Measures of Visual Function and Percentage of Preferred Walking Speed in Older Adults: The Salisbury Eye Evaluation Project

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Purpose. The purpose of this study was to determine the association of static (visual acuity, visual fields, and contrast sensitivity) and dynamic (dynamic visual acuity and motion threshold) measures of vision with mobility performance on a mobility course with obstacles.

Methods. A cross-sectional population-based study of 1504 persons aged 72 to 92 years enrolled in the third round of the Salisbury Eye Evaluation Project. Standardized examinations were used to test binocular visual acuity, better eye-contrast sensitivity, visual fields, dynamic visual acuity, and motion threshold. Cognitive status was assessed by using the standardized Mini-Mental State Examination. Participants were timed when walking a straight 4-m distance and when walking through a mobility course seeded with obstacles. The percentage of preferred walking speed (PPWS) for each subject was calculated as the ratio of mobility course speed to a 4-m walking speed expressed as a percentage.

Results. The mean age of the participants was 78.2 years. The mean 4-m walking speed was 0.82 m/s, whereas the mean mobility course speed was 0.47 m/s. The mean PPWS was 57.1%. All vision variables except visual acuity were associated with PPWS in univariate analyses. Multivariate models found visual fields and the cognitive state to be associated with PPWS. There was no association with dynamic measures of vision.

Conclusions. The mobility performance, as measured by PPWS, was associated with visual fields but not with visual acuity, contrast sensitivity, or dynamic vision measures. Deficits in cognition also play an important role in predicting mobility performance. (*Invest Ophthalmol Vis Sci.* 2006;47:65–71) DOI:10.1167/iovs.05-0582

The US population over the age of 65 years is rapidly growing. In the 2000 census, 12.4% of the population was 65 years or older.[1] This population is projected to grow to 19.6% by 2030.[2] Aging brings with it the prospect of losing independence, and vast efforts are currently being made to study the factors leading to reduced quality of life in a bid to give the growing elderly population more active years. One such factor is the mobility of individuals. A basic level of physical mobility is required to manage many of the activities of daily living satisfactorily.[3] Reduced mobility performance has been shown to be associated with functional dependence,[4,5] falls in the elderly,[6,7] and nursing home placement,[8–12] and it also has been found to predict depression.[13] Many studies have looked at the link between mobility and mortality, and have shown an association.[3,8,14–16] Apart from the personal costs, the adverse sequelae of mobility impairment carry huge costs to society as well.[17–19]

Reduced mobility has been associated with cardiovascular, cerebrovascular, rheumatologic, and sensory impairments.[20,21] Small-scale convenience samples of visually impaired and/or older adults have shown that decrements in vision adversely affect mobility performance.[22–32] With the exception of a study by Brown et al.,[32] most studies have confined their measures of vision to static variables and have shown that visual fields and contrast sensitivity best predict mobility performance.

Mobility performance can be measured by using several metrics. Some studies have used the number of errors or bumps[22,23,27] while walking a mobility course, and others have used time or walking speed.[29,32] More recent studies have used percentage of preferred walking speed (PPWS).[24–26,30] PPWS was put forward by Clark-Carter et al.[33] as a means to make comparisons of the effect of different aids in improving mobility performance across different low-vision populations. Since then, several studies have used it, because it offers the advantage of allowing subjects to act as their own controls, normalizing the data for age and physical factors.[24–26,30]

This study aimed to determine the role of vision as an explanatory factor for decrements in mobility performance in a population-based sample of older persons. We used PPWS to chart the decrements in mobility performance and assessed its association with both static and dynamic measures of vision, as well as with cognitive status.

Methods

Subjects

The Salisbury Eye Evaluation Project is a longitudinal, population-based study of community-dwelling seniors residing in Wicomico County, MD. The original sample was collected in 1993 and comprised 2520 persons aged 65 to 84 years. A description of the original cohort can be found elsewhere.[34]

Data for this study were collected in round three of the study, which was conducted between 1999 and 2000. Follow-up rates were 95% and 86% of those still alive for the second and third rounds, respectively. The participants (n = 1504) were aged between 72 and 92 years. Basic demographic data were obtained from a structured questionnaire. Cognitive status was assessed by using the standardized Mini-Mental State Examination (MMSE).[35] Body Mass Index (BMI) was calculated as the weight divided by the square of the height, with the

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weight measured in kilograms and the height measured in meters. Data on comorbidities were derived from a structured medical-history questionnaire and were confirmed by a subsequent review of the participant's medical records. All participants were examined at a central location by trained technicians who used standardized protocols.

The research followed the tenets of the Declaration of Helsinki, and written informed consent was obtained from all subjects. The protocols were approved by the Johns Hopkins Medical Institution Review Board.

Measures of Visual Function

We assessed the following static measures of vision: visual acuity (VA), contrast sensitivity (CS), and visual fields (VF). A complete description of the methods to measure these parameters is given elsewhere.[36] All vision assessments were performed by using the subject's habitual refractive correction and were measured only once.

Briefly, VA was measured binocularly with an Early Treatment of Diabetic Retinopathy Study (ETDRS) eye chart[37] and was scored as the number of letters correctly read, which was converted to logMAR in the manner specified by Bailey et al.[38] CS was measured using the Pelli-Robson letter sensitivity test,[39] with the best refraction in place. It was scored as the number of letters correctly read and was converted to log CS, with data for the better eye being used in this study.

Monocular VFs (60° radius) were tested with the 81-point, single intensity (24 dB) screening test strategy on a field analyzer (Humphrey Field Analyzer; Carl Zeiss Meditec, Dublin, CA). Binocular VFs were estimated from a composite of the more sensitive of the two visual-field locations for each eye.[40] The number of points missed were counted for the overall binocular VF.

Two dynamic measures of vision were also tested: dynamic visual acuity (DVA) and motion (image displacement) threshold (MT). DVA was tested using a computer-controlled video display with a Landolt C target that moved left or right at a rate of 50°/s. On each trial, a fixation cross appeared in the center of the screen for 500 msec, after which the target appeared and moved left or right for a duration of 500 msec. The target was oriented up, down, left, or right, randomly determined, and the subject had to indicate the orientation of the Landolt C by means of a joystick. Five trials were presented at each target size. If the subject correctly identified two of the five gap positions, the size of the target decreased by a factor of 0.75. Initial gap size was 0.5° (letter size was 5 times the gap size), with a viewing distance of 1 m. If the subject failed to correctly identify the position of a 2.0° gap in two trials, viewing distance was halved. If at that viewing distance the subject failed to identify the position of a 8.9° gap in two trials, the test was stopped and a "failed" score was reported. Fails were scored as 130 minarc. The threshold was defined as the smallest gap size that the subject correctly identified in at least two trials. Data were converted to natural log (ln) minarc.

MT was measured by using a motion sequence composed of randomly positioned dots that moved uniformly in a particular direction, similar to Turano and Wang.[41] A motion sequence (duration of 1.5 seconds) consisted of 3 images, each containing 50 dots. The patterns were generated by a high-resolution graphics board (1280 × 1024 × 8 bits; IMAGRAPH; IMAgraph Corp., Woburn, MA) controlled by a personal computer and displayed on a high-resolution cathode ray tube (CRT) monitor (IKEGAMI, 19-inch diagonal, P104 phosphor; Ikegami Electronics, Inc., Maywood, NJ). The display was refreshed at 60 Hz, without interlace. The configuration of the dots in each image was the same across frames. Across frames, the dots shifted within a spatially fixed window by a constant amount in one of four directions (left, right, up, or down, randomly determined). On each trial, the subject viewed a single-motion sequence and indicated by means of a joystick the direction of movement. Displacement magnitude varied from trial to trial according to a 3-down 1-up staircase procedure. Testing was terminated after 8 reversals, and the threshold was defined as the mean of the displacements at the reversal points.

Percentage of Preferred Walking Speed

Subjects were asked to walk a 4-m path and also through a complex mobility course with obstacles, as comfortably as they could manage. The 4-m path was a straight, unobstructed length. This walk was timed, and each subject's 4-m walking speed was determined. Subjects were then instructed to walk a predefined mobility course under photopic conditions while avoiding objects in their path. The course was seeded with obstacles, including hanging plants, wastebaskets, and wooden life-size "people." A full description of the course is available elsewhere.[42] Before walking the course, the participants were given directions and were required to repeat them until the observers were sure that they understood them. Subjects were permitted to use their usual mobility aid (e.g., walker, cane). A trained observer followed closely behind to record time, as well as to ensure the safety of the subject.

PPWS is derived by dividing a subject's speed from the mobility course by the speed from walking a straight unobstructed section and expressing the ratio as a percentage.[43] Hence, it maps decrements in mobility performance caused by the complex obstacle course over and beyond a straight unobstructed length where the predictors of speed tend to be physical factors. Vision plays a role in navigating the mobility course, and we had hypothesized that static and dynamic measures of vision were important predictors of the decrement in mobility performance when a complex mobility course was introduced.

Data Analysis

Time data were transformed into speed (in m/s) by dividing the distance of the travel path over the time taken to complete the travel path. This provided a more normal distribution of these measures. Hence, the ratio of the two speeds, PPWS, was approximately normally distributed.

Descriptive statistics were computed for all the measured variables, including means, standard errors, and range. We plotted PPWS against the vision variables to characterize the relationships between them as part of our model building process. Based on these plots, we introduced spline terms to explore if we could better characterize the respective distributions.

To assess the associations between PPWS and our measured variables, we modeled PPWS as a function of VA, CS, VF, DVA, MT, and MMSE in two stages by using linear regression models. First, we looked at the relationship of each variable to PPWS by using univariate analyses to identify potential covariates. Next, we built the most parsimonious multiple linear regression (MLR) model to predict PPWS. Age, BMI, and race were included in the MLR model, despite nonsignificance in univariate analyses, to account for any variations in the vision variables related to these factors. A 4-m walking speed was also included in the model because of the correlation with PPWS, such that lesser PPWS tended to be observed in conjunction with faster 4-m speeds. By including it, we attempted to ensure that any associations found would reflect relationships of visual impairment with decreased effectiveness in compensating for the increased complexity of the mobility course task and not merely the relationship of visual impairment with slower walking speeds. Having arthritis, having had a stroke, and using a mobility aid were not included in the MLR model, because they were not significantly associated in univariate analyses.

Because we were trying to understand how each vision variable impacted PPWS, we were concerned about multicollinearity among these variables. Therefore, we calculated variance inflation factors (VIF) for all the dependent variables in our MLR model. All VIFs were below 2.0, suggesting little multicollinearity among the variables.

Model diagnostics suggested lesser heteroscedasticity (unequal variance of the error term across observations) when we used the ln PPWS as the outcome variable in our MLR models. However, because this approach did not eliminate heteroscedascity altogether due to the skewed distribution of some of the independent variables, a bootstrapping approach[44] was used to confirm the validity of associations found in our least-squares MLR model. We checked residuals for model fit and were satisfied with the symmetry displayed. The results of our bootstrap regression model concurred with those from the MLR model. Most analyses were carried out with a statistical package (Stata, ver. 7.0; Stata Corp, College Station, TX).

Results

Mobility data were available for 1351 (90%) of the subjects in our study. The nonparticipants are described in detail elsewhere.[42] Briefly, those without mobility data had been tested in the home or were deemed physically unable to participate. In addition, 7 participants began but did not complete the mobility test. Subjects who did not attempt the mobility course were more likely to be older, frailer, and to have lower scores on the MMSE.

Table 1 shows the demographic and vision profile of the study population. The mean age of the participants was 78.2 years (4.7 SD), with a range between 72 and 92 years of age. Of the participants, 59% were female and 25% were African American. All measures of vision, as well as MMSE declined with age. After age adjustment, there were no significant differences found in the vision variables between males and females. However, females had significantly higher MMSE scores compared with males, and African Americans tended to have worse scores for the vision tests. The mean 4-m walking speed was 0.82 m/s, whereas the mean mobility course walking speed was much slower, at 0.47 m/s.

Four-m walking speed and mobility course speed were highly correlated ($r = 0.84$, $P < 0.001$) (Fig. 1). The mean PPWS was 57.1% (8.9% SD). The distribution of ln PPWS was relatively normal (Fig. 2). Ln PPWS declined with age, female gender, and being African American (Table 2). As BMI increased, PPWS increased, but this association was marginal (0.01% increase per unit increase in BMI) and not significant.

The relationships between ln PPWS and all vision variables were linear or approximately linear. An example of a smoothed plot is shown in Figure 3A. Regression analyses showed a significant association between PPWS and all the vision variables, except VA, after adjusting for age, BMI, gender, race, and MMSE (Table 2). All associations were in the direction of decreasing ln PPWS with decreases in vision and MMSE. An example is shown in Figure 3B. Having arthritis, having had a stroke, and using a mobility aid were not significant in the univariate analysis. These variables were significantly associated with 4-m and mobility course speed but not with PPWS. Hence, it is likely that PPWS allows subjects to act as their own controls as far as these factors are concerned.

In the multivariate analysis, PPWS was significantly associated with VF loss and MMSE (Table 3), such that PPWS decreased with decreasing visual fields and cognitive state. PPWS also decreased with increases in age, BMI and 4-m walking speed. Our model accounted for 18% of the variability in ln PPWS.

Table 1. Participant Characteristics at Round 3 of the Salisbury Eye Evaluation Project

Characteristic (N = 1504)	n (%)
Age, y	
70–74	463 (30.8)
75–79	561 (37.3)
80–84	321 (21.3)
85+	159 (10.6)
Gender	
Male	618 (41.1)
Female	886 (58.9)
Race	
White	1135 (75.5)
African American	369 (24.5)
BMI	
14–24	462 (30.7)
25–29	557 (37.1)
>30	423 (28.1)
Missing	62 (4.1)
Binocular presenting visual acuity (LogMAR)	
>20/20	572 (38.0)
20/20 to 2/40	768 (51.2)
20/50 to 20/100	106 (7.0)
<20/100	47 (3.1)
Missing	11 (0.7)
Log contrast sensitivity, better eye	
<1.50	394 (26.2)
1.50–1.55	376 (25.0)
1.60–1.70	519 (34.4)
>1.70	197 (13.1)
Missing	20 (1.3)
Binocular visual field (points missed)	
0–14	310 (20.6)
15–22	354 (23.5)
23–32	328 (21.8)
33+	314 (20.9)
Missing	198 (13.2)
Dynamic visual acuity (ln minarc)	
<1.2	407 (27.1)
1.2–1.5	231 (15.4)
1.6–2.0	267 (17.8)
>2.0	460 (30.6)
Missing	138 (9.2)
Motion threshold (minarc)	
<2.0	354 (23.5)
2.0–3.0	439 (29.2)
3.1–4.5	287 (19.1)
>4.5	222 (14.8)
Missing	201 (13.4)
MMSE	
0–18	71 (4.7)
19–23	215 (14.3)
24–30	1207 (80.3)
Missing	11 (0.7)
4-m walking speed (m/s)	
Mean (SD)	0.82 (0.23)
Range	0.51–1.10
Mobility course speed (m/s)	
Mean (SD)	0.47 (0.12)
Range	0.31–0.62
Percentage of preferred walking speed	
Mean (SD)	57.1 (8.9)
Range	24.0–98.8

Discussion

In our population-based study of older adults, we found that participants significantly decreased their walking speed when navigating a complex obstacle-laden mobility course. The percentage decrease was related to increasing age and BMI, lower cognition, and increasing loss of visual fields. Although the dynamic measures of vision showed a univariate association with decrements in mobility performance, they were not significant predictors in our multivariate model. VA was not significantly associated with mobility performance in our univariate or multivariate models.

Our finding of an association between VF and mobility performance is in agreement with the results of most previous studies.[22–24,26,28–30] However, unlike some of these studies[22,23,26,28,30] and other small-scale studies,[25,27] we did not find CS to be a significant factor in the multivariate model. Differences in the measure used for mobility performance is

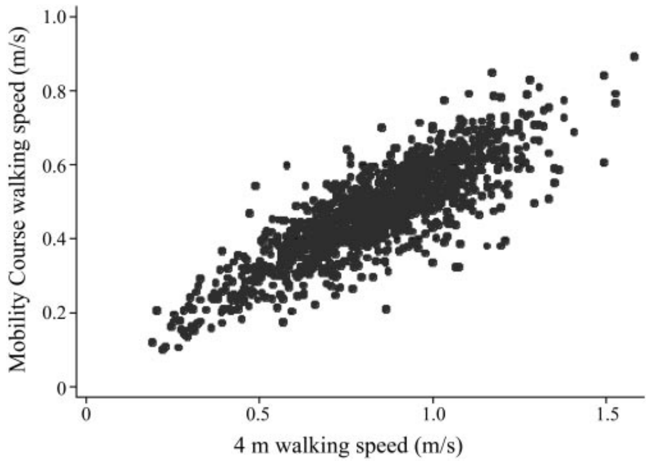

FIGURE 1. Scatter plot of mobility course speed versus 4-m walking speed.

TABLE 2. Univariate Associations of Demographic Factors, Measures of Vision, and Cognition with ln PPWS

Variable	Coefficient	*P* Value
Age (per 5 y)	−0.007	0.16
Gender (female vs. male)	−0.027	0.002
BMI (per unit increase)	0.0002	0.80
Race (African American vs. white)	−0.014	0.17
Mobility aid (use vs. no use)	−0.003	0.86
Arthritis	0.016	0.08
Stroke	−0.010	0.48
Binocular presenting visual acuity (LogMAR)	−0.013	0.54*
Log contrast sensitivity, better eye	0.057	0.01*
Overall visual fields (per 6 points missed)	−0.008	<0.001*
Dynamic visual acuity (per ln minarc)	−0.017	0.005*
Motion threshold (per minarc)	−0.007	<0.001*
MMSE (per unit decrease)	0.010	<0.001†

* Vision factors adjusted for age, BMI, gender, race, and MMSE.
† MMSE adjusted for age and gender.

unlikely to explain the disparate finding. All the previous studies that used PPWS found an association with CS.[25,26,30] In our study, CS was significantly associated with PPWS in univariate but not in multivariate analysis. We examined the intercorrelation between vision variables as a potential explanation for the finding. CS was moderately correlated with VA ($r = 0.49$) and VF ($r = 0.40$). However, the variance inflation factor (VIF) for CS was 1.8 in our multivariate regression model, signifying little multicollinearity with the other variables. The addition of any of the vision variables to the univariate model containing CS caused CS to become nonsignificant, suggesting that it has little role in explaining the variance in PPWS in the presence of the other vision variables. The reason for this is not clear. Our previous work showed an association between CS and the number of bumps on the mobility course.[42] CS reflects the ability to detect the presence of objects in the travel path as a function of object size and its contrast with the surroundings.[45] Hence, it is likely that a deficiency in CS manifests primarily as an increasing tendency to bump into obstacles. Bumping was associated with PPWS, but we did not see an association between CS and PPWS.

Our study found no independent association between the dynamic measures of vision and decrements in mobility performance. This was surprising because, even though there were no moving objects on the mobility course, walking subjects generate motion in the retinal image of static features in the environment. Having moving objects on the course would undoubtedly affect path planning, which may have an effect on the magnitude of the association between MT and PPWS, because MT is a measure of an individual's ability to detect small image displacements. However, unless it was important to determine the fine details of the moving object, having moving objects on the course probably would not affect the magnitude of the association between DVA and PPWS. Previous studies have shown a significant association between mo-

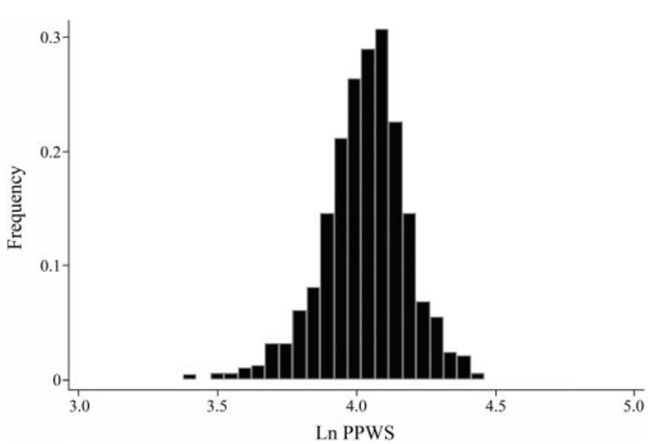

FIGURE 2. Distribution of ln PPWS.

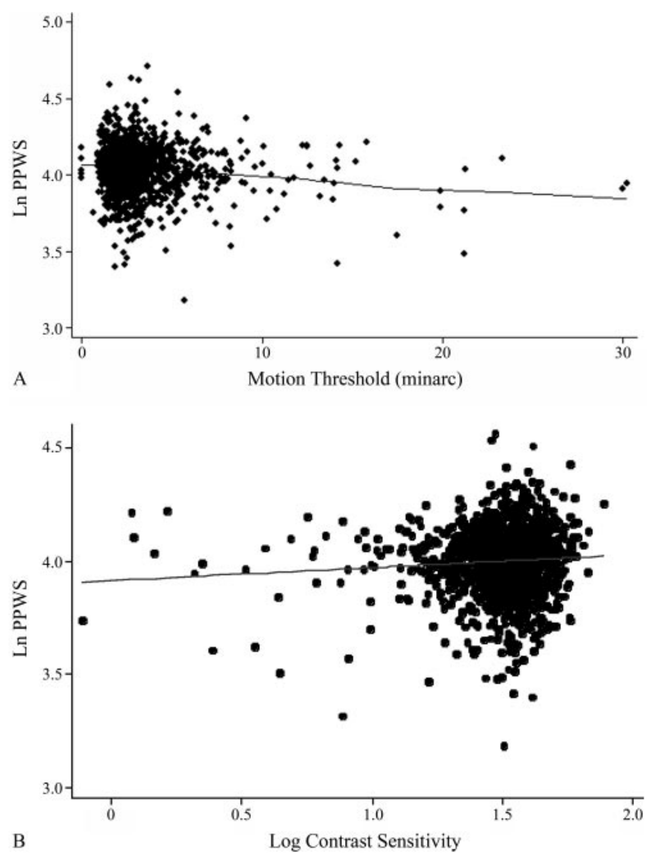

FIGURE 3. Smoothed plot showing the relationship between ln PPWS and motion threshold (**A**). Linear regression for ln PPWS on log contrast sensitivity (adjusted for age, gender, BMI, race, and MMSE) (**B**).

TABLE 3. Associations of Demographic Factors, Measures of Vision, Cognition, and 4-m Walking Speed with ln PPWS in a Multivariate Regression Model

Variable	Coefficient	95% CI*
Age (per 5 y)	−0.0041	−0.0064–−0.0024
Gender (female vs. male)	−0.0080	−0.0251–0.0095
BMI (per unit increase)	−0.0026	−0.0044–−0.0011
Race (African American vs. White)	−0.0055	−0.0279–0.0152
Binocular presenting visual acuity (LogMAR)	−0.0016	−0.0496–0.0660
Log contrast sensitivity, better eye (letters read)	−0.0671	−0.1361–0.0023
Visual fields (per 6 points missed)	−0.0066	−0.0102–−0.0018
Dynamic visual acuity (per ln minarc)	−0.0105	−0.0235–0.0046
Motion threshold (per minarc)	−0.0014	−0.0088–0.0003
MMSE (per unit decrease)	0.0090	0.0054–0.0126
4-m walk speed (m/s)	−0.3341	−0.3861–−0.2832

* From bootstrap regression model.

tion thresholds and postural sway,[46,47] such that the more a feature had to move before its motion was detected, the more a standing person swayed. It could be that threshold-level performance is not needed to effectively navigate around a mobility course. Mobility performance may only be affected when a person suffers a substantial loss in the dynamic measures. Another possibility is that, although the VIFs for the vision factors were below 2.0, which suggested a low multicollinearity among the variables, the collinearity among the variables was sufficient to diminish the strength of the association between DVA and PPWS.

Our study also found a significant association between cognition and PPWS. As the MMSE score decreased, there was a decline in PPWS. It makes sense that mentation plays a role in our mobility task, which involved the comprehension of a set of instructions, some degree of memory capacity to retain these instructions, and the dynamic processing of obstacle information followed by the issuing of motor commands to avoid them, as the subject walked the course. Viser[48] also reported a significantly lower walking speed for demented elderly patients.

We found that vision variables and MMSE explained 18% of the variance in PPWS. Other factors likely to affect PPWS include scanning ability[49] and cognitive processes, such as mental effort[50] and visual attention.[51] In addition, psychological factors are likely to play a part as suggested by Beggs.[24]

Several population-based studies have looked at the associations of measures of vision with mobility performance. However, their measures of mobility performance were vastly different from ours. West et al.[28] dichotomized the results of walking back and forth along a 10-foot length as fast as possible in 1 min into pass/fail, whereas Klein et al.[52] used speed from walking a straight 3-m length in their longitudinal study. The visual demands in carrying out these tasks are not intensive, and the influence of physical factors would be far greater in these tasks. Not surprisingly, Klein et al. [52] reported no association of visual function with decrements in mobility performance over a 5-year period. The study by Turano et al. [29] of 47 subjects with glaucoma compared their walking speeds with 47 normal-vision subjects on a straight, unobstructed route and on an obstacle-laden course. Although they showed that the visually impaired subjects walked significantly slower than normal-vision subjects, there was considerable overlap in walking speeds on the unobstructed route. This suggests that on a relatively simple route, visual impairment does not highly discriminate mobility performance.

One of the characteristics of PPWS is that it is supposedly not sensitive to where a subject is on the walking-speed spectrum. For example, for two subjects who have the same difference between the 4-m walking speed and the mobility-course walking speed, their PPWS changes depending on whether the 4-m walking speed is at the higher or the lower end of the distribution. If one subject had a 4-m walking speed of 0.8 m/s and an obstacle course speed of 0.4 m/s, while another subject had a 4-m walking speed of 0.6 m/s and an obstacle course speed of 0.2 m/s, the absolute difference in speeds is the same (0.4 m/s) for both subjects, whereas the PPWS varies markedly (50% vs. 33%). While this difference is a reflection of the subjects walking efficiency to a great extent, it does depend on how fast the subject walks the 4-m section. Including a 4-m walking speed in our model controls for where on the speed spectrum a subject walks, thereby circumnavigating the effect of the magnitude of the 4 m speed on PPWS. In our multivariate model, we found that a 4-m walking speed was independently associated with PPWS, such that, as subjects walked the 4 m faster, their PPWS was lower. Hence, faster 4-m walkers could not attain the same proportional mobility-course speed as slower 4-m walkers.

In general, our mobility-course walking speed was similar to that reported by others. Kuyk and Elliott[27] and Lovie-Kitchin et al.[53] reported speeds of 0.40 m/s and 0.42 m/s, respectively, from mobility courses that were similar to ours. Brown et al.[32] reported a walking speed of 0.67 m/s for their ARMD subjects on an indoor course under photopic conditions. However, this course did not include any obstacles, and they had a younger population who were most likely fitter and who have a lower BMI. Hassan et al. [30] reported a mean preferred walking speed (walking 20 m) of 1.1 m/s from their sample of 21 ARMD subjects, which was faster than our mean 4-m walking speed. This is somewhat surprising given that their subjects were of similar age. However, their mean PPWS of 42.2% was less than our mean PPWS, probably because of the faster straight course speed, which made it harder to attain a higher PPWS as we found in our study. The ARMD of the subjects may have contributed to the lower PPWS as well.

There are some limitations to our study. Firstly, this is a cross-sectional analysis of associations, and causal inferences cannot be made. It is likely that those with visual loss of a longer duration use compensatory mechanisms to make mobility performance more efficient. Furthermore, ours was an indoor course, which eliminated the effects of environmental variability and did not include any moving objects, thereby reducing fidelity to the real world.

In summary, our data support the conclusion that VF loss and decreased mentation, as measured by MMSE, each contribute independently to decrements in mobility performance as measured by PPWS in our population-based sample. Other static measures and the dynamic measures of vision did not play a significant role in predicting decrements in mobility performance on a complex mobility course. Given the consequences of poor mobility, the association between vision and mobility adds a further claim to targeting interventions toward maintaining or improving visual health in the elderly.

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