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Original Article

The Effect of Muscle Strength and Visual Contrast Sensitivity on Fall Risk Sway Velocity Index

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Abstract

Objectives: The purpose of this study was to examine if fall risk scores were affected by the interaction between muscle strength and visual contrast sensitivity. **Methods:** Ninety-one individuals aged 19-79 years completed assessments of knee extension strength, visual contrast sensitivity, and fall risk. Correlations and moderation analysis were completed in combination with analysis of variance. Data were categorized into groups: 1) higher strength-higher visual contrast sensitivity, 2) higher strength-lower visual contrast sensitivity; 3) lower strength-higher visual contrast sensitivity, and 4) lower strength-lower visual contrast sensitivity. **Results**: Knee extension strength via peak torque relative to body mass ($R= -0.57$, $P<0.001$) and visual contrast sensitivity ($R=-0.63$, $P<0.001$) were both negatively correlated with age, while fall risk scores were positively correlated with age ($R=0.34$, $P=0.001$). The interaction between muscle strength and visual contrast sensitivity was a significant predictor of fall risk scores ($t=2.420$, $P=0.018$) when controlling for age. Participants exhibiting lower strength-lower contrast sensitivity (12.96 ± 1.93) had significantly worse fall risk scores compared to higher strength-higher visual contrast sensitivity (11.53 ± 1.75, $P=0.045$). **Conclusion**: Lower levels of lower body muscle strength combined with lower visual contrast sensitivity interact to negatively influence fall risk.

Keywords: Aging, Fall Risk, Sarcopenia, Strength, Visual Contrast Sensitivity

Introduction

Global estimates suggest mortality and disability-adjusted life years due to falls has increased steadily since 1990[1]. In the United States, unintentional falls are the leading cause of injury and injury-related mortality in adults 65 years and older[2]. In 2020, approximately 14 million older adults reported falling during the previous year, which represented 28% of the population[2]. Medical costs associated with non-fatal and fatal falls are estimated to be 50 billion each year[3]. Given the projected increase (~55%) in the older adult population, along with rising fall rates and related health care expenditures[4], screening for these incidents may be of critical importance to mitigate risk of falls and related injuries[5,6]. Age-related falls and increased fall risk are multifactorial with both intrinsic (e.g., medication history, muscle and joint health, age) and extrinsic (e.g., living situation, environment, walking aids) factors[7]. Two significant intrinsic factors that contribute to falls and increased fall risk include visual deterioration and the loss of neuromuscular function[8–10].

An age-related decline in visual function is generally

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attributed to anatomical changes of the eye, whereby the mass and cross-sectional area of the lens, which is responsible for focal distance, thickens and loses elasticity[8]. The reduction in ciliary muscle diameter, which alters the shape of the lens when viewing objects at different distances, also negatively correlates with age[11]. Further, abrasions of the corneal surface of the eye increase with age[12], and ocular aberrations and neural changes affecting the transfer of resolution to the retinal image contribute to reduced visual contrast sensitivity[13]. Visual contrast sensitivity, the ability to discriminate between two luminance levels in a static image[8], is associated with previous incidents of falling[14–16], predicting future falls[17], and tasks related to fall risk[18]. Contrast sensitivity is measured at low, middle, and high spatial frequencies which are linked to different neural mechanisms[19] and may also be associated with impairments in everyday task performance[20].

Complicating the changes in visual function with aging is the realignment of the neuromuscular system[21]. The most noticeable change is the progressive loss of skeletal muscle mass, especially without exercise or nutritional intervention[22]. Age-related skeletal muscle atrophy is attributed to several factors, including an imbalance between muscle protein synthesis and muscle protein catabolism[23], reduced number and size myofibers[24], reduced satellite cells[25], decreased type II muscle fibers[26], and chronic inflammation[27]. Perhaps more detrimental than skeletal muscle atrophy itself is the greater decline in neuromuscular strength and power that accompanies aging[28]. A downregulation in neuromuscular function may occur as a result of motor unit loss or dysfunction of neuromuscular synapses[29]. Ultimately, reductions in lower body muscle mass and strength interact to decrease walking speed[30] and increase the risk of falling[10]. Given simultaneous visual and neuromuscular function decline with aging, the purpose of this study was to examine if fall risk was affected by the interaction between lower body muscle strength and visual contrast sensitivity. We hypothesized that individuals with lower muscle strength and lower visual contrast sensitivity would have worse fall risk scores compared to those with higher strength and higher visual contrast sensitivity.

Materials and Methods

This study was a cross-sectional research design. Ninety-five males and females between 19-80 years, stratified as younger (19-40 years), middle-aged (41-64 years), and older (65+ years) were recruited for this investigation. Flyers, word of mouth, listservs, electronic advertisements, and social media were used to recruit participants. Participants were included in the study upon completion of the Physical Activity Readiness Questionnaire[31] and study specific health history surveys. Exclusion criteria included previous or current injuries in their neck, back, legs, or hands that prevents strength and balance testing, leg or arm amputation that would limit bilateral testing, blindness or previous eye injury or have lost an eye, are pregnant, previous diagnosis of a spinal cord injury, stroke, respiratory diseases, or other neuromuscular disease, known eye disease (such as glaucoma, macular degeneration, diabetic retinopathy), below 20-40 visual acuity, and known impaired contrast sensitivity. Following study inclusion, anthropometrics, visual, strength, and fall risk assessments were completed during one session.

Anthropometric and Descriptive Measures

Upon arrival at the laboratory, height and body weight were measured with a stadiometer (Seca 213, Chino, CA, USA) and digital scale (DA-Series, Denver Instrument, Arvada, CO, USA), respectively. Age was self-reported. Body mass index (BMI) was calculated as body mass in kilograms divided by height in meters squared.

Vision and Strength Testing

Visual contrast sensitivity was measured for both eyes using the Pelli-Robson letter chart with participants standing one meter away from the chart while using any corrective eye glasses or contacts lenses[32,33]. It is suggested the Pelli-Robson letter chart is suitable for measuring contrast sensitivity at medium spatial frequencies (3 and 5 cycles per degree)[34]. The chart was mounted so that its center was at eye level with standardized room illumination. The score was established based on the faintest triplet of letters that were correctly identified, whereby two of the three letters were read correctly. Visual contrast sensitivity was tested in duplicate and averaged.

Following visual contrast sensitivity testing, participants completed a five-minute, self-paced warm-up on a stationary cycle ergometer (Monark 818E Ergomedic, Vansbro, Sweden). Participants then completed lower body muscle strength testing using the Biodex Pro4 system dynamometer (Biodex Medical Systems, Inc, Shirley New York, USA)[35]. Isokinetic maximal torque was assessed at 60 degrees per second for knee extension-flexion with a 75-degree range of motion on the participants self-described weakest limb, given it would be considered limiting during a fall. Three maximal attempts were collected and maximal peak torque of the three repetitions were included in the analysis.

Fall Risk Assessment

After completing visual and strength testing, the Biodex Balance System SD (Biodex Medical Systems, Inc, Shirley New York, USA) was used to evaluate fall risk[36]. The Biodex Balance System is a multi-axial system that objectively measures the ability to stabilize under active stress and is highly reliable[36]. The standard fall risk protocol was utilized and each participant stood on the force platform in their socks facing the display monitor screen at eye level. Participants were instructed to keep their center of

	Younger (n=29)	Middle-Age (n=33)	Older (n=29)	ANOVA P-value (pη²)
Age (yr)	24.87 ± 5.11	53.40 ± 7.67*	69.90 ± 4.07*#	P<0.001 (0.906)
Height (cm)	171.54 ± 8.62	173.20 ± 9.12	167.85 ± 9.52	P=0.066 (0.059)
Body mass (kg)	77.66 ± 20.12	82.02 ± 16.52	77.94 ± 19.22	P=0.567 (0.120)
BMI (kg/m²)	26.17 ± 5.34	27.29 ± 4.04	27.35 ± 4.55	P=0.540 (0.130)
Strength per kg (Nm/kg)	2.22 ± 0.63	1.85 ± 0.47*	1.45 ± 0.45*#	P<0.001 (0.264)
Visual Contrast Sensitivity (log)	1.82 ± 0.11	1.69 ± 0.15*	1.44 ± 0.22*#	P<0.001 (0.442)
Fall Risk (SVI)	11.55 ± 1.77	11.67 ± 1.99	13.01 ± 1.733*#	P=0.002 (0.130)

*Data are mean ± standard deviation. $p\eta^2$= partial eta squared effect size *Sidak corrected post-hoc test significantly different versus younger group, p<0.05. # Sidak corrected post-hoc test significantly different vs. middle-age group, p<0.05. BMI = body mass index.*

Table 1. Anthropometrics and descriptive characteristics of full sample by age group

balance in the middle of the platform and stay as still as possible. The protocol consists of four conditions: eyes open-comfortable stance, eyes closed-comfortable stance, eyes open-narrow stance, eyes closed-narrow stance. Each condition was performed twice for 45 seconds with a 30 second rest between conditions. The first trial was considered a familiarization trial followed by a second trial used for data analysis. Sway Velocity Index (SVI), which is the total distance the center of pressure traveled in the medial-lateral path over time, was determined for each condition and the overall composite of the assessment. SVI is calculated as: ($LnCPV_{ML}$/body height in cm) x 1000, where Ln is the natural log function of the medial-lateral center of pressure (CPV_{ML}) in mm per second[37].

Statistical Analysis

Outliers within the data set (n=95) were visually inspected using a boxplot for each variable and identified as those greater than 3 times the interquartile range. Four outliers were identified in the fall risk SVI test and removed from the data set (n=91). Following outlier analysis, normality was tested using the Shapiro-Wilk test and all variables met normality assumptions (*P*>0.05). First, univariate analysis of variance (ANOVA) of the full sample categorized by age (younger, middle-aged, and older) was performed on anthropometrics, descriptive characteristics, muscle strength, visual contrast sensitivity, and fall risk SVI. When a significant omnibus ANOVA was detected, follow-up post-hoc testing was determined using Sidak corrections for multiple comparisons. Pearson correlations were also utilized to further visualize the associations between visual contrast sensitivity, knee extensor muscle strength, and fall risk VSI with age.

Moderation analysis was then performed to develop a model using centered visual contrast sensitivity, centered knee extensor strength, and the centered interaction term while statistically controlling for age and sex. For

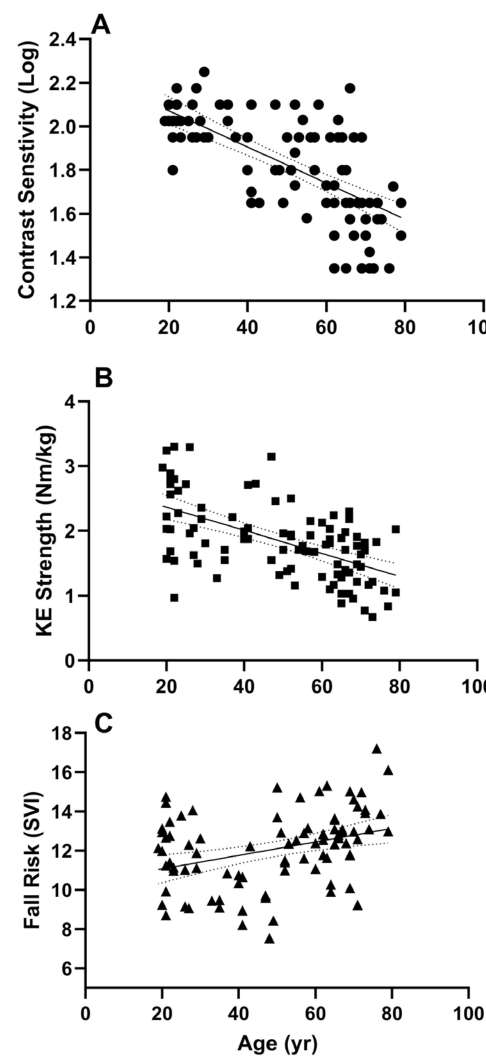

Figure 1. Correlations between visual contrast sensitivity (A), knee extensor (KE) strength (B), and fall risk composite score (C) with age.

Predictors	Unstandardized Beta Coefficients	Standard Error	Standardized Coefficients	t	Significance	95% Confidence Interval
Constant	10.977	0.782		14.037	P<0.001	9.422-12.532
Strength per body mass	-0.751	0.399	-0.227	-1.883	P=0.063	-1.545-0.042
Visual contrast sensitivity	0.738	1.142	0.090	0.647	P=0.520	-1.53-3.008
Strength per body mass x Visual contrast sensitivity	3.794	1.568	0.252	2.420	P=0.018	0.677-6.911
Age	0.025	0.15	0.246	1.709	P=0.091	-0.004-0.054
Sex	-0.616	0.399	-0.159	-1.543	P=0.127	-1.410-0.178

Table 2. Moderation analysis exploring the interaction of strength and visual contrast sensitivity.

	Higher Strength-Higher Contrast Sensitivity	Higher Strength-Lower Contrast Sensitivity	Lower Strength-Higher Contrast Sensitivity	Lower Strength-Lower Contrast Sensitivity	ANOVA P-value ($p\eta^2$)
Age (yr)	33.29 ± 15.17	50.66 ± 17.80*	49.39 ± 16.19*	65.69 ± 10.56*#Ɨ	0.001 (0.404)
Height (cm)	172.38 ± 9.58	172.65 ± 8.94	168.84 ± 7.93	169.29 ± 10.03	0.378(0.034)
Body mass (kg)	76.03 ± 20.33	82.46 ± 16.98	75.60 ± 8.89	82.54 ± 22.39	0.388 (0.033)
BMI (kg/m²)	25.44 ± 5.41	27.42 ± 3.87	26.57 ± 3.02	28.37 ± 4.64	0.128 (0.060)

*$p\eta^2$= partial eta squared effect size *Sidak corrected post-hoc test versus higher strength & higher contrast sensitivity, P<0.05.#Sidak corrected post-hoc test versus higher strength & lower contrast sensitivity, P<0.05.Ɨ Sidak corrected post-hoc test versus lower strength & lower contrast sensitivity, P<0.05. BMI = body mass index.*

Table 3. Anthropometrics and descriptive characteristics with groups based on strength and contrast sensitivity interactions

further exploration of the interaction effects within the data, median splits of the sample were determined for visual contrast sensitivity (1.6900 log) and knee extensor muscle strength (1.8061 Nm/kg). Using these values, participants were re-categorized into four groups: 1) higher strength-higher visual contrast sensitivity (n=24), 2) higher strength-lower visual contrast sensitivity (n=24); 3) lower strength-higher visual contrast sensitivity (n=17), 4) lower strength-lower visual contrast sensitivity (n=26). Univariate ANOVAs were used to determine group differences in anthropometrics, fall risk SVI, and individual fall risk test components following group re-categorization that was not age dependent. All analyses were performed using SPSS statistical software (IBM Corporation, Armonk, New York, USA, version 28) and an alpha level of less than 0.05 was used to determine statistical significance.

Results

The mean and standard deviation (SD) for age, height, body mass, and BMI of the full sample stratified by the three age groups (younger, middle-age, and older) following recruitment are shown in Table 1. Strength per kg (*P*<0.001) and visual contrast sensitivity (*P*<0.001) were significantly lower in middle-age and older adults compared to younger adults. Fall risk SVI was significantly greater in older adults compared to younger adults. Pearson correlations revealed statistically significant associations. Visual contrast sensitivity (R = -0.63, *P*<0.001, Figure 1A) and knee extension strength via peak torque relative to body mass (R= -0.57, *P*<0.001, Figure 1B) were both significantly and negatively correlated with age, while fall risk composite SVI scores were significantly and positively correlated with age (R= 0.34, *P*=0.001, Figure 1C).

Moderation analysis with the full sample revealed a significant model (R=.437, R^2 = 0.224, Adjusted R2=0.179, F= 4.912, P < 0.001) which included strength per body mass, visual contrast sensitivity, interaction between strength per body mass x visual contrast sensitivity and statistically controlled for both age, and sex (Table 2). The interaction between strength per kg and visual contrast sensitivity was the only significant predictor (*P*=0.018) of fall risk SVI while controlling for

	Higher Strength-Higher Contrast Sensitivity	Higher Strength-Lower Contrast Sensitivity	Lower Strength-Higher Contrast Sensitivity	Lower Strength-Lower Contrast Sensitivity	ANOVA P-value (pη²)
Eyes Open-Comfortable Stance	6.86 ± 1.94	6.88 ± 2.32	7.43 ± 2.39	7.42 ± 2.26	0.691(0.016)
Eyes Closed-Comfortable Stance	8.24 ± 2.33	8.10 ± 2.22	9.67 ± 2.66	9.30 ± 2.48	0.085 (0.071)
Eyes Open-Narrow Stance	11.09 ± 2.48	10.72 ± 1.83	11.47 ± 2.01	11.81 ± 2.10	0.303 (0.040)
Eyes Closed-Narrow Stance	15.61 ± 2.82	15.38 ± 2.11	16.80 ± 2.44	17.48 ± 2.64*#	0.013 (0.113)

*pη²= partial eta squared effect size. *Sidak corrected post-hoc test versus higher strength & higher contrast sensitivity, P<0.05. #Sidak corrected post-hoc test versus higher strength & lower contrast sensitivity, P=0.03.*

Table 4. Four components of computerized fall risk testing with groups based on strength and contrast sensitivity interactions.

age (*P*=0.091) and sex (P=0.127).

Further examination of the interaction between muscle strength and visual contrast sensitivity was explored via re-categorization of groups that was not age dependent. The mean and SD for age, height, body mass, and BMI of the four groups after re-categorization based on muscle strength and visual contrast sensitivity metrics are shown in Table 3. There was a significant effect of age between the four groups (*P*=0.001). Post-hoc analysis with Sidak corrections showed that the lower strength with lower contrast sensitivity group was significantly older than the other three groups (*P*<0.05). The higher strength with lower contrast sensitivity and lower strength with higher contrast sensitivity groups were also significantly older than the higher strength with higher contrast sensitivity group (*P*<0.05). There were no differences in height, body mass, or BMI between the four groups (*P*>0.05).

The four components of the fall risk assessment included eyes open-comfortable stance, eyes closed-comfortable stance, eyes open-narrow stance, and eyes closed-narrow stance. When examining the specific components of the testing, there was a significant difference in eyes closed-narrow stance assessment SVI scores between groups (*P*=0.013). Post-hoc testing with Sidak corrections determined that the lower strength with lower contrast sensitivity group had significantly higher eyes closed-narrow stance assessment SVI scores that the higher strength-lower contrast sensitivity (P<0.05) and the higher strength with lower contrast sensitivity group (*P*<0.05, Table 4). There was a significant difference in overall fall risk composite SVI scores between groups (*P*<0.001). Post-hoc testing with Sidak corrections determined the lower strength with lower contrast sensitivity group (12.96 ± 1.93) had significantly worse fall risk composite SVI scores compared to higher strength with higher visual contrast sensitivity (11.53 ± 1.75, *P*=0.045) and higher

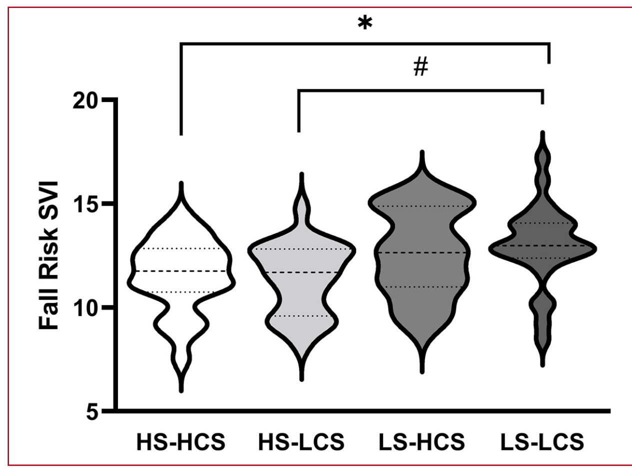

Figure 2. Differences in fall risk composite score between groups. HS-HCS=higher strength with higher visual contrast sensitivity, HS-LCS=higher strength with lower visual contrast sensitivity, LS-HCS=lower strength with higher visual contrast sensitivity, LS-LCS=lower strength with lower visual contrast sensitivity. *Significantly different HS-HCS vs LS-LCS, # significantly different HS-HS-HCSS vs LS-LCS.

strength with lower visual contrast sensitivity (11.37 ± 1.70 *P*=0.018, Figure 2).

Discussion

The concurrent decline in visual and neuromuscular function poses a significant challenge to fall mitigation strategies and overall healthy aging[8,9,22,24]. The purpose of this study was to examine if fall risk was affected by the interaction between lower body muscle strength and visual contrast sensitivity. When examining age related differences alone, older adults were the only group that had higher fall risk SVI scores when compared to younger adults, but both middle age and older adults had reduced strength and lower visual contrast sensitivity compared to younger adults. However, when statistically controlling for age, our moderation analysis revealed that the interaction between strength and visual contrast sensitivity was the most significant predictor of fall risk SVI scores. A secondary finding of this study was that displaying the combination of lower muscle strength and lower visual contrast sensitivity had higher (i.e., worse) fall risk composite scores compared to those demonstrating higher strength and higher visual contrast sensitivity. Lastly, individuals that exhibiting higher strength and lower visual contrast sensitivity had lower (i.e., superior) fall risk scores on the eyes closed-narrow stance portion of the assessment than those with lower muscle strength and lower visual contrast sensitivity, suggesting having higher levels of lower body strength could be protective for fall risk in the absence of visual cues.

The interaction between visual deterioration and the loss of neuromuscular function with aging was of specific interest in this study as it pertains to identifying individuals at risk for future falls. In the current study, younger adults had superior strength and visual contrast sensitivity compared to middle age and older adults. Both visual contrast sensitivity and lower body muscle strength were also significantly and negatively associated with age. However, across all age categories there was a wide amount of variability in strength and visual contrast sensitivity characteristics, suggesting an individual may be optimal in one category but not optimal in another. Alterations in visual contrast sensitivity, even if subtle and not at the threshold for visual impairment, may reduce the perception of border detection on surfaces such as carpets, uneven sidewalks, or other walking terrain[17], especially in poor lighting and if not corrected. This concept was emphasized by Owen et al.[38] who suggested the loss of visual contrast sensitivity may impair older adults' ability to differentiate between objects, especially in cluttered environments, which could increase the likelihood of tripping within the home or near an outdoor hazard. In the event of a trip or stumble, the neuromuscular system must quickly engage with enough force to "catch" the individual, preventing a fall and allowing the recovery of the center of gravity. The strength of the lower limbs is of fundamental importance in this situation as partial or even full body weight may be transferred to only one limb during a potential fall event.

The majority of previous investigations have examined either visual contrast sensitivity and falls[8,9,39] or reduced strength and falls[10]. Thus, examining the interaction of strength and visual contrast sensitivity is critical as reduced outcomes on both are likely to accelerate the potential of falls and these factors may change across the lifespan due to lifestyle factors and current health status (i.e., medications, resistance exercise, conscious effort to wear corrective lenses). In the current study, moderations analysis suggested that strength, visual contrast sensitivity, the interaction between strength and visual contrast sensitivity, age, and sex explained ~18% of the variance in fall risk SVI. For comparison to the literature, Thompson et al.[40], recently showed that poor contrast sensitivity was strongly associated with reduced physical performance in older adults, especially on dynamic balance tasks. Lord et al.[14], also found that quadriceps strength was significantly lower (~25 N) in older adults who had previously fallen and visual contrast sensitivity was negatively correlated with a choice stepping test that simulated fall conditions, requiring rapid reaction time and weight transfer. Our results generally align with these previous studies, as we demonstrated that lower knee extensor strength relative to body weight and reduced visual contrast sensitivity had significantly higher (i.e., worse) fall risk composite SVI scores.

Our findings emphasize the importance of muscle strength and visual contrast sensitivity across the lifespan. Although muscle weakness and the loss of visual contrast sensitivity may be associated with a variety of medical conditions, the results of our study may have also have implications for future examination in individuals with type 2 diabetes. Resistance exercise, which is a strong factor in maintaining or improving strength across the lifespan[41] is critical in mitigating type 2 diabetes[42] which is also associated with reduced contrast sensitivity as a result of diabetic retinopathy[43]. Further, evidence also suggests older adults with type 2 diabetes have a 59% higher chance of falling compared to older adults who do not have diabetes[44]. Therefore, although the sample in our study was generally healthy, examining the interaction between strength per body weight and visual contrast sensitivity in older adults with type 2 diabetes may be warranted in the future to determine if this may explain the increase in falls in this population.

The fall risk assessment used in the present investigation has previously been used to diagnose balance disorders in orthopedics, Parkinson's disease, multiple sclerosis, hearing impairments, and fall prevention[6]. The components of the assessment use visual feedback and active neuromuscular stress to determine subtle variations in movement velocity and center of pressure[36]. We determined that the eyes closed-narrow stance assessment was the most challenging with the highest variability amongst groups. In this capacity, we observed that those with groups displaying higher lower body strength regardless of visual contrast sensitivity status had ~10% lower fall risk SVI scores during the eyes closed-narrow stance assessment. This suggests that having higher levels of strength may be protective in the absence of visual cues, which may translate to lower fall risk during periods of darkness or low light.

A strength of the current investigation was the use of an established stabilographic platform to determine fall risk as opposed to other functional tests that may be less reliable[6]. We also tested individuals that were generally healthy and explored the interaction of factors that are critical to fall risk screening prior to disease progression and diagnosis. Although the cross-sectional design of the study allowed assessment of various age groups, it may be considered a limitation as longitudinal analysis across time would provide more insight into the fluctuations of visual contrast sensitivity, strength relative to body weight, and fall risk scores. For instance, medication used across the lifespan is linked to changes in visual function and alterations in body weight[9,45]. Exercise training is also efficacious across the lifespan to improve strength when consistently performed[41] and can reduce fall rates by 23%[46]. Although we focused on lower body strength of the knee extensor group, the strength of other muscle groups such as the dorsi and plantar flexors could contribute to fall risk scores[14], and our study did not systemically examine exercise training status or history at the time of testing.

Conclusion

Concurrent visual deterioration and the loss of neuromuscular function with aging represents a challenging dilemma to reduce falls. We conclude that lower levels of lower body muscle strength in relation to body weight combined with lower visual contrast sensitivity interact to negatively influence fall risk even when controlling for age and sex. Exhibiting higher lower body strength regardless of visual contrast sensitivity status may also lower fall risk in the absence of visual feedback. Early interventions, such as in middle age, are warranted to improve both lower body strength and maintain visual contrast sensitivity to lower the risk of falls across the lifespan.

Ethics approval

The project was reviewed and approved by the Institutional Review Board at North Dakota State University (HE19261). This study was conducted in accordance with the ethical principles outlined in the 1964 Declaration of Helsinki and its subsequent amendments.

Consent to participate

Written informed consent was obtained by participants before entering study.

Authors's contributions

Contribution of the concept and design of work: Kyle J. Hackney, Mark McCourt, Miranda L. Bradley. Data Acquisition: Kyle J. Hackney, Miranda L. Bradley, Sean Mahoney, Nathaniel R. Johnson, Christopher J. Kotarsky, Adam P. Bradley, Sherri N. Stastny. Data Analysis and interpretation: Kyle J. Hackney, Mark McCourt, Nathanial R. Johnson. Drafting the work or critically reviewing the work: Kyle J. Hackney, Mark McCourt, Sean Mahoney, Miranda L. Bradley, Nathaniel R. Johnson, Christopher J. Kotarsky, Adam P. Bradley, Sherri N. Stastny, Ryan McGrath. Agreement to be accountable for all aspects of the current work. Kyle J. Hackney, Mark McCourt, Miranda L. Bradley, Sean Mahoney, Nathaniel R. Johnson, Christopher J. Kotarsky, Adam P. Bradley, Sherri N. Stastny, Ryan McGrath. All authors read and approved the final version of the manuscript.

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References

1. James SL, Lucchesi LR, Bisignano C, et al. The global burden of falls: global, regional and national estimates of morbidity and mortality from the Global Burden of Disease Study 2017. Injury Prevention 2020; 26: i3–i11.
2. Kakara R, Bergen G, Burns E, Stevens M. Nonfatal and Fatal Falls Among Adults Aged ≥65 Years - United States, 2020-2021. MMWR Morb Mortal Wkly Rep. 2023;72(35):938-943.
3. Florence CS, Bergen G, Atherly A, et al. Medical Costs of Fatal and Nonfatal Falls in Older Adults. J Am Geriatr Soc 2018; 66: 693–698.
4. Houry D, Florence C, Baldwin G, et al. The CDC Injury Center's Response to the Growing Public Health Problem of Falls Among Older Adults. Am J Lifestyle Med 2016; 10: 74–77.
5. Strini V, Schiavolin R, Prendin A. Fall Risk Assessment Scales: A Systematic Literature Review. Nurs Rep. 2021;11(2):430-443
6. Bobowik P, Wiszomirska I, Leś A, et al. Selected Tools for Assessing the Risk of Falls in Older Women. Biomed Res Int 2020; 2020: 2065201.
7. Colón-Emeric CS, McDermott CL, Lee DS, et al. Risk Assessment and Prevention of Falls in Older Community-Dwelling Adults: A Review. JAMA 2024; 331: 1397–1406.
8. Saftari LN, Kwon OS. Ageing vision and falls: a review. Journal of Physiological Anthropology 2018 37:1 2018; 37: 1–14.
9. Reed-Jones RJ, Solis GR, Lawson KA, et al. Vision and falls: A multidisciplinary review of the contributions of visual impairment to falls among older adults. Maturitas 2013; 75: 22–28.
10. Moreland JD, Richardson JA, Goldsmith CH, et al. Muscle Weakness and Falls in Older Adults: A Systematic Review and Meta-Analysis. J Am Geriatr Soc 2004; 52: 1121–1129.
11. Strenk SA, Semmlow JL, Strenk LM, et al. Age-related changes in human ciliary muscle and lens: a magnetic resonance imaging study. Invest Ophthalmol Vis Sci 1999; 40: 1162–1169.
12. Calver R, Cox M, Elliott D. Effect of Aging on the Monochromatic Aberrations of the Human Eye. Journal of the Optical Society of America A 1999; 2069–2078.
13. Ferro M, Artal P, Navarro R, et al. Effects of aging in retinal image quality. JOSA A, Vol 10, Issue 7, pp 1656-1662 1993; 10: 1656–1662.
14. Lord SR, Fitzpatrick RC. Choice Stepping Reaction Time: A Composite Measure of Falls Risk in Older People. The Journals of Gerontology: Series A 2001; 56: M627–M632.
15. De Boer MR, Pluijm SMF, Lips P, et al. Different aspects of visual impairment as risk factors for falls and fractures in older men and women. Journal of Bone and Mineral Research 2004; 19: 1539–1547.

16. Ivers RQ, Cumming RG, Mitchell P, et al. Visual Impairment and Falls in Older Adults: The Blue Mountains Eye Study. J Am Geriatr Soc 1998; 46: 58–64.
17. Lord SR, Dayhew J. Visual Risk Factors for Falls in Older People. J Am Geriatr Soc 2001; 49: 508–515.
18. Lord SR, Murray SM, Chapman K, et al. Sit-to-Stand Performance Depends on Sensation, Speed, Balance, and Psychological Status in Addition to Strength in Older People. The Journals of Gerontology: Series A 2002; 57: M539–M543.
19. Kaur K, Gurnani B. Contrast Sensitivity. StatPearls, https://www.ncbi.nlm.nih.gov/books/NBK580542/ (2023, accessed 28 April 2025).
20. West SK, Rubin GS, Broman AT, et al. How does visual impairment affect performance on tasks of everyday life? The SEE Project. Salisbury Eye Evaluation. Arch Ophthalmol 2002; 120: 774–780.
21. Goodpaster BH, Park SW, Harris TB, et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. J Gerontol A Biol Sci Med Sci 2006; 61: 1059–1064.
22. Sayer AA, Cruz-Jentoft A. Sarcopenia definition, diagnosis and treatment: consensus is growing. Age Ageing 2022; 51: 1–5.
23. Burd NA, Gorissen SH, Van Loon LJC. Anabolic resistance of muscle protein synthesis with aging. Exerc Sport Sci Rev 2013; 41: 169–173.
24. Nishikawa H, Funkunishi S, Asai A, et al. Pathophysiology and mechanisms of primary sarcopenia (Review). Int J Mol Med 2021; 48: 1–8.
25. Verdijk LB, Koopman R, Schaart G, et al. Satellite cell content is specifically reduced in type II skeletal muscle fibers in the elderly. Am J Physiol Endocrinol Metab 2007; 292: 151–157.
26. Nilwik R, Snijders T, Leenders M, et al. The decline in skeletal muscle mass with aging is mainly attributed to a reduction in type II muscle fiber size. Exp Gerontol 2013; 48: 492–498.
27. Baylis D, Bartlett DB, Patel HP, et al. Understanding how we age: insights into inflammaging. Longev Healthspan 2013; 2: 1–8.
28. Clark BC, Manini TM. Sarcopenia ≠ Dynapenia. J Gerontol A Biol Sci Med Sci 2008; 63: 829–834.
29. Manini TM, Hong SL, Clark BC. Aging and muscle: a neuron's perspective. Curr Opin Clin Nutr Metab Care 2013; 16: 21–6.
30. Ploutz-snyder LL, Manini T, Ploutz-snyder RJ, et al. Functionally Relevant Thresholds of Quadriceps Femoris Strength.pdf. Journal of Gerontology: Biological Sciences 2002; 57: 144–152.
31. Warburton DER, Jamnik V, Bredin SSD, et al. The 2018 physical activity readiness questionnaire for everyone (PAR-Q+) and electronic physical activity readiness medical examination (ePARmed-X+). The Health & Fitness Journal of Canada 2018; 11: 31–34.
32. Pelli D, Robson J, Wilkins A. The design of a new letter chart for measuring contrast sensitivity. Clin Vis Sci 1988; 2: 187–199.
33. Elliott DB, Sanderson K, Conkey A. The reliability of the Pelli-Robson contrast sensitivity chart. Ophthalmic and Physiological Optics 1990; 10: 21–24.
34. Rosa C, Aleci C. Psychophysics in the ophthalmological practice—II. Contrast sensitivity. Ann Eye Sci. 2022;7:35.
35. Tuominen J, Leppänen M, Jarske H, et al. Test–Retest Reliability of Isokinetic Ankle, Knee and Hip Strength in Physically Active Adults Using Biodex System 4 Pro. Methods and Protocols 2023, Vol 6, Page 26 2023; 6: 26.
36. Parraca JA, Olivares PR, Carbonell-Baeza A, et al. Test-retest reliability of biodex balance SD on physically active old people. Journal of Human Sport and Exercise 2011; 6: 444–451.
37. Biodex Balance System SD (with v4.X software) Operation/Service Manual 950-440 950-441 950-444. Shirley, New York, 2017.
38. Owen DH. Maintaining Posture and Avoiding Tripping: Optical Information for Detecting and Controlling Orientation and Locomotion. Clin Geriatr Med 1985; 1: 581–599.
39. Amir NN, Kamaruzzaman SB, Effendi-Tenang I, et al. Contrast sensitivity is associated with frailty. Eur Geriatr Med 2021; 12: 313–319.
40. Thompson AC, Johnson E, Miller ME, et al. The relationship between visual function and physical performance in the Study of Muscle, Mobility and Aging (SOMMA). PLoS One. 2023;18(9):e0292079.
41. Rose DJ, Hernandez D. The Role of Exercise in Fall Prevention for Older Adults. Clin Geriatr Med 2010; 26: 607–631.
42. Kobayashi Y, Long J, Dan S, et al. Strength training is more effective than aerobic exercise for improving glycaemic control and body composition in people with normal-weight type 2 diabetes: a randomised controlled trial. Diabetologia 2023; 66: 1897–1907.
43. Chong DD, Das N, Singh RP. Diabetic retinopathy: Screening, prevention, and treatment. Cleveland Clinic Journal of Medicine 2024; 91: 503–510.
44. Freire LB, Brasil-Neto JP, da Silva ML, et al. Risk factors for falls in older adults with diabetes mellitus: systematic review and meta-analysis. BMC Geriatr. 2024;24(1):201.
45. Agostini J V., Han L, Tinetti ME. The Relationship Between Number of Medications and Weight Loss or Impaired Balance in Older Adults. J Am Geriatr Soc 2004; 52: 1719–1723.
46. Sherrington C, Fairhall N, Kwok W, et al. Evidence on physical activity and falls prevention for people aged 65+ years: systematic review to inform the WHO guidelines on physical activity and sedentary behaviour. Int J Behav Nutr Phys Act. 2020;17(1):144.