.1 Vestibular function

As discussed previously, vestibular function decreases significantly in older adults, changing the ability to detect movement and react to falls. The presence of a unilateral vestibular weakness increases fall risk in older adults (OR = 5.17) (Agrawal, Davalos-Bichara, Zuniga, & Carey, 2013). A bilateral vestibular weakness increases fall risk by an even greater factor (OR = 10.2) (Ward, Agrawal, Hoffman, Carey, & Della Santina, 2013). The presence of a vestibular weakness, whether unilateral or bilateral, increases the risk of falls in older adults more than most other factors. This is most likely because the vestibular system's ability to detect motion is more sensitive than any other body system, so any deficit in vestibular function will drastically reduce the ability to perceive motion or changes in body position. In young adults, the vestibular system is the primary sense for balance control, using other sensations (vision and somatosensation) for support. As the vestibular system decreases in function with age, vision and somatosensation must move from support to primary balance function, where they are not as capable as the vestibular system for this role. When vestibular function is decreased drastically, such as in the presence of a unilateral or bilateral weakness, vision and somatosensation are forced to compensate beyond their normal contributions to postural control. In the case of bilateral vestibular loss, the brain receives no information about head position from the vestibular system and is entirely dependent on vision, somatosensation, and the SCM neck reflex for balance.

The vestibular system is also key for perception of verticality. The otolith organs are sensitive to gravity and can detect its effects on the inner ear. Deficits on tests of perception of verticality suggest dysfunction of the otolith organs in one or both ears and will lead to an increased risk of falls, with patients who showed increased variability and difficulty with determining verticality significantly more likely to report a fall (Menant, St George, Fitzpatrick, & Lord, 2012).

2.2.2 Vision

Various visual impairments have been linked to risk of falls. As the vestibular system changes with age, older adults become dependent on vision to maintain balance. This connection is often made by patients, who may blame visual impairment on falls or other balance-related issues (Boon et al., 2015). Self-assessment of visual function and acuity is a predictive factor in falls (Nunes et al., 2014). Patients with visual impairment may be more aware of their problems than patients with vestibular weakens which may lead to an increased fear of falls with a perceived visual impairment, regardless of its etiology or severity. Results show that severe visual impairment is independently related to fall risk, even when the impairment is limited to one eye (Lamoureux et al., 2008). In the same population, however, type of vision loss (visual acuity, depth perception, visual field), duration of vision loss, or etiology were not independently correlated with fall risk (Lamoureux et al., 2010). While these results may appear to be somewhat contradictory, they may be explained by expecting any type of change in the visual system to cause an increase in fall risk. By altering normal visual function, changes in any of the visual domains will lead to increased fall risk.

Various visual skills are critical for maintaining balance in older adults, but not all are routinely measured during routine optometric examinations. Patients who have changes in various visual skills appear to be at greater risk of falls, especially when other sensory information is altered or absent. Lord, Clark, and Webster (1991b) showed that decreased visual acuity and contrast sensitivity lead to increased body sway when standing on a compliant surface when compared to control subjects but not when standing on a solid surface. Subjects with reduced contrast sensitivity also reported more falls than subjects with normal contrast sensitivity, which was linked to increased risk of falls in patients with bilateral cataracts (To et al., 2014); this appears to improve post-surgery (Harwood et al., 2005; Meuleners, Fraser, Ng, & Morlet, 2014), although there is a slightly increased risk of falls up to 6 months post-surgery, possibly related to surgical recovery and the adaptation required for the VOR. Focal area of vision loss, defined as central- or peripheral vision loss (CVL and PVL), do have differential effects on fall risk, as 9 percent of subjects with CVL had a previous fall, whereas 49 percent of subjects with PVL reported at least one previous fall (Patino et al., 2010). The difference seen between CVL and PVL may be related to the ability to use peripheral vision to detect obstacles on the ground which may be a tripping hazard.

The use of multifocal lenses has been linked to falls risk, although the evidence for this is mixed. Lord, Dayhew, and Howland (2002) showed a decrease in edge-contrast sensitivity and depth perception in older adults wearing multifocal lenses which led to an increased risk of falls. Multifocal lenses also lead to greater variability on toe clearance for obstacle avoidance (Johnson, Buckley, Scally, & Elliott, 2007) and increased obstacle contact during clearing while performing a secondary task (Menant, St George, Sandery, Fitzpatrick, & Lord, 2009). Switching older adults to single focus lenses while walking appears to improve their ability to negotiate obstacles (Haran et al., 2010; Johnson, Buckley, Harley, & Elliott, 2008). Other work has shown that older adults are able to adapt to multifocal lenses and may actually be at more risk of falls with frequent changes in their glasses (Ellison, Campbell, Robertson, & Sanderson, 2014). Older adults may not be compliant about changing glasses depending on task, so intermediate addition bifocals may help to improve falls risk without putting the burden of changing glasses on the patient (Elliott, Hotchkiss, Scally, Foster, & Buckley, 2016). Given the mixed results. more investigations are needed to determine the effects of bi- and multifocal lenses on falls risk in older adults.

2.2.3 Lower limb musculoskeletal function and somatosensation

Changes in lower limb musculoskeletal function decrease stability during standing and gait and increase the likelihood of falls in older adults. Any anatomical or functional alterations of joints and muscles decreases strength and flexibility, which decreases reaction speed to postural perturbations. Increased risk of falls has been observed in patients with general lower extremity weakness or any lower extremity disability (Speechley et al., 2005). Reduced knee extension strength in patients with osteoarthritis is a significant predictor of falls (Levinger et al., 2011; Sturnieks et al., 2004), especially immediately pre- and post-knee replacement. Reduced quadriceps strength is also seen in many older adults, especially those who have suffered from a hip fracture, and is a major risk factor for falls in this population (Lord, Lloyd, & Li, 1996; Sherrington & Lord, 1998), although the total number of risk factors was greater in patients with hip fractures (Lloyd et al., 2009). The presence of foot or ankle deformities or weakness have been shown to increase fall risk by Menz et al. (2006) and Awale et al. (2017), with decreased ankle flexibility, more severe hallux valgus deformity, and decreased toe plantar flexor strength independently linked to falls.

Impaired somatosensation, especially related to diabetic peripheral neuropathy, changes gait and postural stability. Patients with diabetic neuropathy showed increased sway, reduced gait speed, and increased step variability when compared to controls, and increased severity of neuropathy was correlated with increases in problems with gait and postural stability (Agrawal, Carey, Della Santina, Schubert, & Minor, 2010; Menz, Lord, St George, & Fitzpatrick, 2004). Plantar tactile sensitivity is linked to fall risk, with patients showing decreased sensitivity having more falls (Menz et al., 2006). Changes in gait and fall risk in patients with decreased sensitivity or proprioception may be due to decreased knowledge of surfaces underfoot and body position in space. Increased foot pain also has been linked to fall risk (Menz et al., 2006), possibly for the same reason, as pain signals may block somatosensory information from reaching cortical centers. Lower limb proprioception deficits have been independently linked to fall risk (Levinger et al., 2011). When combined with neurological changes with age, these changes in musculoskeletal and sensory function can lead to gait disturbances (Pirker & Katzenschlager, 2017). Changes in various gait parameters, including decreased gait speed, swing, double-support phase, swing time variability, and stride length variability have been linked to an increased risk of falling (Espy, Yang, Bhatt, & Pai, 2010; Verghese, Holtzer, Lipton, & Wang, 2009).

2.2.4 Cognitive function

In the absence of a neurological lesion, age-related changes in cognition lead to an increased risk of falls. Intact memory, executive function, and other cognitive functions have previously been explored as critical for postural stability, and any reduction in cognitive resources or abilities decreases stability, especially in the presence of competing stimuli. Even a mild cognitive impairment (MCI) can lead to increased sway (Mignardot, Beauchet, Annweiler, Cornu, & Deschamps, 2014) and has been linked to an increased risk of falls (Tyrovolas, Koyanagi, Lara, Santini, & Haro, 2016). This may be due to overestimation or poor memory of stability limits (Liu-Ambrose et al., 2008). Any decreases in memory appear to be linked to falls risk, with patients with poorer memories showing greater number of falls than their peers with normal memories (Muir, Gopaul, & Montero Odasso, 2012; Speechley et al., 2005). The presence of dementia also alters motor performance during sway and increases fall risk, but few studies have been performed to assess the factors of fall risk in patients with dementia, considering that behavioral characteristics of patients with dementia can lead to falls independent of any physiological risk factor, cognitive or otherwise (Harlein, Dassen, Halfens, & Heinze, 2009).

Decreased performance on tests of cognitive function can predict an increased risk of falls. Decreased performance on Stroop tasks and visuospatial function were related to increased fall risk, as well as decreased postural control and longer reaction time (Martin et al., 2013). The Mini Mental State Examination (MMSE) correlates to fall risk, with decreased scores showing an increase in fall risk, specifically in the visual construction and orientation to place domains (Ramirez et al., 2010). Visuospatial construction, which is the ability to see an object, break it into its constituent parts, and reconstruct it using said parts, may be related to a patient's ability to visually perceive and process the environment and any obstacles during gait. Orientation to place may seem to be unrelated to balance, but the connection may be due to the demands on attention and working memory that both orientation to place and balance put on the cognitive systems. Reduced visual construction would lead to decreased ability to avoid obstacles.

2.2.5 Polypharmacy and medications

Older adults take an average of 15 prescription medications per year (Farrell, Szeto, & Shamji, 2011). Increases in falls risk may be due to single- or multiple medication side effects causing or mimicking other conditions, such as orthostatic hypotension or declines in cognitive function, that are associated with increased fall risk. Psychotropic and cardiovascular drugs appear to have the greatest effect, with antidepressants, anxiolytics, hypnotics and sedatives, antiarrhythmics and drugs from the PRISCUS (Latin for "old and vulnerable") list (medications inappropriate for use in the elderly) showing the most increase in risk of falls and injury (Bauer et al., 2012; Chatterjee, Chen, Johnson, & Aparasu, 2012). Benzodiazepines and anticholinergic agents also have been implicated in increased falls risk (Berdot et al., 2009). Risk of falls increase when changes to medications are made for both psychotropic and cardiovascular medications (Payne, Abel, Simpson, & Maxwell, 2013). When measured using the Drug Burden Index (DBI) [a measure of the cumulative effects of anticholinergic and sedative agents (Kouladjian, Gnjidic, Chen, Mangoni, & Hilmer, 2014)], falls risk increases with DBI. Increasing number of medications is positively correlated with fall risk (Freeland et al., 2012; Kron, Loy, Sturm, Nikolaus, & Becker, 2003).

2.2.6 Cardiovascular function

Any cardiovascular problem that results in decreased oxygenated blood flow to the brain can lead to lightheadedness, dizziness, and loss of consciousness, ultimately leading to a fall. Orthostatic hypotension, which is a decrease in blood pressure when rising to an upright position, has been shown to predict falls in older adults when tested using a tilt table (Heitterachi, Lord, Meyerkort, McCloskey, & Fitzpatrick, 2002); however, previous studies show varied results, possibly due to different methods for testing and varying criteria for the presence of orthostatic hypotension (Caird, Andrews, & Kennedy, 1973; Palmer, 1983; van der Velde, van den Meiracker, Stricker, & van der Cammen, 2007). Heitterachi et al. argue that a single measurement at a set time following standing is too imprecise for proper diagnosis of orthostatic hypotension and that multiple measurements are required. Iatrogenic hypotension increases falls risk in patients taking antihypertensive medications, although the effect appears to be acute. Patients are at an increased risk of falls immediately following initiation of antihypertensive medications (Shimbo et al., 2015). Chronic use of antihypertensive medication in regards to falls risk has shown mixed results, with some studies showing an increased risk (Corrao et al., 2015; Tinetti et al., 2014), and others showing no increase in risk (Marcum et al., 2015; Palmer, 1983).

Similar effects can occur if the ability for blood to carry oxygen is decreased, either due to physiological changes in the blood itself or the diffusing capacity of the lungs. Decreases in red blood cell count, such as occurring in patients with anemia, inhibit oxygenation of blood and can lead to dizziness and imbalance, as shown by Thaler-Kall et al. (2014), showing an increased risk of falls in patients with anemia according to the WHO criteria of a hemoglobin level of less than 12 g/dL in women and 13 g/dL in men when compared to their non-anemic peers. The falls risk also increased when the patients with anemia self-reported a disability due to the anemia. Decreased hematocrit levels has also been associated with risk of falls, especially in residents of nursing homes (Dharmarajan & Norkus, 2004).

2.2.7 Urinary incontinence

Loss of bladder control can lead to a patient needing to use the bathroom more frequently. Multiple trips to the bathroom, especially at night, can increase the risk of falls. Urinary incontinence may be associated with other conditions, such as loss of muscle tone or neurological insult, which can lead to falls as previously discussed. Lee et al. (2011) analyzed data from older individuals with dementia and saw that urinary incontinence was independently associated with risk of falls, independent of severity of dementia or overall physical function. Other risk factors were present, but only urinary incontinence was significant for falls risk in their analysis. Urgency of urination may play a part in the increased risk, as urgency increases falls risk (Moon et al., 2011). Pahwa et al. (2016) showed that falls risk increases with more frequent nocturnal enuresis in women with urinary incontinence. This may be due to frequent rising and walking around in a dark environment, where fallers are not able to use vision to compensate for changes in the vestibular system. Those who traverse more often in these risky nighttime situations are more likely to fall.

2.2.8 Other risk factors

Many other conditions and impairments have been linked to an increased falls risk, either directly or indirectly. Chronic pain (Lazkani et al., 2015), metabolic disorders (Liao et al., 2012), cancer (Spoelstra, Given, von Eye, & Given, 2010), and diabetes (Agrawal et al., 2010; Volpato, Leveille, Blaum, Fried, & Guralnik, 2005) have all been linked to increased falls risk. Almost all associations are products of symptoms of the conditions, such as peripheral neuropathy, diabetic retinopathy, and anemia. The presence of the condition by itself does not appear to increase falls risk. Other conditions change the function and structure of the skeletal system and may directly increase falls risk. A disorder or condition that directly leads to a falls risk may be considered a *primary* risk factor, while a disorder or condition that may result in a primary risk factor may be considered a *secondary* risk factor.

A distinction needs to be made between *risk factors* and *associations* with regard to falls risk. A risk factor, whether primary or secondary, is the presence of a condition or disorder which, due to its direct influence on balance, leads to an increased risk of falls. An association, on the other hand, may be correlated with falls risk, but there does not appear to be a direct causal relationship between the associated factor and falling. For example, hearing loss has been shown to be correlated with falls (Jiam, Li, & Agrawal, 2016); however, no direct causal link between hearing loss and falls has been established. During a difficult listening task, limited cognitive resources may be used for the listening task instead of balance, but Bruce et al. (2017) showed that adults with age-related hearing loss performed similarly on a balance task during a speech in noise test as normal hearing peers. This is likely due to the effects of attention and postural prioritization.

2.3 FUNCTIONAL TESTING OF FALLS RISK

The domains addressed in Table 6 are related to increased risk of falls when compared to other community-dwelling older adults who do not present with deficits in each individual domain, although this is not a comprehensive list of factors that need to be considered. Comprehensive medical evaluation of these domains tests the structure and function of various organs and systems. While useful for intervention purposes, an increased odds ratio is not necessarily predictive of falls. An odds ratio greater than 1 shows that a person with a given condition is at a greater risk for a fall than someone without that condition, but it says nothing about the absolute risk. For example, tests of the vestibular system evaluate the integrity of the vestibular end organs and central vestibular pathways but do not address functional compensation for weakened or altered vestibular responses. These diagnostic evaluations must be separated from functional balance evaluations which are geared specifically to integrated balance function. Functional tests evaluate the integration of body systems involved with postural stability and balance function regardless of the individual organ or organ system function. Many tools used by health care providers seek to test patients in real-world situations, such as standing from a sitting position or during walking. A list of functional balance tests is presented in Table 7.

Table 7. List of functional tests for falls risk assessment. Sensitivity and specificity for prediction of future falls are included. Community dwelling older adults were the subject population in all studies. *Meta-analysis. FRAT – Falls Risk Assessment Tool. Mini-BESTest - Mini Balance Evaluation Systems Test.

Test	**Reference**	**Sensitivity**	**Specificity**
Timed Up and Go	Shumway-Cook, Brauer, and Woollacott (2000)	87	87
	Barry, Galvin, Keogh, Horgan, and Fahey (2014)*	31	74
Berg Balance Scale <45	Muir, Berg, Chesworth, and Speechley (2008)	25	87
<54		61	53
mini-BESTest	Godi et al. (2013)	94	81
Tinetti Assessment	Park (2018)*	68	56
Force plate	Bigelow and Berme (2011)	75	94
5 step test	Murphy, Olsen, Protas, and Overby (2003)	82	82
Dynamic Posturography	Kario et al. (2001)	37	75
FRAT 1 risk factor	Nandy et al. (2004)	59	90
2 risk factors		42	92
3 risk factors		15	97
Functional Reach	Murphy et al. (2003)	73	88
Limits of Stability	Trueblood, Hodson-Chennault, McCubbin, and Youngclarke (2001)		
Reaction Time		43	56
Endpoint excursion		60	55
Maximum excursion		63	46
Movement velocity		33	76
Directional control		54	16
Modified CTSIB	Trueblood, Hodson-Chennault, McCubbin, and Youngclarke (2001)		
Firm closed		43	61
Firm open		20	93
Foam closed		13	81
Foam open		37	66
One leg stance	Vellas et al. (1997)	36	77
Stops when talking	Lundin-Olsson, Nyberg, and Gustafson (1997)	48	95
Tandem Stance	Murphy et al. (2003)	55	94
Dynamic Gait Index	Herman, Inbar-Borovsky, Brozgol, Giladi, and Hausdorff (2009)	91	3
	Shumway-Cook and Woollacott (2000)	59	64
Four Square Step Test	Dite and Temple (2002)	85	88
5 times sit to stand >15s	Buatois, Gueguen, Gauchard, Benetos, and Perrin (2006)	55	65
>12s	Tiedemann, Shimada, Sherrington, Murray, and Lord (2008)	66	55
Physical Performance Test	VanSwearingen et al. 1998	79	71
Spring Scale Test	DePasquale and Toscano (2009)	99	93

By assessing functional balance, the tests listed in Table 7 can be used to predict whether the patient will suffer from a fall in the future. Site-of-lesion tests focus on individual pathologies that may need to be addressed, but functional tests are critical for specific functional balance interventions, such as therapeutic plans or lifestyle modifications (grab bars, footwear modifications, etc.).

2.3.1 Predictivity of functional balance tests

Functional balance tests, while not diagnostic in nature, can be used to assess the contribution of various domains involved in balance and stability. For example, the Modified Clinical Test of Sensory Integration in Balance (mCTSIB) partially isolates the vestibular system by perturbing somatosensation (with foam) or eliminating vision (Shumway-Cook & Horak, 1986). In doing so, the relative contributions of each sensory system to balance function can be assessed, although the quantification of each system's contribution only can be accurately assessed if performing the Sensory Organization Test (SOT) of Computerized Dynamic Posturography (CDP). The mCTSIB has value in falls risk assessment (Kario et al., 2001; Trueblood et al., 2001). Other tests include muscular strength components, such as the 5 time Sit to Stand (Buatois et al., 2008; Tiedemann et al., 2008). Tests such as the Timed Up and Go (TUG) add gait to the test, although the quality of the gait is not analyzed (Barry et al., 2014). For gait analysis, the Dynamic Gait Index is commonly added to the test protocol (Herman et al., 2009).

Predictive falls risk tests are commonly evaluated by calculating their sensitivity and specificity for predicting future falls. Subject's performance on each test is analyzed, and then test subjects are followed up in a specific period (commonly 6 months to one year) and asked if they have fallen in the period since the testing. As shown in Table 7, sensitivity and specificity are generally between 40% and 60%, or there is a large tradeoff between the two values. The Spring Scale Test is the best performing test on the list, but the test is not commonly used in the clinic. Many of the other results have not been replicated. The TUG has strong predictive performance (Shumway-Cook et al. (2000), but a subsequent meta-analysis showed poorer predictive performance of the test for falls (Barry et al., 2014). The TUG is the only listed test that has undergone a meta-analysis.

By focusing on limited domains of balance function, each of the above tests will miss other fall risk factors. Sensitivity and specificity may be artificially reduced in tests which focus on limited domains as other functions involved in balance may not be tested. This would suggest using an approach in falls risk assessment that uses multiple assessment techniques to quantify the risk of falling due to as many known or relevant risk factors as possible. It is difficult to ascertain which risk factor caused a patient to fall, but by covering all factors, targeted intervention may be used to reduce the risk.

One difficulty with focusing on functional balance testing is patient fatigue. Some balance tests, such as CDP or limits of stability, can be physically demanding, pushing patients to their limits to determine balance thresholds. Others, such as the Berg Balance Scale, are lengthy, requiring 30-45 minutes of physical activity. Balance of older adults change with fatigue (Kanekar, Santos, & Aruin, 2008), so the time available for testing must be used wisely. Ideally, many tests would be performed, but patient performance will decrease with multiple tests, so efficiency is needed.

2.4 CONCLUSION

Ideally, a model of falls risk would cover all risk factors for falls, including impairments and functional abilities. An issue that appears when assessing falls risk is the inability to quantify risk across the two domains. Functional testing provides a predictive measure of falls in the form of sensitivity and specificity, while impairment testing shows increased odds ratio for falls when compared to healthy peers. Impairment measures, while showing increased odds of falling, cannot necessarily be considered predictive of falls as focusing on impairment does not distinguish fallers from non-fallers. A large range of increased odds of falling also exist, with impairments leading to an odds ratio of falls anywhere from 1.02 to 10.2. Functional measures have a wide range of sensitivity and specificity depending on the nature of the task and the domains involved in testing. To develop a model of falls risk that incorporates both impairment and function, the strength of each risk factor needs to be considered as well as the performance of functional tests for fall prediction.

3.0 MODELS OF FALLS RISK

Using the International Classification of Functioning, Disability, and Health (ICF) as a framework, a model of falls risk should be developed to quantify the cumulative effect of risk factors on the total fall risk of individual patients. The ICF was developed to provide a framework for discussing health and wellness that goes beyond a simple impairment model in order to fully encapsulate the life effects that a disease or condition may have on a patient (World Health Organization, 2002). Its basic framework is presented in Figure 1. The ICF model incorporates both body functions and structures as well as activity and participation. In the case of falls, body functions and structures are evaluated when various physiological risk factors are checked for during a falls risk assessment. Activity is evaluated during functional testing, and participation may be checked using questionnaires about issues in daily living and attitudes towards any issues the patient is currently having. Each of the three domains are critical for a comprehensive falls risk assessment. If possible, contextual factors also should be included.

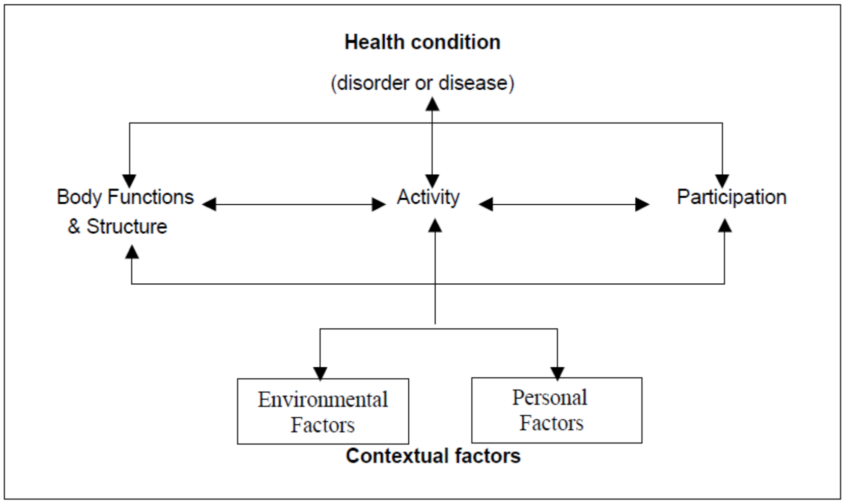

Figure 1. Model of disability in the ICF (WHO, 2002).

To fully quantify the effects of the various risk factors and functional limitations on falls risk, researchers have constructed statistical models which incorporate test results into various types of regression analysis to predict falls risk. The models take various approaches, but all seek to use results to place individuals into one of a number of categories (usually two). A list of models is presented in Table 8.

Table 8. List of falls risk models.

Reference	Included factors	Dependent variables	Statistical model	Type of variables	Significant factors
Stalenhoef et al. (2000)	Demographic data, falls hx, medications, perceived health, alcohol use, mental health, mobility impairment, dependence, ADL/HDL	non-faller, 1 fall, 2 or more falls	logistic regression	dichotomous	Age > 80, female, pain/stiffness in muscles and joints, balance/senses, neurological disorder, antidepressants
Jung, Kang, Kim, Ma, and Bhandari (2016)	Perceived health status, cognitive status, functional physical ability, Fall Efficacy Scale, sleep quality, depression, demographics	none or faller in last year	zero-inflated Poisson model	dichotomous	Perceived health status, perceived cognitive function, FES, depression
Berg, Alessio, Mills, and Tong (1997)	Vision assessment, medications, BMI, blood pressure, cholesterol, fall history, physical activity, performance measures	recurrent & non-faller	logistic regression	continuous and dichotomous	Eyeglasses use, light-headed when standing, low systolic blood pressure, small visual field
Pluijm et al. (2006)	Socio-demographic data, chronic disease, medications, physical impairment, body composition, activity, mobility, psycho-social function, lifestyle factors, biochemical markers, environmental factors	none & recurrent falls	logistic regression	dichotomous	> 2 falls, dizziness, functional limits, grip strength, body weight, fear of falling, pets in house, >11 yrs education, alcohol use
Chen et al. (2005)	Cognition, illness, incontinence, balance, postural sway, proprioception, knee extension & osteoarthritis, reaction time, Parkinson's disease, stroke, medications	no falls, single fall, recurrent falls	Cox and logistic regression	categorical	Balance, SMMSE, illness severity, age, incontinence
Smith et al. (2014)	Demographics, health, chronic conditions, Falls Self-Efficacy, days physically active, days of poor physical or mental health, perceived confidence	number of falls	Poisson regression	categorical, continuous, Likert scales	Number of chronic health conditions, days physical health not good, days mental health not good, FES
Stalenhoef et al. (2002)	Physical, mental, & social functioning, ADLs, cognition, depression, blood pressure, pulse, vision, foot examination, handgrip strength, Get Up and Go, Romberg, postural sway, bending down, one-leg stance, functional reach, home safety	any falls (one-time, recurrent), non-falls	logistic regression	dichotomous and categorical	Gender, age > 80, 2 or more falls, depression, hand grip strength, underweight, postural sway
Kabeshova et al. (2014)	Age, gender, polypharmacy, use of psychoactive drugs, fear of falling, cognitive disorders, sad mood	recurrent faller, non-recurrent faller	regression tree, multiple logistic regression	dichotomous	Age, gender, polypharmacy, psychoactive drugs, fear of falling, cognitive disorders, sad mood

3.1 STATISTICAL MODELING OF FALLS RISK

Falls risk models seek to take the relative contribution of various risk factors for falls and quantify their impact, ultimately using the factors to predict fall behavior. Risk factors are the independent variables, and falls are the dependent variable. Because of the relative infrequency of falls, most (but not all) models do not try to predict the number of falls, instead choosing a more categorical approach to the dependent variable. All the models listed in Table 8 use "no falls" and "falls" as categories. Other categories may be included, such as "one fall," "falls without injury," or "multiple falls with injury." Regardless of the number of categories chosen for a model, the intent is the same: to predict whether a patient is likely to fall given their values of risk factors.

All the models use a variation of regression analysis to construct their model of falls risk. A difficulty that arises is that the dependent variable in the most common types of regression (such as linear or non-linear regression analysis) is continuous, or at least approximates continuous. Measures such as height, hematocrit, or blood glucose level are continuous as they can have any whole number or fractional value based on the precision of the measurement instrument. Word recognition score, on the other hand, can only be whole numbers (the word is repeated either correctly or incorrectly), but over a large enough word list, is continuous enough to be considered for a linear regression as there are enough possible scores over the entire range to approximate continuous. Falls, even in those at risk for multiple falls, occur in small numbers, so the range of number of falls is low. Smith et al. (2002) calculated an average of 0.34 falls with a standard deviation of 0.85, showing that the majority of their subjects (>95%) fell 2 or fewer times. Falls are also discrete events; anything other than whole-number of falls is difficult or impossible to judge or quantify. For Smith et al., 95% of their subjects had either 0, 1, or 2 falls in the year they were tracked. Linear regression would not be appropriate for these data.

3.2 SHORTCOMINGS OF CURRENT MODELS

In general, the models presented above attempt to take many risk factors and distill them into a usable metric for predicting falls in individual patients. By striving to make the model useful, certain concessions are made in the included data for the model to be easily used in the clinical setting. The models may be predictive of falls in certain populations, but the push for clinical usability may distort or omit the contribution of various risk factors.

3.2.1 Data collection

None of the models include all the previously discussed risk factors, generally omitting ones that are more difficult or time intensive to measure. While functional balance is included, none of the models collect any vestibular function data. For other risk factors, there is a heavy reliance on non-standardized questionnaires and patient report. Stalenhoef et al. (2000) does not directly measure any of the data, instead relying on a patient survey for all data collected. Stalenhoef et al. (2002) included many more measured variables. Stalenhoef et al. (2002) and Pluijm et al. (2006) also included environmental factors in their analyses, which none of the other models included. By including environmental factors, these two models are including more of the ICF Model of Disease than the others, even if environmental factors are difficult to quantify. The Vestibular Activity Participation Measure-Extended (VAP-e) is a standardize measure that has been developed to include environmental factors (Grill, Furman, Alghwiri, Muller, & Whitney, 2013), but no such instrument was included in any of the models.

Many independent variables included are dichotomous in nature with only a yes or no answer being possible. Others are continuous (e.g., blood pressure, BMI), or can be treated as continuous (e.g., self-perceived ratings, number of alcoholic drinks, validated questionnaires). In most of the models [excluding Berg et al. (1997) and Smith et al. (2002)], continuous variables were forced into some sort of categorization, with almost all the models using purely dichotomous results for each of the variables. While not all included variables are continuous, those that are were assigned a cutoff value and determined to either be normal or abnormal with no gradations between. Values used for cutoffs were generally determined from the literature for what is considered diseased or not diseased. This may be an issue for falls risk, as the cutoff values for being at risk of a fall may be different than being at risk of a disease. Values used for one purpose may not necessarily be appropriate for another without specific validation, which was not performed by any of the models. For example, Chen et al. (2005) used the Short Mini Mental State Examination (SMMSE) as a measure of cognitive function and used the published normative data as a determiner of normal versus abnormal. The SMMSE was validated for use in screening for cognitive deficits, not falls risk, so it is possible that the cutoff value used for determining abnormal cognitive function may not be appropriate for determining falls risk.

3.2.2 Categorization of dependent variables

While about 1/3 of the population of older adults will fall in a year, falling is a relatively rare event for individuals. If asked about the number of falls they have experienced in the past 12 months, the number will most likely be small in all but the most recurrent fallers. While not diminishing the impact of each event, this makes regression analysis difficult. The models instead use some sort of categorization for falling, which is the dependent variable in all of the predictive models. The categorization of falling is not as straightforward as it may initially appear as evidenced by the various approaches taken by the models. Jung et al. (2016) take the simplest approach, labeling subjects as either a non-faller or faller over the previous 12 months. Stalenhoef et al. (2000) and Chen et al. (2005) take this a step further and separate single fallers from recurrent fallers, creating three categories of falls. Berg et al. also takes this approach, but dropped one-time fallers from the analysis, instead comparing non-fallers with recurrent fallers. This approach may not be appropriate as it dismisses the impact that a single fall can have on an older adult and eliminates a significant group of subjects for relevant analysis. Kabeshova et al. (2007) combines single fallers in with non-fallers into a group called non-recurrent fallers, comparing them to recurrent (2 or more in the past 12 months) fallers. This may not be the best approach for similar reasons as ignoring single fallers as it ignores any differences between non-fallers and single fallers. Smith et al. (2002) avoids categorization by using the number of falls as the dependent variable. While this may lead to statistical problems due to the small range of values, appropriate selection of statistical models can help to alleviate the problems inherent with counting the number of falls.

3.2.3 Statistical issues

3.2.3.1 Logistic regression and its appropriate use Five of the listed models use logistic regression for modeling the falls data. Logistic regression is a special case of the generalized linear model used to estimate probabilities of a binary response variable given one or more predictors. Assumptions are similar to linear regression, except by having a binary case for the dependent variable, logistic regression violates the assumption of continuity required for linear regression. The other assumptions are identical: independence of observations, limited or no collinearity, no important variables are omitted, and no extraneous variables are included.

Logistic regression appears to be a good choice for investigating falls risk, although certain compromises must be made for the method to be valid. The dependent variable must be binary, so most of the falls risk models compare fallers to non-fallers, or recurrent fallers to non-recurrent fallers. Some omit one-time fallers from the analysis. Due to the variable nature of falls, distilling the number of falls into a binary categorization may not be the most appropriate way of predicting future behavior. In setting up the logistic regression, none of the models checked collinearity of the independent variables, so it is unknown whether the data met the assumptions of the statistical model. If this assumption was checked and collinearity was seen, interaction terms can be used to help compensate. None of the models analyzed any interaction terms between variables. All the models did some sort of pre-screening of independent variables, whether omitting variables with a prevalence of less than 10% (Pluijm et al. 2006) or performing a bivariate analysis comparing potential independent variables with falls and only including any that met a predetermined level of significance (Stalenhoef et al. 2002). Once analyzed, these variables were then included into a stepwise logistic regression. These approaches may be misleading as they only compare one variable at a time to the outcome and could lead to a violation of the assumption of inclusion of all important variables. A better approach would be to include all the measured variables in the logistic regression and using that analysis to determine what variables are significant and should be included. By a priori setting a desired level of significance, both the inclusion and exclusion assumptions can be met. These assumptions may be better met by using continuous variables when possible, as logistic regression (or any regression) is more powerful when using continuous variables versus dichotomous dummy variables.

Beyond issues in implementation, more recent statistical literature suggests that logistic regression is not appropriate for estimating probability (Barros & Hirakata, 2003). Logistic regression produces odds ratio (OR), which is considered an estimation of relative risk or risk ratio (or prevalence ratio, which is equivalent). Risk ratio (RR) is the probability of an event occurring in a group with a condition or exposure versus the probability in a control group without the condition or exposure. Odds ratio is similar but uses odds instead of probability. When the prevalence of an event is very low (<10%), the risk ratio and odds ratio are approximately equal, but with more frequent events, then the odds ratio may overstate the risk (Barros & Hirakata, 2003). Given that estimates of prevalence of falls in older adults are usually around 33%, risk ratio is more likely a better choice for an interpretable predictive statistic for falls. There are methods for estimating risk ratio from odds ratio in logistic regression, but they produce much larger confidence intervals compared to methods for directly calculating the risk ratio (Diaz-Quijano, 2012).

3.2.3.2 Zero-inflated versus non-inflated Poisson modeling The Poisson distribution models the number of times an event occurs in each interval. Poisson regression is appropriate for predicting the probability of dependent variables which can be represented as count data given one or more independent variables, which was used by Smith et al. (2014). Depending on experimental design, Poisson regression may be appropriate for predicting falls risk. For this, the dependent variable "falls" would be the number of falls a patient has experienced. This broadens the dependent variable when compared to logistic regression and allows more than two categories of the dependent variable. Given that the mean number of falls in a year is below 1 (Smith et al., 2002), the Poisson distribution of $\lambda = 1$ would be the most appropriate to use.

Poisson regression can run into dispersion problems. One assumption of Poisson distributions is that the mean is equal to the variance of the distribution. Smith et al. (2002) showed a mean of .34 falls, with a variance of .92, in 12 months. If these data are consistent with the population, then the model may not be appropriate due to overdispersion. Zero-inflated models allow for frequent observations of zero values. In falls risk, 67% of older adults will not report a fall in a year, so a zero-inflated model may appear to be appropriate for these data. There are currently no consistent guidelines for what constitutes an excessive number of zero values for choosing a zero-inflated model. Zero-inflated Poisson modeling was performed on falls data by Jung et al. (2016) in an effort to deal with over-dispersion caused by a relatively high number of zeros, e.g., non-fallers, but they used a dichotomous (falls vs. no falls) dependent variable instead of using count data. By limiting the dependent variable to a dichotomous variable, the utility of the zero-inflated model is reduced. In the case of continued dispersion issues, the negative binomial model could be used instead of the zero-inflated Poisson model. The negative binomial model generally fits better and is more straightforward in interpretation than the zero-inflated Poisson, so it is generally recommended as an alternative in these situations (Hilbe, 2014). Another option for dealing with dispersion issues in dichotomous data would be to use the Poisson distribution with a robust sandwich estimator as described by Zou (2004), which was especially developed for dealing with a dichotomous dependent variable.

3.2.3.3 Regression tree and falls risk Regression tree analysis was originally developed for segmenting target audiences for marketing purposes but has since been utilized by health sciences and public health. Kabeshova et al. (2014) used the technique to analyze which combination of risk factors were associated with an increased risk of falls. Regression tree (also called decision tree) methods divide subjects based on the presence or absence of a feature until a stopping criterion is met. This continual analysis and splitting helps to look at specific combinations of risk factors and their effects on falls risk. Binary partitioning occurs within each node. The threshold of splitting is determined to maximize the difference in outcome between the two groups. Regression tree analysis differs from previously discussed techniques by determining a profile of risk factors which can lead to falls as opposed to being predictive based on a combination of all included risk factors. This has the advantage of requiring less information to classify a patient into a high- or low-risk group but could potentially lead to missing important risk factors.

If a patient does not fall into an exact profile as determined by the regression tree analysis, they may be misclassified depending on the design of the regression tree. For example, in Kabeshova et al.'s (2014) analysis, if a patient did not have a fear of falling, was male, and had evidence of cognitive decline, they would be unclassifiable for falls risk, as that combination does not appear in the tree. While analysis may determine that cognitive decline may not be a significant splitting factor for males without fear of falls, this analysis may lead clinicians to ignore otherwise significant risk factors for falls. For classifying subjects in large public health studies, regression tree analysis may be useful, but when determining the relative contributions of risk factors (and their possible interactions) in falls, regression tree may not be appropriate. By dichotomizing all variables, whether a priori or based on analysis, the relative contributions of risk factors are not quantified and some may be completely ignored in certain cases.

3.3 CONCLUSION

Collecting and analyzing data on falls risk is not a straightforward endeavor. To comprehensively look at the contributions to falls risk, a multitude of risk factors must be included. Many measurements of risk factors are based on normative data for diagnosis of various pathologies, which may not be appropriate for falls risk. While 33% of older adults will fall in any given year, most will only fall a few times, so the difference in number of falls between those who fall and those who do not is relatively small. Dividing fallers from non-fallers this way does not capture the severity of the fall. The dependent variable of falls can be divided up in a few different ways, each of which may or may not be appropriate depending on the study design. Commonly-used statistical methods for predicting categories (such as logistic regression) are arguably not appropriate for falls risk data, as the study design of the models are more akin to time-to-event studies as opposed to cross-sectional. Relying on odds ratios, which are estimated by logistic regression, likely overstates the difference in risk between groups. Additionally, the previous models of falls risk ignore any possible interaction between variables by omitting any interaction terms in their analysis. Intact systems can help to compensate for reduced function in others, but only so much. Reduction in function in multiple systems will heavily influence compensatory strategies, possibly influencing balance greater than would be expected due to individual system reductions. These likely interactions between sensory and motor systems are not explored in the previous models of falls risk.

4.0 PROPOSED MODEL OF FALLS RISK

Some shortcomings of the previously discussed models of falls risk stem from the immediate desire to create a clinic-ready tool for predicting falls in individual patients. While this may eventually come out of a model of falls risk, the rush for something usable in everyday situations may dilute the ability of the model to fully describe the relative contributions of risk factors in falls. While the models may be useful, they are incomplete. The desire for immediate clinical integration of the models leads to compromises and streamlined methods, leaving a model of falls risk that lacks a true theoretical foundation. To fully understand the contributions of various factors in falls, a theoretical model that describes falls risk is needed. This model could be the underpinning of various clinical tools, but the model itself would not seek to be predictive for individual patients, instead weighing risk factors quantitatively and showing what contributes to falls. Many risk factors likely interact with one another, and these interactions also can be analyzed, adding to the understanding of falls risk factors. A theoretical model can be used to identify values for various risk factors at which an older adult may be at greater risk of falls, helping to develop normative data specifically for falls risk as opposed to using current diagnostic values which may or may not be appropriate for identifying fall risk. The model can be updated and expanded once additional risk factors are identified. The model will make predictions about how well various intervention strategies can reduce the risk of falls. A theoretical model serves as the foundation for clinical strategies and increase the understanding of the nature of falls in older adults. Table 9 compares the previously discussed models with characteristics desirable for an "ideal" model of falls risk, acknowledging that none of the models fulfil all criteria.

Table 9. Characteristics of an ideal model of falls risk. Desired characteristics are listed in the first row. Previously discussed models are included to show which characteristics have been included in each model. X's indicate which models correspond to each item.

Model	**Report Risk Ratios**	**Use of continuous data (when possible)**	**Inclusion of interaction terms**	**Inclusion of risk factors and functional test results**	**Covers all domains from the ICF**
Stalenhoef et al. (2000)					X
Jung, Kang, Kim, Ma, and Bhandari (2016)	X	X		X	
Berg, Alessio, Mills, and Tong (1997)				X	
Pluijm et al. (2006)		X		X	X
Chen et al. (2005)				X	
Smith et al. (2014)	X				
Stalenhoef et al. (2002)		X		X	X
Kabeshova et al. (2014)				X	

4.1 DATA COLLECTION AND ANALYSIS

To build an accurate model of falls risk, as many of the related risk factors must be included. This would involve evaluations across numerous specialties, involving much time and expense. Luckily, datasets which include many, if not all, risk factors and fall information already exist, being used for various public health and epidemiological purposes. For the present investigation, data from the National Health and Nutrition Examination Survey (NHANES) was used to build the model of falls risk. Risk factors included in the analysis are listed in Table 10. The NHANES was selected because it includes more fall risk factors than other epidemiologic data sets. The data are publicly available.

Table 10. NHANES variables included in analysis, including corresponding risk factor. WAIS – Welcher Adult Intelligence Scale.

Risk Factor	Variable	Units/divisions
Vestibular	mCTSIB Foam pad eyes closed	seconds
	Problems with dizziness in past year?	Yes/no
	Problems with balance in past year?	Yes/no
Lower extremity disease	Number of insensitive areas on feet	1-6
	Left posterior tibial systolic blood pressure	mm HG
	Right posterior tibial systolic blood pressure	mm HG
	Joint pain affecting a lower extremity	# of sites (0-6)
	Pain down either leg below knee	Yes/no
	Lower back pain	Yes/no
Vision	Difficulty seeing steps/curbs dim light	1-5
	Difficulty noticing objects on side	1-5
	Prescription right sphere	diopters
	Prescription right cylinder	diopters
	Prescription right axis	degrees
	Prescription left sphere	diopters
	Prescription left cylinder	diopters
	Prescription left axis	degrees
	Surgery for cataracts	Yes/no
	Use of glasses/contacts for near	Yes/no
	Use of glasses/contacts for distance	Yes/no
Muscle strength	Time to peak force - quadriceps	ms
	Average peak force - quadriceps	Newtons
Osteoporosis	Pelvis bone mineral density	grams/cm^2
Cognitive function	WAIS II number of items completed	number
	WAIS II number of items correct	number
Cardiovascular function	Systolic blood pressure	mm HG
	Diastolic blood pressure	mm HG
	Hemoglobin	g/dL
	Hematocrit	percentage
	Taking prescription for hypertension	Yes/no
Medications	Number of medications	number
Frailty	Body mass index	kg/m^2

Data from NHANES 2001-2002 was used in building the model. This timeframe of data was selected because it includes the most relevant data related to falls risk. Balance data was only collected from 1999 to 2004. The balance examination includes questions about mobility and falls as well as performance on various balance tasks. NHANES 2001-2002 also includes a vision examination and muscle strength testing, both of which have been previously linked to falls risk. 2001-2002 is the only NHANES where all 3 of these examinations were completed. Subjects in the NHANES are generally tested longitudinally, so much additional data for these subjects was collected in ensuing testing cycles. Data collected either before or after this set may not reflect the state of the subject during the timeframe of interest. This may be older data, but this is the only dataset available which contains examinations related to all the areas of interest in the proposed analysis. Although more sophisticated methods of measurement may exist now, the data was collected using validated methods and reflect the state of the participants at the time. It is possible that the data is not a representative sample of older adults at this current time. However, this should not be an issue with building a model of falls risk. The sample was designed to span the range of health and well-being across a wide range, which older adults at the current time will still fit into. The distribution of health outcomes may be skewed in one direction, but it will still lie within the total range of possibility.

For sampling purposes, the goal was to build a sample that is representative of community-dwelling, independent older adults. An equal number of male and female subjects was selected to control for gender effects. Subjects were community-dwelling adults 60 years of age and older. The age of subjects was chosen as the risk of falling increases over 60 years (CDC 2006). Any subject who was not ambulatory was excluded, although the use of an assistive device, such as a cane or walker, did not cause exclusion. Various neurological and musculoskeletal conditions can lead to changes in ambulation and postural control, and by including subjects with these conditions, their contributions to falls risk can effectively be quantified and compared. Additional factors that may interact with the chronic conditions may be found through building the model.

4.1.1 Limitations of NHANES data

The NHANES, not being a data set concerned primarily with balance, has some limitations that must be addressed for falls risk. The first issue is the limited vestibular testing. Balance testing was performed and inferences about vestibular function can be made, but there is no diagnostic data about the function and health of the vestibular system. This is a common shortcoming among the currently available data. Most epidemiologic studies that concern dizziness or vertigo use questionnaires to estimate the prevalence of vertigo, dizziness, and falls (Grill, Muller, Brandt, & Jahn, 2013). The Baltimore Longitudinal Study of Aging (BLSA) has begun to collect vestibular data on its subjects by performing video head-impulse testing (vHIT), but only 109 subjects have been successfully tested, with another 14 unable to complete testing (Li et al., 2015). This is a promising start to directly collecting vestibular data on subjects, but the numbers are as yet insufficient for use in the proposed analysis. Vestibular function can be inferred by comparing test performance when all balance senses are used versus performance when one or more are eliminated, such as eyes open versus eyes closed. This approach is commonly used when using the Modified Clinical Test of Sensory Interaction and Balance (mCTSIB) (Cohen, Blatchly, & Gombash, 1993; Cohen, Mulavara, Peters, Sangi-Haghpeykar, & Bloomberg, 2014), which was included in the NHANES. As a proxy for vestibular function, the difference in time until falling between eyes open on floor and eyes closed on foam was used. Eyes open on the floor allows the subject to use all the primary balance sensory systems to maintain postural stability, while eyes closed on foam eliminates vision and perturbs proprioception, leaving the subject to rely on vestibular input to maintain stability. Comparing the two conditions provides a rough estimate of vestibular function. This is not an ideal measure of vestibular function, but for the purposes of this analysis using the NHANES data, must suffice.

The second issue with the NHANES data is related to questions about falls. The only question related to previous falls is, "During the past 12 months, have you had difficulty with falling?" This question is open to interpretation by the subject. Someone who has suffered from one fall may not think they have had difficulty with falls. This would place subjects who may have had a fall in the past year into the no fall group. The question also does not quantify the number of falls suffered in the past year. Subjects are dichotomized based on perceived difficulty with falls. This may appear to run into the same problem that previous falls risk models encountered when defining the dependent variable of falls, but unlike previous studies, this considers the subject's perception of their falls, moving away from the idea that all falls are equal. A subject who has fallen once due to circumstances beyond their control (such as ice or a loose rug) or is not injured may not consider that they have had difficulty with falls, whereas one who fell due to vertigo or loss of balance might. Subjects who are more active also may suffer from a fall due to the nature of their activity but may be less likely to consider that they have difficulty. By treating these falls as different, subjects who are at risk for falls due to individual patient factors can be separated from those at a normal risk of falls from everyday life. The wording of the question does not ask about number of falls, which forces the dependent variable into a binary variable as opposed to a continuous or count variable. Smith et al.'s data showed that the mean number of falls is approximately .34, and 95% of their subjects had 2 falls or fewer. As fall data are already close to being binary, treating it as such may be appropriate. The NHANES questionnaire, by using difficulty with falls as opposed to fall versus no fall, dichotomizes the subjects differently from the previously discussed falls risk models in a way that takes subject perception of their falls into account. It would be preferable to have fall count in addition to the NHANES question to compare perception of difficulty and actual number of falls, but in its absence, perception of difficulty with falls provides sufficient information for the proposed analysis.

In reviewing the various CPGs for falls risk assessment, most of the documents recommend an analysis of environmental factors. Indeed, for a model of falls risk to incorporate the entire ICF model, environmental factors need to be included. Performing a qualitative analysis of a patient's environment is relatively straightforward but converting that to qualitative data for use in the proposed model is much more difficult. One possible method would be to create a questionnaire including environmental factors that increase falls risk (number of stairs in house, loose rugs, lack of grab bars in bathrooms, etc.) and to assess and total the risk using a standardized measure. Some questionnaires include environmental risks as a yes/no question, but the NHANES data does not include any questions, either yes/no or a quantified score, on environmental factors. This is a limitation that the NHANES data has in common with most of the other models of falls risk, as only two (Stalenhoef et al. 2002 and Pluijm et al. 2006) analyze environmental data, and only Stalenhoef et al. use a checklist to quantify environmental factors. The checklist was previously developed by the same group but does not have a predictive value for falls (Stalenhoef, Diederiks, Knottnerus, Witte, & Crebolder, 1998). A thorough, quantitative analysis of environmental factors would help to build a more complete model of falls risk.

4.1.2 Sample size calculation and power analysis

One thousand three hundred and thirty-eight (1,338) subjects were included. Sample size was determined using the enumeration method described by Lyles, Lin, and Williamson (2007), displayed in Table 11 and Figure 2, and was computed using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). Base rate exposure ($\beta 0$) was estimated from previous data stating that approximately 1/3 of older adults will fall in a given year (Centers for Disease Control and Prevention, 2006). $\beta 1$, which represents the increase in exposure for each unit increase of the input variables, was chosen from previous studies looking at risk and odds ratios for falls risk factors. The mode of risk ratios listed in Table 6 is approximately 1.3. Given that the dependent variable of difficulty with falls in the NHANES data is binary, $\lambda = 1$ was chosen as the Poisson distribution to be tested. R^2 was approximated from previous models of falls risk.

Table 11. Power analysis and sample size calculation for modified Poisson regression. Calculation was performed in G*Power.

z tests - Poisson regression		
Options:	Enumeration method, Wald-test	
Analysis:	A priori: Compute required sample size	
Input:	Tail(s)	One
	Exp(β1)	1.2
	α err prob	0.05
	Power (1-β err prob)	0.8
	Base rate exp(β0)	0.33
	Mean exposure	1
	R^2 other X	0.7
	X distribution	Poisson
	X parm λ	1
Output:	Noncentrality parameter λ	6.280096
	Critical χ^2	2.705544
	Df	1
	Total sample size	1338
	Actual power	0.805441

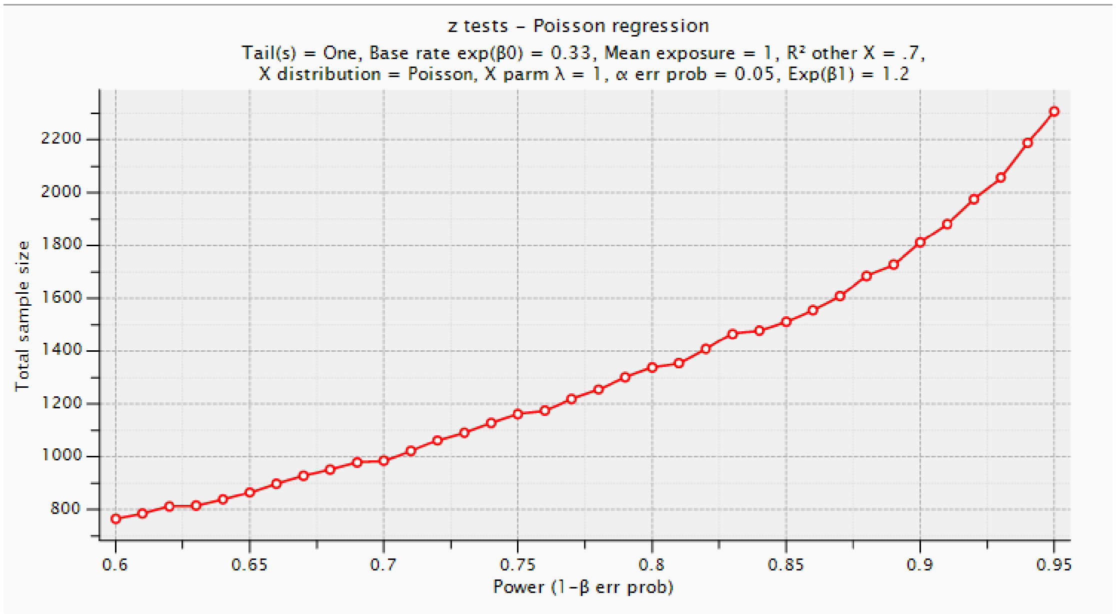

Figure 2. Distribution of statistical power based on sample size for Poisson regression.

4.1.3 Statistical analysis

Statistical analysis was performed using modified Poisson regression. Zou (2004) proposed a modified Poisson regression technique to estimate risk ratios for binary data. This method is robust against over- and under-dispersion, such as what is seen in Smith et al.'s data. It is also more flexible than the previously mentioned alternative, negative binomial regression (of which Poisson regression is a variation). One issue with the modified Poisson regression is that individual subject probabilities may be greater than 1, although this is not an issue if overall risk ratios across the sample are the interested outcome. To predict individual fall risk, this method would not be appropriate, but in creating an overall model of falls risk, the interest lies in predicting risk ratios. If the interest is in extending the prediction to individuals, Miettinen (1982) suggested a doubling-of-cases method. This may be desirable for a predictive tool for use in the clinic; however, for developing a theoretical model of falls risk, this correction is unnecessary, as it will not be used to predict falls risk in individual patients.

Poisson regression directly estimates risk ratios, avoiding the previously discussed issues seen in logistic regression. Goodness of fit testing using the χ^2 test for model fit was performed to assess the suitability of the Poisson distribution for the data. Poisson regression assumes that the mean and variance of the dependent variable are equal. Smith et al.'s data showed a mean number of falls of .34 and a variance of .92. Using these data, Poisson regression would not be appropriate. For this model, difficulty with falls is being used as the dependent variable instead of number of falls, so it is unknown if the model will be over- or underdispersed. A robust sandwich estimator (Zou, 2004) was used to compensate for inappropriate dispersion.

The desired outcome of the analysis is twofold: 1) to determine which risk factors and interaction terms are significantly related to falls risk, and 2) to determine the relative risk (RR) of each of the included risk factors and interaction terms. Risk factors and interaction terms were considered significant if $p > .05$ when included in the regression model. Relative risk can be calculated from the coefficient estimates in the regression model for each significant risk factor.

4.1.3.1 Combining variables The NHANES variables listed in Table 10 were included in the data analysis, but some of the variables were combined to simplify the model. Left- and right posterior tibial systolic blood pressure were combined, and the lower number were included as posterior tibial systolic blood pressure. For vision, the worse eye prescription (sphere, cylinder, and axis) was used instead of each parameter for each eye to establish and quantify the overall deviation from normal vision and the need for vision correction. Previous data show that vision problems in one eye leads to an increase of falls risk, so including only the worse eye is appropriate.

4.1.3.2 A priori interactions Included interaction components are listed in Table 12. The included interactions were chosen from the major systems involved in balance function (vestibular, vision, somatosensation, muscular) as well as cognitive function. Lower limb joint pain also was included, as pain decreases somatosensory sensitivity as discussed above. Deficits in any one of these systems leads to an increase in falls risk. Other systems can be used to compensate, but if deficits occur in multiple systems, it is hypothesized that the deficits will combine to create a much greater risk of falls than for each individual deficit. All two-way interaction components between the listed variables were included. The overall analysis was performed with and without the interaction terms and was compared using a Wald χ^2 test to determine if the model with interaction terms predicts significantly more variance in falls risk than the model without interactions.

Table 12. Systems to be included as interaction terms and their corresponding variables. All two-way interaction combinations of the listed variables will be included in the data analysis.

System	**Variable**
Cognition	WAIS II items correct
Vestibular	mCTSIB foam pad, eyes closed
Vision	Worse eye prescription (diopters)
Somatosensation	Number of insensitive areas on feet
Muscular function	Quadriceps peak force
Lower extremity pain	Joint pain affecting a lower extremity (number of locations)

4.1.3.3 Missing Data To minimize the amount of missing data, only subjects who had undergone a majority of included surveys and examinations were initially included in the analysis. Multiple imputation was performed on the missing data in order to include all subjects in the final analyses.

4.2 MODEL HYPOTHESES AND PREDICTIONS

Previous models of falls risk were constructed to provide clinicians a tool to predict the likelihood of their patients to fall. The models included well-established risk factors, but generally cut down the number of included variables for improved clinical utility and therefore are most likely incomplete. The models also do not account for any interactions between risk factors, suggesting that the risk factors combine in a linear fashion. The proposed model of falls risk seeks to alleviate these issues.

As discussed above, many variables can be considered risk factors for falls, including deficits within systems involved in balance, but also including many factors not traditionally thought of as being directly involved with balance. It is the goal of this model to include as many primary risk factors for falls as possible. By including as many primary risk factors as practical, a more complete model of falls risk results. The model can explain the increase in risk for falls with each condition and show each risk factor’s relative contribution to falls risk.

In addition to including many primary risk factors, the model also includes interaction terms to model how the risk factors combine to increase falls risk. It is hypothesized that the model which includes the interaction terms will fit the data better than the model that excludes the interaction terms. Formally stated, the hypothesis is:

$$H_0: R^2_{\text{interactions}} = R^2_{\text{no interactions}}$$

$$H_a: R^2_{\text{interactions}} > R^2_{\text{no interactions}}$$

By including the interaction terms, the influence of sensory or motor losses in multiple systems will increase falls risk at a much greater rate than in a simply additive system. Using interaction terms in the model suggest that fall risk factors influence each other and will cause a greater risk of falls together than what would be expected when included by themselves. If the null hypothesis is rejected, this would predict that intervention aimed at only one risk factor may reduce falls, but interventions targeting multiple risk factors would reduce the risk at a much greater rate, at least regarding the primary balance systems. This has already been suggested in the literature, as multiple studies also show the effectiveness of Tai Chi in balance intervention, which incorporates multiple sensory, motor, and cognitive factors in its practice (Gallant, Tartaglia, Hardman, & Burke, 2017; Gatica-Rojas, Cartes-Velasquez, Salgado-Mendez, & Castro-Ramirez, 2016; Lin, Wong, Chou, Tang, & Wong, 2000; Wolf, Barnhart, Ellison, & Coogler, 1997; Y. Wu, MacDonald, & Pescatello, 2016).

5.0 RESULTS

5.1 SUBJECTS AND DATA COLLECTION

Subjects were selected from the NHANES 2001-2002 dataset. Subjects were included if they had undergone all of the balance evaluations and completed the balance questionnaires. Data for all of the included independent variables (see Table 10) were extracted from the database. 1,626 subjects underwent the balance evaluation. Due to the large amount of evaluations completed on the subjects, missing data was expected (Table 13). Subjects were excluded if they did not have data for more than one-third of the independent variables included in the final analysis. While not eliminating missing data, this reduced the amount of missing data to be accounted for in the final analysis. Independent sample t-tests were performed to ensure that the sample was not significantly changed in regards to the balance-related variables. None of these three variables were significantly different when the excluded patients were removed (vestibular function: p = .220; balance: p = .186; dizziness: p= .478; problem with falls: p = .123). After excluding these subjects, 1,388 subjects were eligible for inclusion in the analysis. Of these, 1,338 subjects (667 male/671 female; age range 60-85 years; mean age 72.05, standard deviation 8.09) were ultimately included in the analysis, selected in order to keep the number of males and females approximately equal. In order to include all subjects in the analysis, multiple imputation was performed on any independent variable that included missing data. Descriptive statistics for each variable are listed in Table 13, both before and after multiple imputation. All of the included variables had means and standard deviations that were not significantly different from values prior to imputation. Of the patients included in the final analysis, 122 (9.2%) reported problems with falls.

Table 13. Percentage of missing data for each of the included independent variables for the included subjects. Mean and standard deviation for each included variable are listed both before and after multiple imputation.

				Before Imputation		After Imputation	
	Number of Cases	Missing	Percent Missing	Mean	Std. Dev	Mean	Std. Dev
mCTSIB	1338	0	0.0	11	12.1	11	12.1
Insensitive spots on feet	1164	174	13.0	.30	1.15	.52	1.01
Leg systolic blood pressure	1164	174	13.0	159.63	27.17	159.13	28.68
Pain count lower limb	1338	0	0.0	.14	.556	.14	.556
Lower back pain	1338	0	0.0	.37	.483	.37	.483
Steps curbs in dim	1260	78	5.8	1.67	1.43	1.59	1.10
Sphere worse	1139	199	14.9	1.22	1.62	1.30	1.58
Quad time to peak force	1049	289	21.6	1.15	.88	1.28	.83
WAIS II Correct	1338	0	0.0	35.1	22.8	35.1	22.8
Medications	1200	138	10.3	3.11	2.75	3.11	2.75
Bone density	1088	250	18.7	1.32	.20	1.13	.20
Systolic	1164	174	13.0	133.06	37.42	133.52	37.48
Hemoglobin	1109	229	17.1	14.08	1.44	14.09	1.44
Dizziness	1338	0	0.0	.21	.41	.21	.41
Balance	1338	0	0.0	.24	.51	.24	.51
Hypertension meds	1335	3	0.2	.48	.50	.48	.50
Near glasses	1164	174	13.0	.83	.43	.83	.38
Far glasses	1159	179	13.4	.22	.42	.22	.42

5.2 DATA ANALYSIS

5.2.1 Collinearity

A collinearity matrix of all of the independent variables was produced in order to identify any predictors that may correlate with one another. If r > | .3 |, one of the two variables was removed from the analysis in most cases. This is a very conservative threshold for collinearity, but this was chosen due to the large number of variables that overlapped in what they measured. In order to simplify the model, using a low threshold helps to ensure that the amount of overlap is kept to a minimum in the final model. Table 14 lists the variables with high collinearity. When faced with a pair of variables with high collinearity, the decision as to which variable to remove was based on two factors: 1) do either of the variables exhibit high collinearity with any other variables, and 2) do each of the variables measure a unique construct, or is there another variable that measures something similar? For example, WAIS items correct has a correlation of -0.314 with difficulty seeing objects on the side. Difficulty seeing objects on the side also correlated with difficulty seeing curbs or steps, which is a measurement of a similar construct (edge detection and peripheral vision), so difficulty seeing objects on the side was excluded in that pair. Cataract surgery correlated with multiple visual measurements, so cataract surgery was also excluded. Hemoglobin and hematocrit also had a high correlation but measure similar constructs (the capacity of blood to carry oxygen), so ultimately hematocrit was dropped.

Table 14. Variables with high collinearity.

Included variable	Removed variable	Correlation coefficient
Lower back pain	Lower leg pain	.318
Difficulty seeing steps	Difficulty seeing objects on side	.630
Use of glasses for near	Cataract surgery	.330
Sphere worse	Cataract surgery	.604
Sphere worse	Cylinder worse	.519
Sphere worse	Axis worse	.512
WAIS items correct	WAIS items complete	.996
Bone density	Quad peak force	.420
Bone density	Body Mass Index	.314
Systolic blood pressure	Diastolic blood pressure	.641
Number of medications	Medication for hypertension	.362
Hemoglobin	Hematocrit	.974

In one case, variables with correlation above the threshold were both included. Systolic blood pressure and lower leg systolic blood pressure have a correlation coefficient of .395. While both can be considered indicators of cardiovascular health, lower leg systolic blood pressure also can be considered a measure of peripheral cardiovascular function and lower extremity health, therefore it was included in the final analysis.

5.2.2 Poisson regression

Once collinear variables were excluded, a Poisson regression was performed on the dependent variable of trouble with falls, with the previously listed independent variables included as predictors. A robust sandwich estimator was included to compensate for dispersion issues. No interactions were included in the initial analysis. Results are shown in Table 15.

Table 15. Poisson regression results. * indicates a significant predictor (p < .05). Predictors with a negative coefficient indicate that risk of trouble with falls increases as the predictor decreases while a positive coefficient shows that risk of trouble with falls increases as the predictor increases.

Parameter	**β**	**Std.Error**	**Hypothesis Test**		
			Wald Chi-Square	**df**	**p-value**
(Intercept)	-1.273	0.9003	2.000	1	0.157
Dizziness	-0.406	0.1979	4.210	1	*0.040
Balance	-2.536	0.2870	78.079	1	*<0.001
Near glasses	-0.093	0.1975	0.220	1	0.639
Far glasses	0.050	0.1768	0.079	1	0.779
mCTSIB	-0.013	0.0080	2.535	1	0.111
Insensitive	0.127	0.0467	7.361	1	*0.007
Paincount lower limb	-0.079	0.0518	2.350	1	0.125
Lower back pain	0.242	0.1581	2.345	1	0.126
Steps/curbs dim	0.058	0.0601	0.918	1	0.338
Sphere worse	-0.046	0.0507	0.829	1	0.363
Quad time to peak force	0.027	0.0507	0.274	1	0.601
WAIS Correct	-0.014	0.0036	14.308	1	*<0.001
Medications	-0.125	0.0496	6.356	1	*0.012
Bone density	-0.126	0.4329	0.084	1	0.771
Systolic	0.001	0.0019	0.120	1	0.729
Hemoglobin	0.065	0.0553	1.388	1	0.239

The following predictor variables were significant in the Poisson model: dizziness ($p = .040$), balance ($p < .001$), number of insensitive points on the feet ($p = .007$), WAIS II items correct ($p < .001$), and number of medications ($p = .012$).

A second Poisson regression was performed, this time including interactions. Results are shown in Table 16. When interactions are included, the following predictors are significant in the model: dizziness ($p = .017$), balance ($p< .001$), WAIS II items correct ($p < .001$), medications ($p = .003$), insensitive areas X quadriceps time to peak force ($p = .005$), and insensitive areas X WAIS II correct ($p = .002$).

A Wald χ^2 test was performed to compare the two models. The test was significant ($\chi^2 = 10.85$, df = 1, $p < .001$), indicating that the model including the interactions was a significantly better fit in the Poisson regression than the model that did not include interactions. Risk ratios (RR) were computed for each of the significant predictors in each of the models. RRs are listed in Table 17.

Table 16. Poisson regression results, including a priori interactions. * indicates a significant predictor.

Parameter	β	Std.Error	Hypothesis Test		
			Wald	df	Sig.
(Intercept)	-1.047	0.8705	1.447	1	0.229
Dizziness	-0.473	0.1989	5.664	1	*0.017
Balance	-2.566	0.2903	78.167	1	*<0.001
Near glasses	-0.181	0.2142	0.713	1	0.398
Far glasses	-0.012	0.1808	0.004	1	0.948
mCTSIB	-0.001	0.0213	0.003	1	0.960
Insensitive	-0.537	0.2791	3.706	1	0.054
Paincount legs	-0.049	0.0472	1.077	1	0.299
Lower back pain	-0.495	0.3964	1.559	1	0.212
Steps/curbs dim	0.068	0.0601	1.285	1	0.257
Sphere worse	0.027	0.0992	0.075	1	0.784
Quad time to peak force	-0.081	0.0594	1.873	1	0.171
WAIS Correct	-0.032	0.0083	14.891	1	*<0.001
Medications	-0.145	0.0488	8.806	1	*0.003
Bone density	-0.066	0.4344	0.023	1	0.879
Systolic	0.001	0.0018	0.146	1	0.703
Hemoglobin	0.086	0.0536	2.550	1	0.110
mCTSIB * Insensitive	-0.001	0.0062	0.027	1	0.869
mCTSIB * Lower back	0.011	0.0153	0.540	1	0.462
mCTSIB * Sphere	-0.001	0.0052	0.063	1	0.801
mCTSIB * Quad	-0.006	0.0093	0.452	1	0.501
mCTSIB * WAIS Correct	0.000	0.0004	0.125	1	0.723
Insensitive * Lower back	0.188	0.1181	2.532	1	0.112
Insensitive * Sphere	-0.002	0.0307	0.005	1	0.945
Insensitive * Quad	0.314	0.1116	7.916	1	*0.005
Insensitive * WAIS	0.005	0.0017	9.981	1	*0.002
Lower back * Sphere	-0.064	0.0978	0.423	1	0.515
Lower back * Quad	0.271	0.2102	1.663	1	0.197
Lower back * WAIS	0.010	0.0067	2.184	1	0.139
Sphere * Quad	-0.096	0.0729	1.730	1	0.188
Sphere * WAIS	0.002	0.0019	1.378	1	0.240
Quad * WAIS	0.005	0.0045	1.207	1	0.272

Table 17. Risk ratios for significant predictors in each model.

				Model w/ interactions		
Variable	**RR**	**95% CI**		**Variable**	**RR**	**95% CI**
Dizziness	1.50	1.02-2.21		Dizziness	1.61	1.09-2.37
Balance	12.66	7.19-22.22		Balance	12.99	7.35-23.26
Insensitive spots on feet	1.14	1.04-1.24		WAIS items correct	1.03	1.02-1.05
WAIS items correct	1.01	1.00-1.02		Number of medications	1.16	1.05-1.27
Number of medications	1.13	1.03-1.25		Insensitive spots on feet * quad time to peak force	1.37	1.10-1.70
				Insensitive spots on feet * WAIS items correct	1.01	1.00-1.01

6.0 DISCUSSION

A large number of conditions and pathologies have been linked to falls risk in older adults. This comes as little surprise, as changes in vestibular, visual, musculoskeletal, somatosensory, and cardiovascular functions, among others, can lead to either transient or permanent postural instability. It has been hypothesized that the combination of these effects will lead to an increased risk of falls in older adults. Previous studies examining individual risk factors generally control for any other health condition and specifically look at one risk factor at a time. In older adults, age- and non-age-related changes generally do not occur in isolation, so the relative contribution of each risk factor needs to be understood. The relative contribution was examined in this analysis.

6.1 POISSON MODEL RESULTS

6.1.1 Significant predictors of problems with falls

The single largest contributor to the perception of difficulty with falls was whether or not a patient had a problem with their balance in the past year, with a relative risk of 12.99 in the interactions model. Balance is a multisystem function, relying on inputs from, among others, vestibular, vision, and somatosensory systems, and producing outputs through the musculoskeletal system. Cognitive and other central processes mediate the analysis, motor planning, and execution of any movements needed to maintain balance. Deficits in any of these systems can lead to difficulty maintaining posture. This may be perceived in a general sense as a difficulty with balance. A patient with balance difficulties may or may not be aware of the reasons for their balance difficulty but are keenly aware of the result of any deficits.

Other risk factors were found to be significant in the analysis, but the risk ratios are much smaller than that of the presence of balance problems. Dizziness and number of medications were significant in both models, and number of insensitive spots on the feet was significant in the no interactions model (although insensitive spots becomes significant in two interactions in the interactions model). A common thread between these significant predictors is that they are risk factors that a patient will likely be acutely aware of. The patient will know the number of medications they are taking and if they have had problems with dizziness. They may not be aware of the exact number of insensitive spots on their feet but are likely aware that they cannot feel the surface they are standing on as they once could. Having an awareness of problems that can be directly linked to balance and falls can explain these significant predictors in the model. While other risk factors may lead to falls, those that directly and identifiably lead to a perception of balance problems will lead to a perception of problems with falls.

Cognitive function was also a significant predictor in both models as measured by the WAIS II, although the risk ratio was the lowest of all of the significant risk factors. Cognitive function was significant when interacting with insensitive spots on the feet. Cognitive function is likely significant in falls risk as greater demand is put on the cognitive system when the inputs from the primary balance senses decrease due to aging or pathology. While the demand for cognitive processing increases, the cognitive resources are decreasing, leading to a situation where the demands may overwhelm the remaining cognitive resources. Indeed, one of the most significant predictors of falls seen in previous research is if the patient stops walking to talk (Lundin-Olsson et al., 1997). If a patient uses so many cognitive resources to maintain a steady, stable gait that they cannot devote any to communication, that suggests that the cognitive system is pushed to its limit simply to maintain stability. While patients may not be aware of a cognitive decline directly, they may know that it takes more concentration to maintain postural stability. If a patient needs to concentrate more to avoid a fall, then they are more likely to report a problem with falls. Previous research confirms that Mild Cognitive Impairment (MCI) is positively correlated with fear of falling (Borges Sde, Radanovic, & Forlenza, 2015; Uemura et al., 2014), but if MCI then progresses to Global Cognitive Impairment (GCI), dementia, or Alzheimer's disease, the fear of falling decreases (Uemura et al., 2014; Uemura et al., 2012). These studies suggest that, if a patient has a cognitive impairment but is aware enough to realize it, they are more likely to think they have a problem with falls. Beyond a mild impairment, the patient may not have enough cognitive resources to perceive a problem even if they are at risk for falls. Decreased motor planning abilities have been seen in patients who report a fear of falls (Sakurai et al., 2017).

6.1.2 Non-significant risk factors

All of the risk factors included in the analysis were previously shown to individually increase the risk for falls in older adults, although only a few were ultimately significant in the Poisson analysis. This does not necessarily mean that they should not be considered risk factors for falls, but it does suggest that in the overall risk of falling, the significant factors are more powerful in their ability to predict a problem with falling. Each risk factor may predict falls in an absolute sense when all other risk factors are controlled for, but the overall contribution when taken in total is relatively small. Some of the risk factors, such as hemoglobin, systolic blood pressure, or bone density, are

6.2.4 Other limitations

Other investigations and examinations that were completed in the NHANES study also had their limitations with regard to balance function. Proprioceptive abilities in the trunk and lower limbs can be inferred from questions about leg and back pain, as the presence of pain reduces proprioception (Brumagne et al., 2004). A direct measurement of proprioception would have been more reliable. Patients were asked if they wore corrective lenses, but they were not asked how long they had been wearing them. The VOR compensates when wearing glasses due to the retinal slip caused by the lenses which takes time, relying on the patient not avoiding head movement (Demer, Goldberg, Jenkins, & Porter, 1987; Watanabe, Hattori, & Koizuka, 2003). Patients were not asked how often they use their glasses or what situations they use them in. Full time use of glasses or contact lenses would facilitate compensation better than part time use. They were asked what they used the corrective lenses for (distance vs. close) but were not asked what type of lenses they used (single vision vs. multifocal). As there is still some uncertainty with regard to the effect of multifocal lenses on falls risk, including this information would be helpful.

This analysis used a cross section of data, collected in a much larger, longitudinal investigation. Many of the predictor variables have been collected over the 40+ year span of the study, but others were only collected over a short period of time. Some changes in various systems may be seen throughout the study in patients who participated for a long time span, but many of the risk factors were only collected once or twice. Change over time may be a much better predictor of falls risk. For instance, a patient who has been wearing a stable prescription for myopia and wears corrective lenses full time over the course of many years may be more adapted to a visual deficiency than one with a rapidly changing prescription, or who does not wear their lenses full time. VOR compensation occurs over a relatively short period of time (3-4 months),

the combination of many, each causing an increase in perceived dizziness or imbalance, may be a greater risk than any individual factor ZRXOG EH LQ .LVRODW

6.3.2 Interventions for patients at risk for falls

The distinction between primary, secondary, and tertiary risk factors is important when considering possible interventions to reduce falls risk. If a patient presents with an obvious risk factor, especially a primary risk factor, intervention would logically include treatment with the goal of either promoting adaptation and habilitation in relation to the risk factor if not correcting the issue outright. If a patient complains of dizziness or imbalance that is not obviously related to a primary risk factor, a full medical workup would be warranted to find any issues that may be the cause of the imbalance. The goal of this treatment would be to reduce dizziness or imbalance in relation to the risk factor. According to the present model, any intervention that reduced the sense of imbalance in patients will reduce the fear of falling. As fear of falling and fall risk are strongly correlated (Gettens & Fulbrook, 2014), reducing the fear should reduce the risk of falls, although reducing the fear of falling in isolation does not seem to reduce falls (Parry et al., 2016). The effectiveness of this targeted treatment would need to be investigated to confirm or refute this prediction.

6.3.3 Changes in balance systems over time

The present model looks at a cross section of data from a very limited timespan. There are no indications of how this current state was arrived at for any of the data collected, hence the change of each of the systems over time cannot be seen. Exactly how the risk factors changed over time may be predictive of issues with falls. Changes occurring gradually over time as a consequence of normal aging processes may lead to different consequences than those that occur as result of an acute event or lesion. It would be reasonable to hypothesize that older adults are more able to adapt to slow, gradual changes than acute events; however, they may not be aware of these changes as they happen, so they may not be cognitively aware that such changes have taken place until after having suffered an adverse event. For those who have arrived at the current state as a result of an acute event, they may be more aware that their balance abilities have changed and take some action in order to help alleviate any balance problems they may have as a result. Time elapsed since such event may influence its effect on balance and falls risk. Speed of change in balance systems and other related risk factors that can affect balance may be predictive for falls risk. This would help to determine an individual patient's deviance from their own normal, as opposed to normative data generated from an average of a population. This "deviance from an individual's normal" would likely have predictive value. In order to determine which time course leads to more risk of falls, a longitudinal study which follows patients for a significant period of time would be warranted.

6.3.4 Clinical impact of falls risk models

A likely goal in creating a model of falls risk is to develop a tool for detecting those at risk of falling in order to intervene before a fall leads to a life-changing injury. Indeed, many of the previously discussed models were created specifically with that goal in mind. Those models sought to separate patients into groups of fallers and non-fallers by using simple, clinically available procedures, questionnaires, or checklists. The current model suggests that the most predictive factor in falls risk is the perception of any kind of imbalance. Any condition or factor

7.0 CONCLUSION

As the population ages, falls in older adults will continue to require more resources from the health care system. Any effective effort to reduce falls will decrease the related costs and increase quality of life in those who may suffer from falling. A comprehensive model of falls risk is required to identify those at most risk of falls so that appropriate interventions may take place. The model presented here seeks to consider changes in the primary balance systems and other systems that have been linked to falls in the past. The analysis shows that the largest predictor of reporting a problem with falls is being off balance. Many risk factors that have previously been shown to be linked to falling were not shown to be significant in the overall model; however, that does not mean that they are not linked to falls. Most, if not all, of the risk factors included in the model can cause lightheadedness, unsteadiness, or dizziness, all of which would then be reported by the patient as a problem with their balance. Essentially, anything that can cause a patient to report a problem with their balance should be considered a risk factor for falls. The most effective intervention for decreasing falls risk would therefore likely be those that directly resolve the issue that is causing the imbalance. In some cases, such as secondary effects from diabetes, intervention would be to treat the underlying condition, hopefully resolving symptoms that cause imbalance. In others, such as vestibular or musculoskeletal pathology, effective intervention may be less related to treating the condition and more rehabilitative or compensative measures involving

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