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Visual impairment predicts greater declines in physical performance over time: the Health, Aging and Body Composition Study

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Abstract

Background Poor vision has been associated with physical dysfunction and falls in older adults, but it is not known whether particular types of visual impairment (VI) may predict greater rates of decline in mobility over time in older adults.

Methods Multi-center longitudinal cohort study of 2219 older adults (mean age = 75.5 years; 52.4% female; 37.4% black) who completed self-reported (visual function questions (VFQ)) or performance-based (visual acuity (VA); log contrast sensitivity (LCS); stereoacuity (SA)) vision testing at year 3 and the short physical performance battery (SPPB) at year 4. Analyses were performed including all 2219 participants (Cohort A) and 1795 of these participants with SPPB ≥ 9 (Cohort B) at year 4. Separate linear mixed models were constructed to evaluate the relationship of each vision measure with rate of change in performance on the SPPB and its components (gait speed, balance time, and chair pace) over 8 years.

Results In cohort A, compared to the predicted decline at the mean vision level, a significantly faster rate of decline in SPPB was experienced by those with a 1 standard deviation worse year 3 logMAR VA (-0.044; 95% CI -0.065, -0.024), LCS (-0.062; 95% CI -0.082, -0.041), and VFQ (-0.045; 95% CI -0.065, -0.025) and those with a SA > 85 arcsec (-0.095; 95% CI -0.139, -0.052) versus those with SA ≤ 85 (all $p < 0.001$ for difference in slopes). Cohort B showed similar but stronger findings for SPPB, and demonstrated that worse logMAR VA, LCS and VFQ were significantly associated with a faster decline in gait speed, while worse logMAR VA, LCS, and SA were significantly associated with greater decline in balance times. Only poor SA > 85 arcsec was significantly associated with declines in chair pace.

Conclusions All VI measures predicted faster declines in SPPB. Older adults with VI may benefit from targeted intervention to prevent declines in mobility.

Keywords Visual impairment, Contrast sensitivity, Short physical performance battery, Gait, Balance

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Introduction

Identifying potentially modifiable risk factors for mobility decline is an increasingly important public health goal as the world population ages. Older adults who experience decline in physical performance are at a markedly increased risk of adverse outcomes such as falls [1] and mobility disability [2]. There is growing evidence that visually impaired older adults in particular are at increased risk of falls [3], hips fractures [4], and mortality [5]. However, the majority of the literature examining the relationship of poor vision to mobility function is cross-sectional [6–14], and it is not known whether particular types of visual impairment may predict longitudinal declines in mobility upstream of mobility disability or falls.

We have previously shown that contrast sensitivity, or the ability to perceive differences in shades of light and dark, may be more strongly associated with performance on the short physical performance battery (SPPB) than more commonly tested measures of vision such as distance visual acuity [6], stereoacuity [6], or self-reported visual function [6, 15]. Moreover, in a cohort of cognitively unimpaired older adults with good visual acuity and self-reported vision, participants with moderate impairment in LCS demonstrated subtle balance and gait dysfunction that became more apparent when subjected to a challenge task [15]. However, these associations were cross-sectional and whether impairments in contrast sensitivity or other measures of visual function, such as visual acuity (VA) or stereoacuity (SA) predict declines in physical performance over time is not known. Moreover, it is important to understand if declines in different types of mobility function are related to different types of visual impairment, since that would suggest different potential etiologies and possible opportunities for intervention.

In this study, we utilized data from the Health, Aging and Body Composition (ABC) study to investigate the relationship of both self-reported and performance-based (visual acuity (VA), stereoacuity (SA), contrast sensitivity (CS)) measures of visual function to longitudinal performance on mobility measures collected over 8 years of follow-up. Given our earlier cross-sectional work, we expected impaired visual function to be a strong predictor of declines in SPPB over time, especially its components of gait speed and balance.

Methods

Study participants

The Health, Aging and Body Composition (ABC) study was a prospective cohort study of 3,075 community-dwelling, high-functioning older adults who were 70–79 years of age at the time of enrollment. The study design has been described in detail before. In brief, baseline study visits occurred between 1997 and 1998. All age-eligible Black community residents and a random sample of White Medicare beneficiaries were recruited from Pittsburgh, PA and Memphis, TN. To be eligible, participants needed to report no difficulty walking up 10 steps without resting, walking one-quarter mile, or performing activities of daily living. They also had to have no intention to move outside the area for 3 years and have no known life-threatening cancer. The institutional review board at each study site approved the study protocols and all participants provided written informed consent. The methods for clinical and sociodemographic characteristic collected in Health ABC have been previously described [6]. Pure tone average (PTA) using 0.5, 1, 2, and 4, Khz was measured at visit 5, and was categorized as severe hearing impairment (PTA ≤ 25), moderate hearing impairment (PTA > 24 and ≤ 40 kHz), and no hearing impairment (PTA > 40) in the better ear.

Visual function

Participant binocular visual function was assessed while wearing usual corrective lenses for distance or bifocals when relevant. Distance VA was measured with high-contrast Bailey-Lovie charts at 5- or 10-foot testing distance [16]. If participants were unable to read the top line at 10 feet then they stood at 5 feet. The number of letters read correctly was corrected for reading distance and then used to calculate the Snellen equivalent (e.g., 20/40), and the $\log_{10}$ minimum angle of resolution (logMAR) wherein lower logMAR indicates better visual acuity. At 10 feet or 3-M, Bailey explains that the viewing distance has decreased 2-fold from the standard viewing distance of 6-M, and thus we expect a person should be able to read an extra 15 letters or 0.3 logMAR [17]. The correction is based on $\log_{10}$ [2] = 0.3, and 0.3 log units being equivalent to 3 lines of vision or 15 letters. Similarly, a 5-ft or 1.5-M viewing distance requires a correction of 0.6 logMAR or 30 letters based on $\log_{10}$ [4] = 0.6. A binary variable of VA worse than 20/40 vs. 20/40 or better was also created for analysis based on criteria for visual impairment from the American Academy of Ophthalmology [18].

For binocular CS assessment, participants wore their usual corrective lenses for distance or bifocals, and read the letters on a Pelli-Robson chart at a 10-foot distance from highest to lowest contrast; if they were unable to read the top (highest contrast) line at 10 feet then they stood at 5 feet to ensure they could read the optotype size which is uniform across the chart. The subsequent letters and lines decrease in log contrast units as they move down the chart, with each line being worth 0.30 units. The $\log_{10}$ contrast sensitivity (LCS) units were determine using the total number of letters read correctly ($\log_{10}$ (0.05 x number of letters read)– 0.15) [19]. LCS ranges from 0 to 2.25 with higher numbers indicating better CS.

The Health ABC alert value of ≤ 1.3 LCS, or ability to read fewer than 30 letters on the Pelli-Robson chart, indicated severe impairment. We also examined moderate CS impairment (LCS < 1.55 log units), or ability to read fewer than 34 letters, which has been used in prior cohort studies for adults ≥ 60 years old [6, 11, 20, 21].

For binocular stereoacuity evaluation, participants viewed stereo images on three Frisby stereo-plates which contained a depth cue consisting of a central circular pattern printed on the front rather than back of the plate such that the circular area appears closer than the rest of the image [22]. They viewed the plate with the largest depth differential (340 s of arc (arcsec)) first, and if the depth cue was correctly identified, they viewed the middle plate (170 arcsec), and then the plate with the smallest depth differential (85 arcsec). The SA was recorded based on the thinnest plate where the depth cue was correctly identified. Inability to discriminate the smallest depth differential (SA > 85 arcsec) was considered poor stereoacuity. In addition, a variable for any VI was created if participants had a VA < 20/40, SA > 85, or LCS < 1.55.

Participants answered a series of 8 questions about their self-perceived visual function with Likert-like responses (e.g., no difficulty at all, a little difficulty, moderate difficulty, extreme difficulty, etc.). These questions had been adapted from the National Eye Institute Visual Function Questionnaire-25 (NEI-VFQ-25) [23], and were scored utilizing the 0-100 scoring system where higher numbers indicate better vision. A weighted mean score for these visual function questions (VFQ) was created by averaging the subscale scores [24].

Physical performance

The SPPB was administered at visit year 4, 6, 10 and 11 [25]. The year 4 visit occurred in 2000–2001 and the year 11 visit occurred in year 2007–2008. The overall 12-point SPPB score is constructed from three sub-categories – gait speed, standing balance, and chair stands – each scaled from 0 to 4. Gait speed (m/sec) was measured as the time it took to complete a 6-m walking course. Participants had gait speeds of 0 m/sec recorded if they attempted but were unable to complete the walk test unassisted. Chair stands (stands/sec) were estimated from the amount of time it took for a participant to stand up and sit down from a chair five times without using his/her arms for assistance. The standing balance test (seconds) in Health ABC required participants to maintain side-by-side stand for 10 s and then the semi-tandem, full-tandem, and single leg stands for 30 s each (range 0–90 s total). The cutoffs for each four-point scale based on quartile performance have been previously published [25]. The four-point scales in each category were summed to create a composite SPPB summary score where higher scores indicating better performance.

Statistical analyses

For this analysis, we defined two cohorts, with cohort A consisting of 2219 participants who completed visual function testing at the year 3 study visit (which occurred between 1999 and 2000) and completed the SPPB at year 4 (2000–2001). Participants with worse CS and poor SPPB at year 4 were more likely to have missing outcomes. Individuals with poor SPPB < 10 are at higher risk of mortality [26]. Thus, we sought to examine individuals with better initial SPPB in cohort B who would be more likely to benefit from intervention in a future study. To do this, we defined a second cohort (cohort B) which was limited to the 1795 participants who had visual function testing at year 3 and an SPPB ≥ 9 at year 4 (Supplemental Figure S1). The association between year 3 visual acuity < 20/40 or LCS < 1.55 and baseline participant characteristics was assessed using t-tests for means and chi-square tests for categorical variables in each cohort.

Separate linear mixed effects models (see Supplemental Appendix 1 for complete description of statistical analyses) were constructed to examine the relationship between each visual test at year 3 – either the self-reported VFQ weighted score or performance-based (e.g. VA, LCS, SA, any VI) visual function tests – and the rate of change for each of the performance based physical function measures: (a) SPPB score, (b) gait speed (m/s), (c) balance time (range 0–90 s), (d) chair pace (stands/sec). Since each visual measure captures a different aspect of visual function, they were modeled separately. Results for continuous predictors using logMAR VA, LCS, weighted VFQ or a binary indicator of SA (> 85 vs. ≤ 85) are presented in the main tables/figures and the dichotomous predictors representing any VI, VA < 20/40, LCS < 1.55 and LCS ≤ 1.33 are presented in the Supplemental Materials. Briefly, for the linear mixed effect models, elapsed follow-up time (i.e., change in age) was generated using the exact visit dates for each participant. The rate of change/year in function at the separate levels of year 3 visual function variables were obtained and a contrast (i.e., t-test) for the difference in rates between the worse vs. better vision level was performed. To characterize the linear relationships for continuous variables, we computed the rate of change in physical function (e.g., for SPPB) for two individuals who are 1 standard deviation apart in terms of their visual function and examined the difference in these rates. For the purpose of comparison, the "better" vision level was set at the mean and the "worse" vision level was set to 1 SD worse than the mean. A 1 SD from the mean of logMAR visual acuity is 0.15 which indicates 1.5 lines or ~ 7–8 letters. A 1 SD from the mean of log CS is 0.18 which indicates 3.6 letters.

There was a baseline difference in race for moderately impaired LCS (< 1.55) and in sex for VA (< 20/40) (Table 1). By adding sex by change in age and race by

Table 1 Characteristics of participants in Cohort A by LCS 1.55 or better versus < 1.55 and visual acuity 20/40 or better versus < 20/40

	Overall ***(n = 2219)***	**LCS < 1.55** ***(n = 635)***	**LCS 1.55 or better** ***(n = 1584)***	**LCS** ***P*-value**	**VA < 20/40** ***(n = 911)***	**VA 20/40 or better** ***(n = 1308)***	**VA** ***P*-value**
Age (years) at Year 3, mean (SD)	75.5 (2.9)	76.4 (3.0)	75.2 (2.7)	< 0.0001	76.1 (2.9)	75.2 (2.8)	< 0.0001
Female sex, n (%)	1162 (52.4)	327 (51.5)	835 (52.7)	0.6034	503 (55.2)	659 (50.4)	0.0250
African American race, n (%)	830 (37.4)	297 (46.8)	533 (33.6)	< 0.0001	355 (39.0)	475 (36.3)	0.2039
Physical Function Measures at Year 4							
SPPB, mean (SD)	9.73 (2.05)	9.05 (2.44)	10.00 (1.81)	< 0.0001	9.35 (2.30)	9.99 (1.82)	< 0.0001
Gait Speed (m/sec) over 3, 4, or 6 m, mean (SD)	1.12 (0.24)	1.04 (0.24) (*n* = 626)	1.15 (0.23) (*n* = 1575)	< 0.0001	1.08 (0.24) (*n* = 900)	1.15 (0.24) (*n* = 1301)	< 0.0001
Narrow Walk Gait Speed (m/sec), mean (SD)	0.87 (0.48)	0.71 (0.50) (*n* = 605)	0.93 (0.45) (*n* = 1568)	< 0.0001	0.78 (0.49) (*n* = 884)	0.93 (0.45) (*n* = 1289)	< 0.0001
Chair Pace (stands/sec), mean (SD)	0.34 (0.14)	0.31 (0.16)	0.36 (0.14)	< 0.0001	0.32 (0.15)	0.35 (0.13)	< 0.0001
Balance Time (sec), mean (SD)	64.75 (24.68)	56.82 (27.35)	67.93 (22.76)	< 0.0001	59.58 (26.57)	68.36 (22.59)	< 0.0001
Visual Function Measures at Year 3							
Any Visual Impairment	1303 (58.7)	635 (100.0)	668 (42.2)	< 0.0001	911 (100.0)	392 (30.0)	< 0.0001
Visual Acuity < 20/40, n(%)	911 (41.1)	451 (71.0)	460 (29.0)	< 0.0001	911 (100.0)	0 (0.0)	< 0.0001
Log MAR VA, mean (SD)	0.31 (0.15)	0.41 (0.19)	0.27 (0.11)	< 0.0001	0.44 (0.15)	0.22 (0.06)	< 0.0001
LCS $\leq$ 1.30 log units	180 (8.1)	180 (28.3)	0 (0.0)	< 0.0001	161 (17.7)	19 (1.5)	< 0.0001
LCS, mean (SD)	1.56 (0.18)	1.36 (0.19)	1.64 (0.08)	< 0.0001	1.47 (0.21)	1.63 (0.12)	< 0.0001
Frisby SA > 85 arcsec, n (%)	663 (29.9)	325 (51.2)	338 (21.3)	< 0.0001	376 (41.3)	287 (21.9)	< 0.0001
Weighted VFQ score (scale 0-100), mean (SD)	87.83 (11.99)	81.82 (15.38)	90.24 (9.30)	< 0.0001	84.59 (14.16)	90.08 (9.60)	< 0.0001

LogMAR VA = logarithm of the minimum angle of resolution visual acuity; LCS = log contrast sensitivity; SA = stereoacuity; VFQ = visual question questions; SD = standard deviation

change in age interactions to the models, we investigated for confounding between these variables and rates of decline attributed to levels of vision impairment. We adjusted for possible differential rates of decline included due to initial age, since visual impairment may be associated with age, but could also be in the causal pathway between biological changes due to aging and mobility disability. At times, the HABC study recorded gait speeds as 0 m/sec ($N = 16$ in year 4, $N = 30$ in year 6, $N = 71$ in year 10, $N = 73$ in year 11); for our primary analysis, these participants were treated as having a missing gait speed, but in a sensitivity analysis we left the value of 0. The correlations between individual vision measures were also estimated. All statistical analyses were completed in SAS version 9.4 (SAS Institute, Cary, NC).

Results

Participant characteristics

A total of 2219 participants were included in cohort A and 1795 in cohort B. The mean age at year 3 was 75.5, with 52.5% being female, and 37.4% Black or African American in cohort A. Participant characteristics were stratified by VA < 20/40 and LCS < 1.55 for calculating descriptive statistics (Table 1—Cohort A; Supplemental Table S1—Cohort B). Participants with poor VA or LCS were more likely to be older. Those with poor LCS were more likely to be black, and those with poor visual acuity were more likely to be female. Of note, nearly 80% of participants had hearing impairment (PTA ≤ 40 kHz) in the better ear at year 5, which precluded meaningful consideration of vision independent of hearing. 75% of participants wore corrective lenses for distance or bifocals during visual function testing. The different visual variables showed mild to moderate correlation with each other (see Supplement). LogMAR visual acuity is negatively correlated with LCS (Pearson's correlation=-0.63), and positively correlated with Weighted VFQ score (Pearson's correlation = 0.42). LCS and weighted VFQ score are negatively correlated (Pearson's correlation=-0.36). Frisby > 85 arcsec binary indicator was moderately correlated with each variable (point biserial correlations = 0.25 for visual acuity, -0.35 for LCS, and – 0.25 for weighted VFQ).

SPPB

In Cohort A, for all measures of vision, better vision was associated with an unadjusted rate of change in SPPB of approximately – 0.3 units/year which was similar to the overall, unadjusted rate of change in SPPB of -0.324 units/year, 95%CI (-0.343, -0.305) (Table 2). Those whose year 3 performance was 1 standard deviation (SD) worse than the mean value for logMAR VA, LCS, and weighted VFQ had significantly faster declines in SPPB than those at the mean; similarly, those with a SA score > 85 arcsec had a significantly faster decline in SPPB than those with a stereoacuity score of 85 arcsec or better (all $p < 0.0001$; Table 2; Fig. 1). These differences in SPPB

Table 2 Relationship of visual function with the longitudinal slopes of the change in physical performance in Cohort A (LogMAR, LCS, Frisby, Weighted VFQ)

Physical Function	Vision Variable	Slope (95% CI); *p*-value for Better Vision Value of Vision Variable or at Mean for Continuous Predictors	Slope (95% CI); *p*-value for Worse Vision Value of Vision Variable or 1 SD Worse than Mean for Continuous Predictors	Difference in slopes (95% CI); *p*-value	Sex and Race Adjusted Difference in Slopes (95% CI); *p*-value
SPPB	LogMAR VA	-0.281 (-0.308, -0.254); <0.0001	-0.327 (-0.346, -0.308); <0.0001	-0.046 (-0.066, -0.025); <0.0001	-0.044 (-0.065, -0.024); <0.0001
	Log contrast sensitivity (LCS)	-0.262 (-0.289, -0.235); <0.0001	-0.326 (-0.345, -0.307); <0.0001	-0.064 (-0.085, -0.044); <0.0001	-0.062 (-0.082, -0.041); <0.0001
	Frisby > 85 arcsec	-0.298 (-0.320, -0.276); <0.0001	-0.397 (-0.434, -0.360); <0.0001	-0.099 (-0.143, -0.056); <0.0001	-0.095 (-0.139, -0.052); <0.0001
	Weighted VFQ score	-0.279 (-0.305, -0.252); <0.0001	-0.326 (-0.345, -0.307); <0.0001	-0.048 (-0.068, -0.027); <0.0001	-0.045 (-0.065, -0.025); <0.0001
Gait Speed	LogMAR VA	-0.027 (-0.030, -0.025); <0.0001	-0.029 (-0.030, -0.027); <0.0001	-0.001 (-0.003, 0.000); 0.1307	-0.001 (-0.003, 0.000); 0.1137
	Log contrast sensitivity (LCS)	-0.027 (-0.029, -0.025); <0.0001	-0.029 (-0.031, -0.027); <0.0001	-0.002 (-0.004, -0.000); 0.0262	-0.002 (-0.004, -0.000); 0.0260
	Frisby > 85 arcsec	-0.028 (-0.030, -0.026); <0.0001	-0.031 (-0.034, -0.028); <0.0001	-0.003 (-0.007, 0.001); 0.0938	-0.003 (-0.007, 0.001); 0.1210
	Weighted VFQ score	-0.027 (-0.030, -0.025); <0.0001	-0.029 (-0.030, -0.027); <0.0001	-0.001 (-0.003, 0.000); 0.1213	-0.001 (-0.003, 0.000); 0.1256
Balance Time	LogMAR VA	-2.671 (-2.920, -2.422); <0.0001	-2.893 (-3.072, -2.715); <0.0001	-0.223 (-0.413, -0.033); 0.0217	-0.220 (-0.410, -0.031); 0.0226
	Log contrast sensitivity (LCS)	-2.552 (-2.803, -2.300); <0.0001	-2.903 (-3.081, -2.726); <0.0001	-0.352 (-0.544, -0.159); 0.0003	-0.310 (-0.503, -0.117); 0.0016
	Frisby > 85 arcsec	-2.767 (-2.974, -2.560); <0.0001	-3.183 (-3.532, -2.835); <0.0001	-0.416 (-0.821, -0.011); 0.0443	-0.341 (-0.746, 0.064); 0.0991
	Weighted VFQ score	-2.673 (-2.923, -2.424); <0.0001	-2.890 (-3.068, -2.711); <0.0001	-0.216 (-0.406, -0.027); 0.0255	-0.182 (-0.372, 0.007); 0.0593
Chair Pace	LogMAR VA	-0.016 (-0.017, -0.014); <0.0001	-0.016 (-0.017, -0.015); <0.0001	-0.000 (-0.001, 0.001); 0.6099	-0.000 (-0.001, 0.001); 0.5200
	Log contrast sensitivity (LCS)	-0.016 (-0.017, -0.014); <0.0001	-0.016 (-0.017, -0.015); <0.0001	-0.000 (-0.001, 0.001); 0.6093	-0.000 (-0.002, 0.001); 0.5253
	Frisby > 85 arcsec	-0.015 (-0.016, -0.014); <0.0001	-0.018 (-0.020, -0.016); <0.0001	-0.003 (-0.005, -0.000); 0.0402	-0.002 (-0.005, -0.000); 0.0415
	Weighted VFQ score	-0.016 (-0.017, -0.015); <0.0001	-0.016 (-0.017, -0.015); <0.0001	0.000 (-0.001, 0.001); 0.9442	-0.000 (-0.001, 0.001); 0.9681

SPPB = Short physical performance battery; VA = visual acuity; LCS = log contrast sensitivity; Unadjusted rate of change associated with 1 year of aging: SPPB – 0.324 (-0.343, -0.305); Gait Speed – 0.029 (-0.030, -0.027); Balance – 2.870 (-3.048, -2.69); Chair Pace – 0.016 (-0.017, -0.015)

slopes remained significantly different after adjusting for sex and race (Table 2; Fig. 1).

Cohort B likewise showed significant differences in the SPPB slopes for each vision variable, but the magnitude of the difference in slopes was slightly larger (Table 3; Fig. 2). For example, in cohort A the adjusted difference in SPPB slopes for a 1 SD worse logMAR VA was – 0.044 units/year (95% CI -0.065, -0.024) whereas for Cohort B the difference in SPPB slopes was – 0.058 units/year (95% CI -0.079, -0.037). The difference in slopes for cohort A for a 1 SD worse LCS was – 0.062 units/year (95% CI -0.082, -0.041) and for Cohort B was – 0.072 units/year (95% CI -0.093, -0.051). Similar findings were observed in those meeting cut-offs for impaired VA, LCS and any VI (Supplemental Table S2 and S3 and Figure S2 and S3). In a sensitivity analysis adjusting for age at year 3, the results were somewhat attenuated, yet retained statistical significance for SPPB and all endpoints showed similar patterns to those obtained without this adjustment (Supplemental Figures S4 and S5).

Gait speed

For all measures of visual function in cohort A, the estimate of rate of decline in gait speed at better vision levels was similar to the unadjusted rate of change in gait speed over time of -0.029 m/sec/year (95% CI -0.03, -0.027) (Table 3). There was a significantly faster decline in gait speed among participants with a 1 SD lower LCS compared to the mean (difference in slopes – 0.002 m/sec/year (95% CI -0.004, -0.000, $p = 0.0262$) and this remained significant with adjustment for race and sex, but there was no significant difference in the slopes for those with worse logMAR VA, VFQ, or Frisby SA (Table 2; Fig. 1). However, in cohort B, there was a significantly faster decline in gait speed when comparing logMAR VA, LCS and VFQ values at the mean to those that were 1 SD worse than the mean in both unadjusted and adjusted models (Table 3; Fig. 2). Frisby SA was not significantly associated with a faster decline in gait speed in either Cohorts A or B (Tables 2 and 3).

Using cut-offs that are commonly used for impairment, both moderately impaired (< 1.55) and severely impaired LCS (≤ 1.3) were associated with a faster decline in gait speed than those with better LCS in cohort A (Supplemental Table S2 and Figure S2) and cohort B (Supplemental Table S3, Figure S3). However, VA < 20/40 did not predict declines in gait speed.

In a sensitivity analysis including gait speeds of 0 m/sec in the linear mixed models for cohort A, steeper slopes were observed and the effect of visual function on the slopes was greater (Supplemental Table S4, Figure S6).

Balance time

The overall unadjusted rate of change in balance time was – 2.870 s/year, 95% CI (-3.048, -2.69) in Cohort A. There was a significantly faster decline in balance time among participants with a SA > 85 or a 1 SD worse than the mean value for LCS, logMAR VA, or VFQ compared to those with better visual function (all $p < 0.05$) (Table 2; Fig. 1). When adjusting for race and sex, the difference in slopes remained significant for logMAR VA and LCS. In cohort B, the rate of decline in balance time was significantly steeper for those with worse logMAR VA, LCS, VFQ, and SA in both unadjusted and adjusted models (Table 3; Fig. 2). In addition, the effect size of the balance time slopes and the difference in balance time slopes was larger in cohort B compared to cohort A. For example, the adjusted difference in the relationship of LCS on change in balance over time was – 0.526 s/year (95% CI -0.724, -0.329) in cohort B and – 0.310 s/year (95% CI -0.503, -0.117) in cohort A. Similarly, the adjusted difference in relationship of logMAR VA on balance time slopes for cohort B was – 0.416 s/year (95% CI -0.611, -0.222) and for cohort A was – 0.220 s/year (-0.410, -0.031).

Using cut-offs for impairment, a moderately impaired LCS (< 1.55) in cohort A and B, and a severely impaired LCS (≤ 1.3) in cohort B were associated with a faster decline in balance time than those with better LCS (Supplemental Table S2 and Figure S2) and cohort B (Supplemental Table S3, Figure S3). However, VA < 20/40 did not predict declines in balance time.

Chair pace

For all measures of visual function in cohort A, better vision was associated with a decline in chair pace that was similar to the unadjusted rate of change in chair pace of -0.018 stands/sec/year, 95% CI (-0.019, -0.016). Only SA > 85 arcsec was associated with a significantly steeper decline in chair pace in both unadjusted and adjusted models in cohort A and cohort B (Tables 2 and 3; Figs. 1 and 2), and severely impaired LCS (≤ 1.3) was also associated with steeper decline in chair pace in cohort B (Supplemental Table S3 and Figure S3).

Discussion

In this study, we demonstrated that older adults with worse self-reported or performance-based visual function showed significantly faster declines in performance on the SPPB over time than those with better vision. Different types of visual function had different relationships to the components of SPPB, yet estimated effects were consistently in the same direction and when combined into the composite SPPB measure, provide a distinctive association in all analyses. Among those with an initial SPPB score ≥ 9, there were significant associations

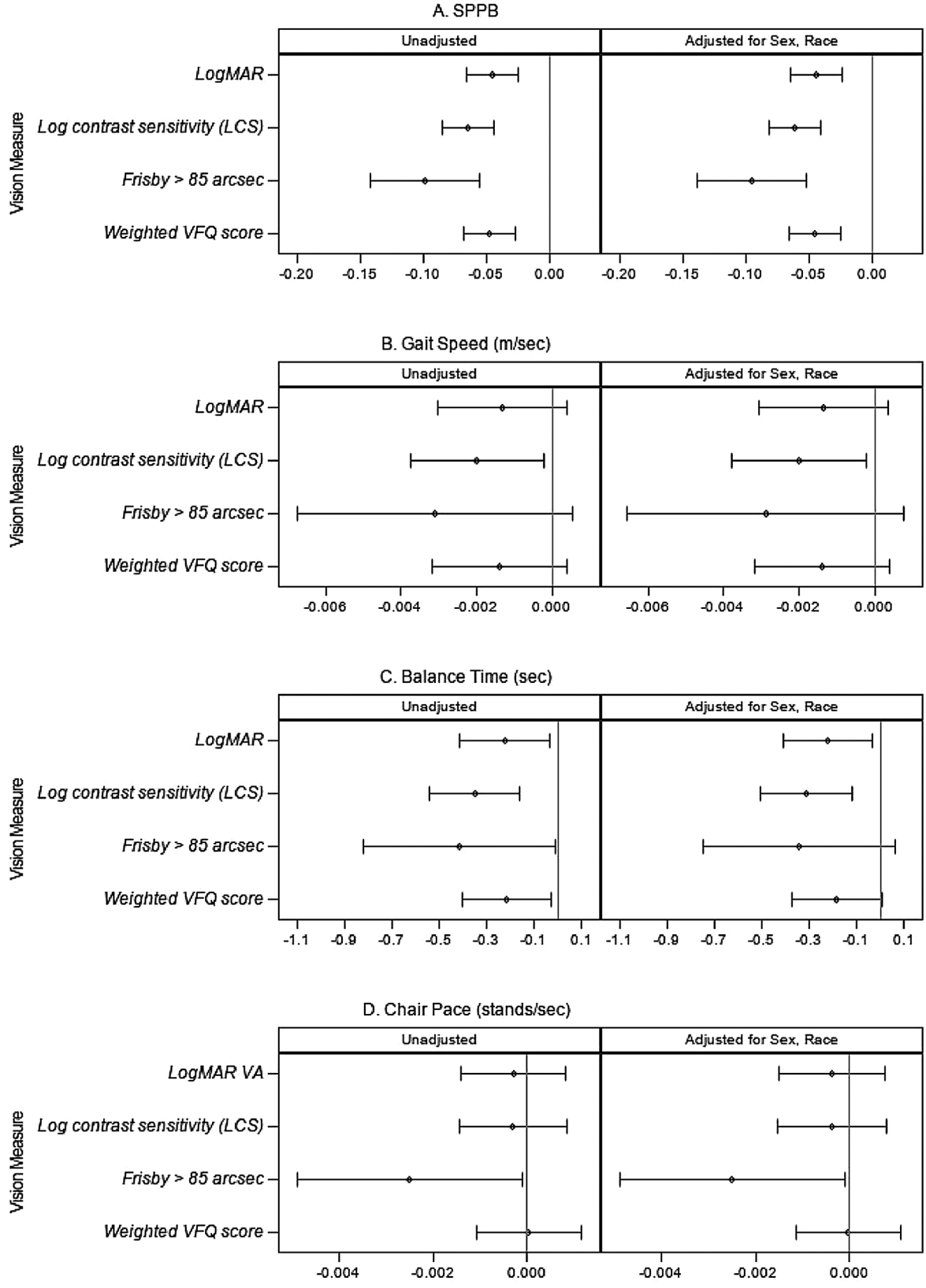

Fig. 1 Differences in Rates of Change of Short Physical Performance Battery Between Levels of Vision in Cohort A. Legend: Difference in the slope of Short physical performance battery (**A**), Gait speed (**B**), Balance time (**C**), and Chair pace (**D**) for worse vision value versus better vision value of categorical vision variable. Vision variables were logMAR visual acuity, log contrast sensitivity (LCS), Frisby stereoacuity > 85 arcsec, weighted visual function questionnaire (VFQ). Point is the difference in the slopes and bars are the 95% confidence interval

Tabl 3 Relationship of visual function with the longitudinal slopes of the change in physical performance in Cohort B (LogMAR, LCS, Frisby, Weighted VFQ) -- limited to participants with SPPB ≥ 9 in Year 4

Physical Function	Vision Variable	Slope (95% CI); *p*-value for Better Vision Value of Vision Variable or at Mean for Continuous Predictors	Slope (95% CI); *p*-value for Worse Vision Value of Vision Variable or 1 SD Worse than Mean for Continuous Predictors	Difference in slopes (95% CI); *p*-value	Sex and Race Adjusted Difference in Slopes (95% CI); *p*-value
SPPB	LogMAR VA	-0.281 (-0.309, -0.252); <0.0001	-0.339 (-0.360, -0.319); <0.0001	-0.059 (-0.080, -0.038); <0.0001	-0.058 (-0.079, -0.037); <0.0001
	Log contrast sensitivity (LCS)	-0.266 (-0.295, -0.238); <0.0001	-0.340 (-0.361, -0.320); <0.0001	-0.074 (-0.095, -0.053); <0.0001	-0.072 (-0.093, -0.051); <0.0001
	Frisby > 85 arcsec	-0.310 (-0.333, -0.286); <0.0001	-0.416 (-0.457, -0.376); <0.0001	-0.106 (-0.153, -0.059); <0.0001	-0.104 (-0.151, -0.057); <0.0001
	Weighted VFQ score	-0.275 (-0.303, -0.246); <0.0001	-0.340 (-0.360, -0.320); <0.0001	-0.065 (-0.087, -0.044); <0.0001	-0.064 (-0.085, -0.042); <0.0001
Gait Speed	LogMAR VA	-0.027 (-0.030, -0.025); <0.0001	-0.029 (-0.031, -0.028); <0.0001	-0.002 (-0.004, -0.000); 0.0366	-0.002 (-0.004, -0.000); 0.0342
	Log contrast sensitivity (LCS)	-0.027 (-0.029, -0.025); <0.0001	-0.029 (-0.031, -0.028); <0.0001	-0.002 (-0.004, -0.000); 0.0128	-0.002 (-0.004, -0.000); 0.0184
	Frisby > 85 arcsec	-0.028 (-0.030, -0.026); <0.0001	-0.032 (-0.035, -0.029); <0.0001	-0.004 (-0.008, 0.000); 0.0606	-0.003 (-0.007, 0.001); 0.0978
	Weighted VFQ score	-0.027 (-0.030, -0.025); <0.0001	-0.029 (-0.031, -0.028); <0.0001	-0.002 (-0.004, -0.000); 0.0381	-0.002 (-0.004, -0.000); 0.0464
Balance Time	LogMAR VA	-2.808 (-3.070, -2.547); <0.0001	-3.229 (-3.417, -3.042); <0.0001	-0.421 (-0.617, -0.226); <0.0001	-0.416 (-0.611, -0.222); <0.0001
	Log contrast sensitivity (LCS)	-2.677 (-2.937, -2.416); <0.0001	-3.241 (-3.427, -3.055); <0.0001	-0.564 (-0.761, -0.367); <0.0001	-0.526 (-0.724, -0.329); <0.0001
	Frisby > 85 arcsec	-3.045 (-3.261, -2.829); <0.0001	-3.688 (-4.062, -3.313); <0.0001	-0.642 (-1.074, -0.210); 0.0036	-0.569 (-1.002, -0.136); 0.0100
	Weighted VFQ score	-2.821 (-3.082, -2.559); <0.0001	-3.231 (-3.419, -3.044); <0.0001	-0.411 (-0.608, -0.213); <0.0001	-0.377 (-0.574, -0.179); 0.0002
Chair Pace	LogMAR VA	-0.017 (-0.018, -0.015); <0.0001	-0.018 (-0.019, -0.017); <0.0001	-0.001 (-0.002, 0.000); 0.0607	-0.001 (-0.002, 0.000); 0.0535
	Log contrast sensitivity (LCS)	-0.017 (-0.018, -0.015); <0.0001	-0.018 (-0.019, -0.017); <0.0001	-0.001 (-0.002, 0.000); 0.1674	-0.001 (-0.002, 0.000); 0.1692
	Frisby > 85 arcsec	-0.017 (-0.018, -0.015); <0.0001	-0.020 (-0.023, -0.018); <0.0001	-0.004 (-0.006, -0.001); 0.0050	-0.004 (-0.006, -0.001); 0.0065
	Weighted VFQ score	-0.017 (-0.018, -0.015); <0.0001	-0.018 (-0.019, -0.017); <0.0001	-0.001 (-0.002, 0.000); 0.1794	-0.001 (-0.002, 0.000); 0.1738

SPPB = Short physical performance battery; VA = visual acuity; LCS = log contrast sensitivity; Unadjusted rate of change associated with 1 year of aging: SPPB −0.337 (-0.358, -0.317); Gait Speed −0.029 (-0.03, -0.027); Balance −3.21 (-3.40, -3.02); Chair Pace −0.018 (-0.019, -0.016)

of worse logMAR VA, LCS and VFQ with decline in gait speed, and all measure of vision were associated with differences in balance time. Moreover, the strength of the associations of vision with SPPB and its components were stronger in cohort B, as they started with a higher level of baseline physical function (e.g. mean SPPB at year 4 was ~0.77 units higher in cohort B vs. cohort A). Overall, the findings highlight that visual impairment can predict decline in SPPB performance over time, especially in older adults who are starting out with higher physical performance.

While many prior studies have suggested that poor visual and physical function are associated [6–14], the majority of investigations have been cross-sectional. Whether particular types of visual function may predict decline in mobility over time has been understudied. Prior investigations of VI to future mobility disability have also yielded mixed results which may stem in part from the higher likelihood of drop-out among participants with visual impairment and mobility disability as well as differences in the measures of vision that were examined. For example, in the Salisbury Eye Study (SEE), participants with VA worse than 20/40 or visual field less than 20 degrees were more likely to self-report mobility disability than those without visual impairment, but the trajectory of mobility disability did not significantly differ between those with and without visual impairment [10]. A separate analysis found SEE participants with VA worse than 20/40 were more likely to self-report functional declines in activities of daily living and instrumental activities of daily living, suggesting progression of disability [7]. A prior study in the Health ABC cohort showed that participants with impaired CS, VA, or SA had higher incident self-reported limitations in walking and stair climbing [11]. However, after 5 years of follow-up, only those with CS and SA impairment reported greater limitations in both. Similarly, in this current analysis, we found that all measures of poor visual function predicted faster declines in SPPB, but that participants in cohort A were less likely to have follow-up if they had worse vision or worse initial SPPB. When examining those with initial SPPB scores of at least 9 in cohort B, we observed a stronger relationship of visual impairment to SPPB decline and some of the subcomponents of SPPB. For example, while steeper declines in gait speed were only associated with worse LCS in cohort A, there were significantly steeper declines in gait speed for those with worse logMAR VA, VFQ and LCS in cohort B. Similarly, there were significantly steeper declines in balance times for those with worse logMAR VA and LCS in cohort A, whereas all measures of visual function were associated with significantly steeper balance times in cohort B. It is also important to consider what defines a clinically meaningful change in mobility performance. Perera et al. have reported that a meaningful change in SPPB ranged from 0.27 to 0.55 units, and recommended 0.5 units as a good estimate for approximating a clinically meaningful change [27]. In the overall cohort A, those without impaired SA would have a predicted decline of greater than 0.5 SPPB after approximately 1.7 years of follow-up, whereas those with SA impairment (SA > 85) would reach this level approximately 5 months sooner. In addition, after 5 years of aging, these two groups would be predicted to have a difference in average SPPB scores that is approximately 0.5 units apart, consistent with a clinically meaningful difference. Similarly, the between group differences in predicted SPPB for continuous vision values 1 SD apart would reach a difference of 0.5 SPPB units (a clinically meaningful difference in the change) after approximately 11 years for logMAR VA, 10 years for the weighted VFQ score, and 8 years for LCS.

The relative importance of vision to future mobility function is also related to how different types of vision are processed and how they may be related to gait and balance. VA is measured using high contrast dark letters on a white background and tests the size of the letter that can be resolved. Older adults with poor distance VA can experience difficulty detecting obstacles which may undermine their confidence when moving through space. Moreover, the ability to resolve objects in daily life is also strongly influenced by the contrast and luminance differences between the object and its surroundings which can greatly vary in real world settings. CS is critical to the perception of edges in low contrast conditions, and like SA, it can affect depth perception. We previously demonstrated a persistent contribution of poor CS and SA to shorter balance times in Health ABC when controlling for VA and VFQ [6]. Lord and colleagues have also shown that impaired CS and SA are associated with greater postural sway on a foam surface independent of quadriceps strength or visual acuity [28]. Compliant or uneven surfaces reduce proprioceptive input, causing one to rely more on other senses such as vision to maintain postural stability and mobility. We have also shown that impaired CS may also be associated with not only poor balance but also slower gait speed in the absence of significant visual acuity impairment [15]. If CS impairment limits one's depth perception or ability to perceive one's position in space while moving in relation to the environment, this may destabilize posture and also lead to a reduction in gait speed. Moreover, difficulty perceiving edge contrasts may limit one's detection of hazards on the ground and increase the risk of falls [29]. The relationship of vision to chair pace over time only showed a significant difference in the slopes for those with worse SA or severe impairment in LCS. Chair pace evaluates functional lower extremity power, so it is intuitive that this may not have a consistent relationship to many aspects of vision.

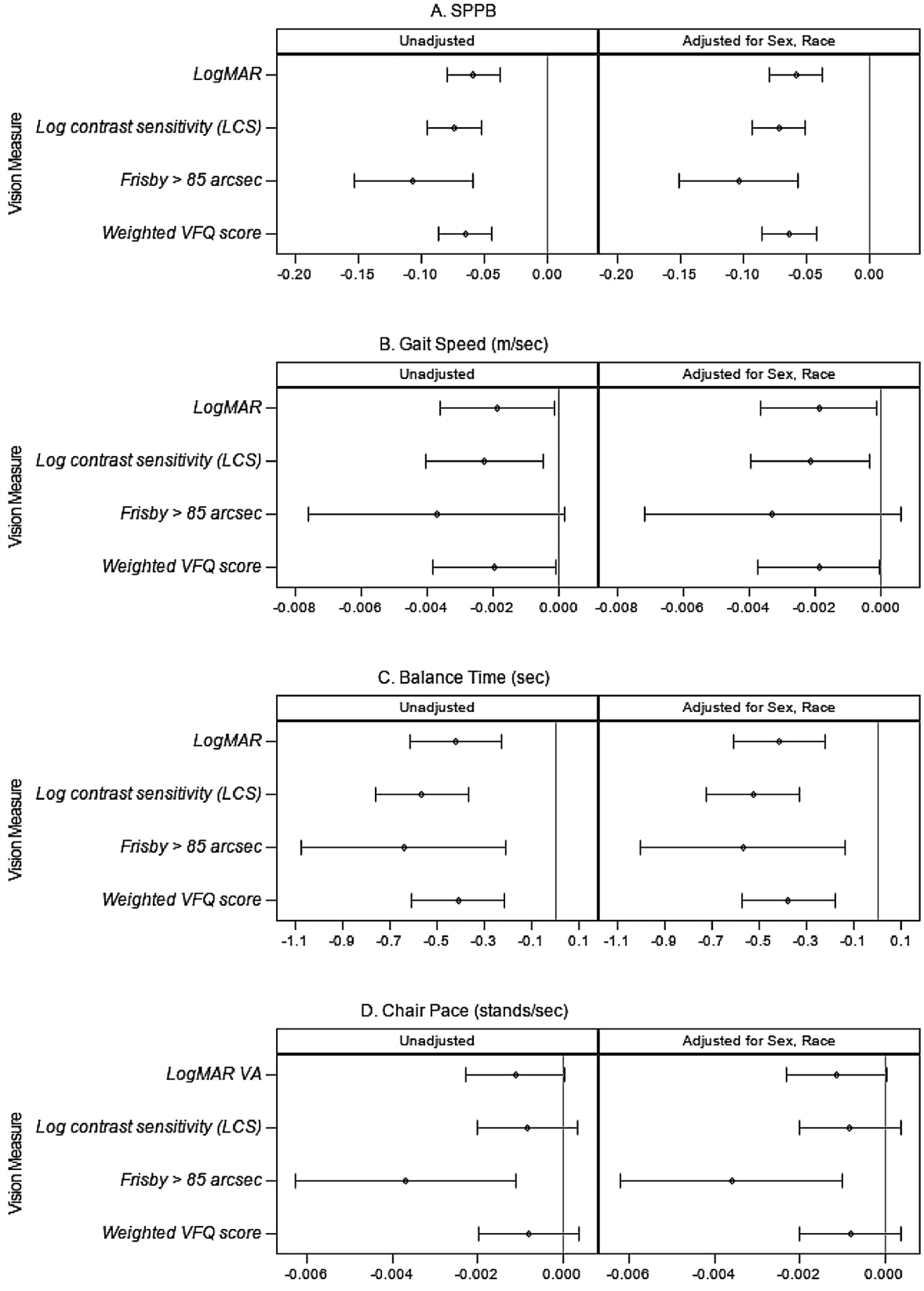

Fig. 2 (See legend on next page.)

(See figure on previous page.)

Fig. 2 Differences in Rates of Change of Short Physical Performance Battery Between Levels of Vision in Cohort B. Legend: Cohort B was limited to participants with SPPB ≥ 9 in Year 4. Difference in the slope of Short physical performance battery (**A**), Gait speed (**B**), Balance time (**C**), and Chair pace (**D**) in cohort B for worse vision value versus better vision value of categorical vision variable. Vision variables were logMAR visual acuity, log contrast sensitivity (LCS), Frisby stereoacuity > 85 arcsec, weighted visual function questionnaire (VFQ). Point is the difference in the slopes and bars are the 95% confidence interval

However, the task requires one to stand up without using one's hands, and it may be that older adults with poor SA and very poor LCS experienced more difficulty with this task due to greater limits in their depth perception which made it harder to stand up unassisted. Thus, CS, SA, and VA impairment may be important risk factors for accelerated decline in mobility function over time, which could predispose to eventual mobility disability.

The importance of these findings depends in part on whether visual function can be intervened upon through treatment and whether such intervention may prevent mobility decline. Stereoacuity deficits that stem from ocular misalignment, or strabismus, may be managed through the use of prisms in glasses or can be corrected with strabismus surgery. Extraocular motility disorders, such as convergence insufficiency, can be treated with ocular convergence exercises. CS and VA impairment are associated with multiple age-related eye diseases (e.g. cataracts, age-related macular degeneration, glaucoma). Treatment of glaucoma and age-related macular degeneration may slow or halt disease progression but it is not known if this could decrease further risk of mobility decline. Cataract surgery, however, is an effective treatment for improvement of both visual acuity and contrast sensitivity, and a recent randomized control trial demonstrated that first eye cataract surgery reduced the rate of falls and risk of fractures in older adults [30]. Recovery of both visual acuity and contrast sensitivity via cataract surgery has also been shown to promote functional and structural brain recovery in visual and cognitive-related areas of the brain [31]. Cataract surgery is also associated with reduced risk of dementia [32], which is a strong risk factor for mobility dysfunction and falls. Whether recovery of CS through cataract surgery could improve mobility and brain function in areas affecting mobility is not known.

Despite the association of poor vision and mobility dysfunction, evidence-based interventions to improve mobility function in older adults with visual deficits are generally lacking and have not been widely implemented. Both exercise and balance training have successfully reduced fall risk in other populations.[30] A recent network meta-analysis published in JAMA for the primary outcome of injurious falls also found that randomized controlled trials that combined exercise and vision assessment and treatment showed a significant reduction in falls compared to usual care [33]. It is possible that older adults with VI may benefit from exercises to improve mobility function or reduce falls, but such interventions may need to be tailored to the needs of patients with low vision. In particular, it may be more beneficial to target older adults who also have better SPPB (> 10) (e.g. cohort B) as they may be more likely to benefit from early interventions that aim to reduce risk for mobility decline or disability.

Limitations

This study has several limitations. Visual function was only measured at one time-point, under binocular testing conditions, and while wearing usual corrective lenses for distance or bifocals. Participants did not complete an ophthalmic examination to assess for eye pathology or refractive error. The description of testing conditions in the public use dataset for Health ABC does not detail the lighting conditions of the test, which could mean the absolute values are underestimating true visual function if the charts were not adequately illuminated. Moreover, the Pelli Robson was tested at a longer distance than the 1-M described in the original methods by Pelli and Robson. The public use study documentation explains that if participants were unable to read the top line (which has the highest contrast) at 10 feet, then they stood at 5 feet to ensure they could read the optotype size (which is large), at maximum contrast. Since the optotype size is uniform across the chart, but the contrast decreases with each letter and line, the measurement of relative contrast is still relevant. However, it is possible the measured values could be underestimating the absolute value of contrast sensitivity function. Thus, the cut-offs should be checked in other population-based cohorts. Participants that had gait speeds of 0 during the longitudinal follow-up were treated as missing values in the primary study results. In a sensitivity analysis, we estimated the impact of these missing gait speeds on the results and found that the strength of the association is attenuated by excluding these visit dates (Supplemental Table S4, Figure S6). However, since a gait speed of 0 m/sec indicates the participant could not complete the gait task unassisted (i.e. without a walker), it may not mean the participant was entirely non-ambulatory. Thus, the true strength of the association between visual function and decline in gait speed over time may fall in between the main paper results (0 m/sec was set to missing) and the sensitivity analysis (0 m/sec was retained). Thus, our analyses are conservative,

and may be underestimating the effect of vision on the slopes of gait and SPPB. Older adults with mobility dysfunction and visual problems may also be more likely to be lost to follow-up which could have biased the remaining sample in cohort (A) We only followed participants through year 11 because of higher attrition rates after that date. Moreover, in a recent systematic review, older adults with SPPB scores < 10 were at significantly higher risk of mortality [26]. Thus, the lower SPPB scores in cohort A could have limited our ability to examine the relationship of vision to mobility due to higher rates of loss to follow-up and mortality. In cohort B we required an initial SPPB of at least 9 at year 4, so that we could better evaluate the relationship of vision to SPPB and its components over time. Not surprisingly, by starting with a cohort that had better initial SPPB scores, we were able to observe a stronger relationship with more vision measures and subcomponents of SPPB in cohort (B) When considering interventions to reduce risk of mobility decline and mortality among those with VI, future studies should consider targeting such older adults with higher baseline functional status before they have severe mobility limitations (i.e. SPPB of 9 or less).

Although analyses of the NEI-VFQ8 and NEI-VFQ9 have been shown to be reliable and valid when compared against visual acuity worse than 20/40, binocular visual field loss, and chronic eye disease [24], the questions on the NEI-VFQ are mostly focused on high contrast settings and may not accurately reflect self-perceptions of impaired contrast sensitivity. However, it is notable that a lower self-reported VFQ score was associated with greater decline in SPPB, including gait speed and balance time. Future studies should investigate whether this simplified questionnaire could be utilized to identify older adults at risk of mobility decline due to poor self-perceived visual function. Of note, the majority of participants had hearing impairment in the better ear at the year 5 visit, which may have also contributed to mobility performance. However, hearing was not evaluated at the same time point as vision which limited the ability to examine the role of multisensory deficits. Moreover, since 80% of participants had hearing impairment at visit 5, it was not feasible to run the analysis in the 20% of the cohort with unimpaired hearing. Also, other conditions that could impact mobility over time, such as cardiovascular or pulmonary fitness, were not included in this analysis as we did not have a priori reasons to believe these would interact with visual function and time.

Conclusions

We have demonstrated that older adults with impairment in multiple visual measures have faster rates of decline in SPPB than those with better vision. In particular, greater declines in gait speed were observed in those with worse VA or LCS, and greater declines in balance time were observed in those with worse VA, LCS or SA. Poor self-reported visual function was also associated with greater declines in SPPB, gait and balance, which could support use of standardized questionnaires to identify older adults with poor vision who may be at risk of mobility decline. Future studies should test whether interventions to improve visual function or mobility can slow or reverse the decline in mobility function of visually impaired older adults, especially those who have better baseline physical function.

Abbreviations

Health ABC	Health, Aging and Body Composition Study
LCS	Log contrast sensitivity
VA	Visual acuity
SA	Stereoacuity
VFQ	Visual function questions
SPPB	Short physical performance battery
NEI-VFQ	National Eye Institute-Visual Function Questionnaire
logMAR	$\log_{10}$ minimum angle of resolution

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions

Study concept and design (ACT, MEM, JDW, SBK), acquisition of data (ACT, CCW, MEM, SBK), analysis of data (CCW, MEM), interpretation of data (ACT, CCW, MEM), initial draft of manuscript (ACT), and revision of manuscript (ACT, CCW, MEM, JDW, SBK).

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Data availability

The data for this study can be requested from the Health ABC study public use dataset (https://healthabc.nia.nih.gov).

Declarations

Ethics approval and consent to participate

The institutional review board at each study site approved the study protocols for the Health, Aging and Body Composition study, and all participants provided written informed consent.

Consent for publication
Not applicable.

Competing interests
Dr. Thompson is a consultant for Topcon Medical, Inc. which had no relationship to this study. The authors have no other conflicts of interest to report.

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