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Non-standard Vision Measures Predict Mortality in Elders: The Smith-Kettlewell Institute (SKI) Study

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Abstract

Purpose—To determine which vision tests predict mortality within 10 years in a community-based elderly sample.

Methods—Nine hundred residents of Marin County, CA, aged 58 to 101 (mean 75 years at baseline), underwent a battery of tests, including high contrast acuity, low contrast acuity, low contrast/low luminance acuity, acuity in glare, contrast sensitivity, color vision, stereopsis, standard and attentional fields. The association between the vision tests and mortality within 10 years of baseline was assessed with Cox Proportional Hazards models controlling for age, sex, education level, depression, cognitive status and self-reported medical conditions.

Results—Forty-three percent of the sample died within 10 years of baseline. When controlling for mortality-related covariates, impairment in any of the vision measures was associated with increased risk of death. However, non-standard vision measures (i.e. impairment in low contrast/low luminance acuity, standard field integrity and the impact of the attentional task on field integrity) were more highly associated with mortality than standard high contrast acuity.

Conclusions—In agreement with other studies, we find that visual impairment is a significant predictor of death. However, the strongest relationship was found for measures other than high contrast acuity. These results suggest that non-standard vision measures may be more sensitive indicators of generalized aging in the oldest-old.

Keywords

Aging; Attentional visual fields; Mortality; SKILL Dark Acuity; Visual impairment

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Introduction

Many researchers have investigated the relationship between vision and mortality in aging individuals. Most report statistically significant increases in the risk of death with eye diseases[1-17] (But see also[18]) and visual impairment.[4,9,15,19-30] (But see also[17])

To our knowledge, of the studies that have assessed the relationship between visual impairment and mortality, only one has included a vision measure other than high contrast acuity. Pedula et.al. (2006) found that women with reductions in high contrast acuity or contrast sensitivity had a higher mortality rate than those with good vision on either measure.[26]

Some authors have begun to question the strong reliance on standard acuity for vision assessment (for a review, see[31]). Clearly, high contrast acuity is the “gold standard” used by clinicians and researchers alike, but recent research suggests that it may not be the best predictor of everyday function, particularly when considering the rapidly growing elderly population.[32-38] Studies have shown that, although elders maintain good high contrast acuity into old age, the same individuals can show a wide range of performance on non-standard vision tests.[36,39,40]

The purpose of the current study is to confirm the previously reported association between visual impairment and mortality, but also to extend our understanding of this relationship by including vision measures other than standard high contrast acuity. Models were adjusted for age, sex, self-reported medical conditions, depression and cognitive status, since these variables are associated with mortality. (e.g. [41-44])

Materials and Methods

Participants

Smith-Kettlewell Institute (SKI) Vision Study[32,39] participants were a sub-sample of the Buck Center for Research in Aging's (BCRA) population-based study of health and functioning (H&F) of older adults in Marin County, CA. The BCRA Study has been described in detail previously.[45] Briefly, the BCRA cohort (non-institutionalized residents of Marin County, CA, aged 55 and older) was identified through Health Care Financing Administration of Medicare-eligible residents (those 65 years and older) and through random digit dialing. Sixty-nine percent (N=2018) of those eligible agreed to participate in the baseline wave of the BCRA H&F Study (between 1989-91), and N=1521 participated in the follow-up BCRA H&F wave (1992-95).

Potential subjects for the SKI Study Vision sample were identified from those who had participated in the BCRA H&F follow-up (N=1521). Of these, 92.8% were eligible and invited to participate in the SKI Vision Study (N=1410). This included all participants aged 80 years and older, and a random sample of 88% of those younger than 80. Of the 1410 subjects eligible to participate, 9% had died since completing the H&F follow-up, 27% refused, and <1% could not be located. Nine hundred elders (63.8%) participated in the SKI Study at baseline (11/92-12/95), and the remaining sample was tested at three subsequent

follow-up (FU) waves of testing (i.e. FU1: 1/98-7/99, N=597; FU2: 1/00-3/02, N=452; FU3: 2/05-12/06, N=254), and the final wave began in 7/08.

This study adhered to the tenets of the Declaration of Helsinki, and was approved by the Institutional Review Board (IRB) for Smith-Kettlewell Eye Research Institute and the California Pacific Medical Center. At each wave of testing, an explanation of all test procedures was given and each participant signed the IRB-approved consent form.

Measures

Vision Measures—The SKI Study was intended to assess vision in a group of elderly individuals under everyday viewing conditions; all testing was completed binocularly with the participant's presenting (habitual) correction (glasses or contact lenses).

The vision test battery used for the SKI Study has been described in detail elsewhere.[39] The vision tests used for the current analysis are listed below.

1. High- and low-contrast distance acuity were assessed using Bailey-Lovie charts[46,47] at a 3 m viewing distance.
2. Low contrast/low luminance acuity was assessed with the dark chart of the Smith-Kettlewell Low Luminance (SKILL) Card[48] at a 40 cm viewing distance. The SKILL Dark chart consists of black letters on a dark grey background.
3. Low contrast acuity in the presence of surrounding glare was assessed with the Berkeley Glare Test[49] at 40 cm.
4. Contrast Sensitivity was assessed using the Pelli-Robson Chart[50] at a 3 m viewing distance. The chart was scored letter by letter (each letter corresponds to 0.05 log unit).[51]
5. Stereopsis was assessed using the Frisby Test.[52] This test measures the type of depth perception that requires the two eyes to operate together, and is important for near tasks. The test consists of 3 plates of different thickness. At a viewing distance of 40 cm, the plates yield disparities of 340, 170, and 85 arcsec, with smaller numbers indicating better performance.
6. Color vision was assessed using the Farnsworth Panel D-15 Test.[53] This test requires that participants demonstrate color discrimination by placing colored caps in the appropriate order starting at a fixed color. The calculated Color Confusion Score indicates the severity of the color defect. A score of 0 indicates no arrangement errors (i.e. perfect performance).[54]
7. Standard and attentional visual fields were measured with a modified Synemed perimeter.[39] The test consisted of detection of bright, peripheral flashed targets without and with an added attentional task (silently counting central flashes). Standard field score was the percentage of locations missed (corrected for false-positive responses). The attentional field was scored as the percentage of locations missed (corrected for false positive responses AND the difference between actual and reported central attentional flashes). The difference between the attentional and

standard field scores yielded a measure of the impact of attention on visual field integrity. This measure is somewhat similar to the useful field of view.[55,56]

All acuity measures (1-3 above) were scored as number of letters read correctly and converted to logarithm of the minimum angle of resolution (logMAR). These acuities are also reported as a "Snellen equivalent" (e.g. 20/20).

For each vision measure, two visual impairment "pass/fail" criteria were computed, and participants were coded as 0 (pass) or 1 (fail). These criteria were devised to define visual impairment for the non-standard acuity measures that are comparable to those of standard high contrast acuity. For high contrast acuity, Criterion 1 was "worse than 20/40" or >0.30 logMAR, which is equivalent to 3 lines (0.30 log units) poorer than the "normal" visual acuity of 20/20 (0.0 logMAR). Criterion 2 was "worse than 20/70" or >0.54 logMAR, which is equivalent to 5.4 lines poorer than "normal" acuity.

The first criterion (20/40) is the requirement for driver's licensure, and has been used by many previous mortality studies. [4,9,15,17] The second criterion (20/70) is used to qualify an individual legally as visually impaired and thus eligible for the associated services. Separate analyses were run using the two visual impairment criteria.

A method similar to that used for high contrast acuity was employed to establish comparable criteria for the other vision measures used in this study. For each measure, a "normal" value was defined (i.e. a value expected in a young, healthy individual). For spatial vision measures (i.e. acuities and contrast sensitivity: 1-4 above), Criteria 1 and 2 were defined as 0.30 and 0.54 log units worse than this young, normative value. Normal values were defined for stereopsis, color vision, standard field integrity and the impact of attentional task on visual field integrity, and cut-off values were selected. Table 1 presents the normal values and the two visual impairment cut-off criteria used for each vision variable.

Other Covariates—Baseline age and years of education were included as continuous variables. The remaining covariates were coded as dichotomous variables.

The Center for Epidemiological Studies-Depression Scale (CES-D)[57,58] was used to assess the presence of depressive symptoms. The CES-D for each participant was categorized as 'not depressed' (CES-D score <16) or 'depressed' (score of 16 or more).

The Short Portable Mental Status Questionnaire (SPMSQ)[59] was used to indicate cognitive status. The SPMSQ was categorized as 'no cognitive impairment' (< 3 errors) or 'cognitively impaired' (3 or more errors).

Self-reported medical conditions were obtained by asking each participant "Have you been told by a doctor that you have…." (heart disease, hypertension, cancer, diabetes, stroke, arthritis). Each variable was categorized as 'not reported' or 'reported'.

Mortality Status—Date of death was obtained from the Social Security Death Index, local newspaper obituaries, or reports from relatives. Years from baseline to date of death was

calculated for each participant, and those known to be alive for over 10 years after their baseline measure or missing were censored.

Data Analysis

Stata/SE 9.2 for Macintosh (Stata Corporation, College Station, TX) was used for all data analyses. To assess the difference between survivors and those who died, t-tests were used for continuous variables, and chi square tests were used for categorical measures.

Initial univariate analyses to assess the risk of death within 10 years of baseline were conducted using Kaplan-Meier estimates, followed by multivariate Cox proportional hazards models adjusting for age, sex, and all possible covariates. Proportional hazards assumptions for the separate models were tested using Stata's linktest, as well as tests based on the Schoenfeld residuals.[60]

Preliminary analyses also included all possible “age by variable” and “sex by variable” interaction terms. None was significant ($p<0.10$) and therefore interaction terms were therefore excluded from the final analyses.

Results

The mean age of the 900 participants at baseline was 75.5 years (SD=9.3, range=58.4-101.9), and 46.0% of the participants were male. As noted previously,[38] this is a highly educated sample, with 73.4% reporting more than 12 years of education. Within 10 years of the baseline test, 43.0% (N=387) of the participants had died. Mean time to death for these individuals was 5.18 years (SD=2.65, range=0.08-9.86). Table 2 presents the baseline characteristics for the total sample, those who were still alive, and those who died within 10 years of baseline. As expected from previous studies, those who died were more likely than the survivors to be older, male, less well-educated, cognitively impaired, and to self-report a history of several medical conditions. Participants who died within 10 years of baseline were not significantly more likely than survivors to be depressed, although there was a trend in this direction ($p=0.07$).

Table 3 presents descriptive statistics for the vision variables separately for the survivors and for those who died. Means and standard deviations for each measure are presented, along with the percentage of participants who failed according to the two sets of visual impairment pass/fail criteria. Regardless of whether the data were analyzed as continuous measures (t-tests) or as dichotomous measures (chi squares), each vision measure was significantly worse in the group who died within 10 years of baseline when compared with survivors ($P<0.0001$).

The results of Cox Proportional Hazards Models are presented in Table 4. This table present hazards ratios (HRs) and 95% confidence intervals (CIs), for each individual vision variable adjusted for covariates (age, sex, education level, cognitive impairment, depression, and each individual self-reported medical condition) for both visual impairment criteria.

When using Visual Impairment Criterion 1 (Table 4: high contrast acuity worse than 20/40, reduced by >0.30 log units with comparable reductions from normal in other vision

measures), all individual vision variables except high contrast acuity are significantly associated with mortality even when controlling for all other covariates. HRs range from 1.30 (CI: 1.02-1.66) for low contrast acuity to 1.69 (CI:1.35-2.13) for standard visual field integrity. When Visual Impairment Criterion 2 is used (Table 4: high contrast acuity worse than 20/70, reduced by >0.54 log units with comparable reductions from normal in non-standard measures), all individual variables except color vision remain significant when other covariates are included. HRs range from 1.40 (CI: 1.11-1.78) for impact of attentional task on visual field integrity, to 1.94 (CI: 1.52-2.47) for standard visual field integrity.

Since many of the vision variables under investigation are significantly correlated (particularly the spatial vision measures), including all simultaneously in regression models would cause their effects to cancel out. Therefore, stepwise Cox proportional hazards regression models were used to determine the vision variables with the strongest relationship to mortality while adjusting for all other covariates. Both backward and forward stepping models were run, and these yielded the same significant vision variables for both visual impairment criteria: Low contrast, low luminance acuity, standard visual field, and the impact of attentional task on visual fields.

The final model including all covariates along with these three vision variables for the two Visual Impairment Criteria is presented in Table 5. HRs and CIs are provided for all variables. For Visual Impairment Criterion 1 (i.e. reduction in vision comparable to 20/40 acuity), age, sex, self reported heart disease, low contrast/low luminance acuity, standard visual field and impact of attentional task on visual field are statistically significant. The same variables were also significant for Criterion 2 (i.e. reduction in vision comparable to 20/70 acuity), along with self-reported history of stroke.

Discussion

Each of the vision measures assessed was associated with mortality at either visual impairment criterion. However, when controlling for age, sex and other mortality-related covariates, visual impairment defined as high contrast acuity poorer than 20/40 or 20/70 was not as strong a predictor as other vision measures with equivalent criteria as defined by reduction from young normal. In fact, for the 20/40 criterion commonly used, high contrast acuity was not a significant predictor of death when age is included in the model.

These results are consistent with those reported by Knudtson et al (2006), that visual impairment was associated with reduced survival for the younger (<65) but not older (65-84) age groups[15]. Similarly, Kulmala et. al. (2008) found that visual acuity was associated with mortality in 75-year-old participants, but not 80-year olds[28]. The mean age of our sample at baseline was 75.5 years, with ages ranging from 58 to 103 years. It is likely that the older age of our participants could account for the weaker association between high contrast acuity and mortality.

Most other studies evaluating the relationship between visual impairment and mortality used a visual impairment criterion of 20/40 best-corrected in better eye, [4,9,15,17] whereas our tests were all performed with habitual (presenting) correction under binocular viewing conditions.

Since uncorrected refractive error is a common occurrence with older individuals,[61-64] our 20/40 cut-off likely included a number of participants who would have been classified as unimpaired with the proper spectacle correction. This could account for our lack of a significant association between high contrast acuity and mortality when controlling for other covariates (Table 4, Criterion 1).

We do not regard this as weak point for our study, since it could be argued that testing vision under participants' normal everyday viewing conditions would be a more valid indication of their functional abilities,[38] and some have recommended that the International Classification of Disease (ICD) criterion for defining visual impairment be changed to habitual (presenting) acuity.[65, 66]

The findings of the current study are somewhat different from the results reported by Pedula et al (2006), who also used habitual, binocular viewing conditions.[26] When using all-cause mortality as the outcome measure, these investigators found that both high contrast acuity and contrast sensitivity were independent predictors. Although these authors state that Pelli-Robson contrast sensitivity was used, the description provided appears to be for grating contrast sensitivity, so test differences could contribute to the lack of agreement between the studies. Furthermore, since the data in that study were evaluated in quartiles of increased impairment, it is difficult to compare directly to the current study or to address in relationship to clinically meaningful standards.

It is likely that the non-standard vision measures investigated in the current study serve as surrogates for some eye conditions that have been shown to be associated with mortality. We would hypothesize that failure on such tests in the presence of normal visual acuity is indicative of subclinical eye disease. As stated previously, eye diseases such as cataracts, age-related macular degeneration and glaucoma are significantly associated with mortality. We cannot directly test this hypothesis, because information on eye disease was not available for all participants. Although all participants were asked to provide permission to access their eye records, many records were unavailable due to: participant refusal, records were not provided by the participant's eye practitioner, and several participants reported never having seen an eye doctor. Furthermore, many of the records obtained were not concurrent with vision test dates in a manner that would allow us to definitively say whether the participant had eye disease at the baseline test.

Complete information on all three age-related eye conditions was available for 803 participants (89.2% of the sample). Partial information (incomplete for one or two eye conditions) was available for 73 participants (8.1% of the sample), and no information was available for an additional 24 participants (2.7% of the sample). When separate analyses including existing eye condition information were conducted (either excluding those with missing data or using imputation techniques to replace missing values), the pattern of results was similar to that reported in Tables 4 and 5. As expected, the associations between each of the spatial vision measures and mortality were reduced.

Further research is needed to assess the potential public health impact of this finding. We suggest that, in addition to regular medical and vision screenings, older individuals could be

given simple non-standard vision tests, and those who do poorly could be evaluated in a more comprehensive health evaluation.

In conclusion, we find that non-standard vision tests, and in particular low contrast, low luminance acuity and visual field integrity in the absence or presence of an additional attentional task, are significant predictors of mortality within 10 years in this sample of community-dwelling elders. Furthermore, these non-standard vision tests appear to be more sensitive predictors of mortality than high contrast acuity in this elderly sample.

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Table 1

Vision Variables, Normative Values, and Pass/Fail Cut-off Values for Two Visual Impairment Criteria.

Vision Variables	"Normal" Values*	Visual Impairment Pass/Fail Criteria*	
		Criterion 1	Criterion 2
High Contrast Acuity	20/20 (0.0 logMAR)	20/40 (>0.30 logMAR)	20/70 (>0.54 logMAR)
Low Contrast Acuity	20/27 (0.12 logMAR)	20/53 (>0.42 logMAR)	20/91 (>0.66 logMAR)
Low Contrast/Low Luminance Acuity	20/40 (0.30 logMAR)	20/80 (>0.60 logMAR)	20/138 (>0.84 logMAR)
Low Contrast Acuity in Glare	20/40 (0.30 logMAR)	20/80 (>0.60 logMAR)	20/138 (>0.84 logMAR)
Contrast Sensitivity	1.85 log units (1.4%)	<1.55 log units (2.8%)	<1.30 log units (5.0%)
Stereopsis	16 arcsec (pass all 3 plates)	>85 arcsec (fail ≥ 1 plate)	>320 arcsec (fail all 3 plates)
D-15 Color Vision	Color confusion score = 0	Color confusion score ≥30	Color confusion score ≥100
Standard Visual Field	0 errors	≥ 5% errors	≥ 10% errors
Impact of Attentional Task on Field	0 errors	≥ 25% errors	≥ 50% errors

*Acuity measures are presented in Snellen equivalent and (logMAR). Contrast Sensitivity is presented in log units and % Weber contrast.

Table 2

Baseline Characteristics for the Total Sample and by 10-year Mortality Status.

Baseline Characteristics	Total Sample (N=900)	Alive (> 10 years after Baseline) (N=513)	Died (within 10 years of Baseline (N=387)	
Age, mean (SD), years	75.5 (9.3)	71.4 (7.4)	80.8 (8.9)	
Sex (% male)	46.0%	42.3%	50.9%*	
Education, mean (SD), years	14.7 (3.0)	15.1 (2.6)	14.2 (3.5)	
% Depressed (CES-D Score >15)		7.8%	6.4%	9.6%†
% Cognitive Impairment (SPMSQ>2)	5.5%	3.7%	8.0%	
% Self-Reported Medical History:				
Hypertension	42.4%	38.5%	47.6%	
Heart Disease	34.7%	25.6%	46.8%	
Cancer	30.6%	28.0%	34.1%*	
Stroke	8.3%	4.3%	13.7%	
Diabetes	7.7%	6.2%	9.6%†	
Arthritis	35.8%	30.9%	42.4%	

Alive vs. Died: All statistically significant ($p<0.005$) except where noted:

* $p<0.05$,

† $p>0.05$

Table 3

Vision Characteristics and Percentage of Participants Failing Each Test for each Visual Impairment Criterion by 10-year Mortality Status.

	Alive			Died		
Vision Variables	**Mean (SD)**	**Criterion 1 % Fail**	**Criterion 2 % Fail**	**Mean (SD)**	**Criterion 1 % Fail**	**Criterion 2 % Fail**
High Contrast Acuity (logMAR)	0.07 (0.18)	6.2	1.7	0.25 (0.29)	26.4	9.9
Low Contrast Acuity (logMAR)	0.30 (0.21)	19.9	5.4	0.53 (0.31)	53.7	25.9
Low Contrast/Low Luminance Acuity (logMAR)	0.61 (0.21)	42.8	11.6	0.88 (0.34)	77.8	46.5
Low Contrast Acuity in Glare (logMAR)	0.72 (0.29)	56.8	19.7	1.07 (0.47)	85.1	58.2
Contrast sensitivity (log units)	1.63 (0.27)	27.9	6.0	1.32 (0.43)	64.9	31.2
Stereopsis (plates passed)	2.43 (0.93)	35.3	9.3	1.67 (1.40)	58.7	32.7
D-15 Color Vision (Color confusion Score)	16.1 (42.2)	15.3	4.4	40.5 (71.6)	35.5	11.7
Standard Visual Field (% errors)	3.4 (8.7)	19.1	7.3	9.7 (14.7)	54.3	33.4
Impact of Attentional Task on Field (% errors)	21.5 (22.6)	34.9	10.6	37.5 (26.6)	64.2	27.4

Alive vs. Died: All statistically significant ($p<0.0001$). See Table 1 for the pass/fail criteria for each individual vision variable.

Table 4

Odds of Dying within 10 years of Baseline by Visual Impairment Criteria: Results of Cox Proportional Hazards Models.

Vision Variables	Visual Impairment Criterion 1 HR (95% CI)	Visual Impairment Criterion 2 HR (95% CI)
High Contrast Acuity	1.27 (0.98-1.65)§	1.49 (1.05-2.13)‡
Low Contrast Acuity	1.29 (1.01-1.64)‡	1.42 (1.09-1.85)†
Low Contrast/Low Luminance Acuity	1.47 (1.11-1.94)†	1.83 (1.45-2.32)*
Low Contrast Acuity in Glare	1.45 (1.05-2.00)‡	1.53 (1.19-1.96)†
Contrast Sensitivity	1.32 (1.02-1.71)‡	1.59 (1.24-2.05)*
Stereopsis	1.33 (1.07-1.66)‡	1.56 (1.23-1.98)*
D-15 Color Vision	1.32 (1.05-1.65)‡	1.11 (0.80-1.54)§
Standard Visual Field Integrity	1.68 (1.33-2.11)*	1.92 (1.51-2.45)*
Impact of Attentional Task on Field	1.51 (1.20-1.91)*	1.40 (1.11-1.78)†

Models adjusted for all factors listed in Table 2 (age, sex, education, depression, cognitive impairment, and self-reported health conditions). HR= Hazard Ratio, CI = Confidence Interval. Significance levels:

*p <0.001;

†p<0.01;

‡p<0.05;

§p>0.05.

See Table 1 for the pass/fail criteria for each vision variable.

Table 5

Odds of Dying within 10 years of Baseline by Visual Impairment Criteria: Results from Cox Proportional Hazards Models.

Variable	Visual Impairment Criterion 1 HRs (95% CIs)	Visual Impairment Criterion 2 HRs (95% CIs)
Age (per 5 years)	1.32 (1.22-1.43)*	1.33 (1.24-1.43)*
Sex (male)	1.48 (1.20-1.82)*	1.49 (1.21-1.84)*
Education (per year)	0.99 (0.95-1.02)§	0.99 (0.96-1.03)§
Cognitive Impairment (SPMSQ >2 errors)	1.23 (0.85-1.79)§	1.18 (0.81-1.72)§
Depression (CESD score >15)	1.04 (0.74-1.47)§	1.08 (0.77-1.54)§
Hypertension (self report)	1.20 (0.98-1.48)§	1.20 (0.97-1.48)§
Heart Disease (self report)	1.64 (1.34-2.01)*	1.54 (1.26-1.89)*
Cancer (self report)	1.05 (0.61-1.79)§	1.13 (0.67-1.92)§
Stroke (self report)	1.33 (0.84-2.12)§	1.60 (1.01-2.53)‡
Diabetes (self report)	1.08 (0.76-1.54)§	0.96 (0.67-1.37)§
Arthritis (self report)	1.05 (0.59-1.86)§	1.02 (0.58-1.81)§
Low Contrast/Low Luminance Acuity	1.39 (1.04-1.84)‡	1.70 (1.33-2.16)*
Standard Visual Field Integrity	1.61 (1.28-2.02)*	1.69 (1.33-2.17)*
Impact of Attentional Task on Field	1.46 (1.16-1.84)†	1.37 (1.08-1.73) †

Adjusted for all variables listed in this table. HR= Hazard Ratio, CI = Confidence Interval.

Significance levels:

* p <0.001;

† p<0.01;

‡ p<0.05;

§ p>0.05.

See Table 1 for the pass/fail criterion for each vision variable.