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ORIGINAL RESEARCH

Sensory Impairment, Functional Balance and Physical Activity With All-Cause Mortality

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Objective: No study has comprehensively examined the independent and combined effects of sensory impairment, physical activity and balance on mortality risk, which was this study's purpose. **Methods:** Data from the population-based 2003–2004 National Health and Nutrition Examination Survey (NHANES) was used, with follow-up through 2011. Physical activity was assessed via accelerometry. Balance was assessed via the Romberg test. Peripheral neuropathy was assessed objectively using a standard monofilament. Visual impairment was objectively assessed using an autorefractor. Hearing impairment was assessed via self-report. A 5-level index variable (higher score is worse) was calculated based on the participant's degree of sensory impairment, dysfunctional balance and physical inactivity. **Results:** Among the 1658 participants (age 40–85 yrs), 228 died during the median follow-up period of 92 months. Hearing (Hazard Ratio [HR] = 1.18; $P = .40$), vision (HR = 1.17; $P = .58$) and peripheral neuropathy (HR = 1.06; $P = .71$) were not independently associated with all-cause mortality, but physical activity (HR = 0.97; $P = .01$) and functional balance (HR = 0.59; $P = .03$) were. Compared with those with an index score of 0, the HR (95% CI) for those with an index score of 1 to 3, respectively, were 1.20 (0.46–3.13), 2.63 (1.08–6.40) and 2.88 (1.36–6.06). **Conclusions:** Physical activity and functional balance are independent contributors to survival.

Keywords: epidemiology, exercise, survival

Research demonstrates that sensory impairment (eg, vision, hearing, and peripheral neuropathy) is associated with increased mortality risk. For example, of the 18 studies examining the vision impairment-mortality relationship, most,[1–15] but not all,[16–18] reported a statistically significant relationship. However, only 6 studies (with 4 of them derived from 2 data sets)[4,7,9,11,16,17] accounted for physical activity when examining the vision impairment-mortality relationship. Importantly, each of these 6 studies used self-report physical activity methodology, which is prone to considerable measurement error.[19] Further, among the 6 studies including self-report physical activity as a covariate when examining the vision impairment-mortality relationship, most of these studies used a discrete classification of physical activity (eg, walking disability vs. no walking disability). Carefully considering physical activity in the vision-mortality relationship is important because vision impairment is associated with reduced physical activity.[20–24] Additionally, among the studies examining the relationship between vision impairment and mortality, the majority of them were conducted in non-U.S. populations, including adults from Australia,[6,7,9,14] China,[1,3,18] Denmark,[17] Finland,[11] France,[12] and India.[5] Among the U.S.-based samples, 2 were representative samples,[8,15] with the others employing convenience samples in California,[13] Maryland,[2] Wisconsin,[4,16] or 4 centers across the country (Oregon, Minnesota, Maryland, and Pennsylvania).[10]

In addition to vision, research demonstrates that reduced hearing sensitivity, and in particular, hearing impairment, is predictive of premature mortality.[14,25–40] Similar to the studies evaluating the vision-mortality relationship, the majority of these studies have come from non-U.S. populations, utilizing nonrepresentative samples, and almost exclusively employed older adult samples. Hypothesized mechanisms to explain the hearing-mortality relationship include 1) increased risk of frailty,[41] 2) increased risk of other sensory impairments (eg, vision impairment),[30] 3) increased fall risk,[42] 4) social isolation,[43] 5) communication difficulties,[44] 6) increased cardiovascular disease risk,[45,46] and 7) impaired psychological functioning.[47] In addition to these potential mechanistic factors, it is possible that the association between hearing impairment and premature mortality may also be a result of the detrimental effects that hearing function may have on physical activity levels.[22,48–50] Residual confounding may be a possibility in the previous studies[14,25–40] examining the association between hearing impairment and mortality as few of these studies statistically controlled for physical activity, which is not surprising as only recently has research demonstrated that hearing impairment is associated with reduced physical activity.[22,48–50]

In addition to vision and hearing, and although less investigated, work also demonstrates an independent contribution of peripheral neuropathy on all-cause mortality risk.[51,52] Each of these factors (vision, hearing and peripheral neuropathy) may influence functional balance,[42,53,54] which is important to consider as dysfunctional balance is associated with reduced physical activity,[55] and reduced physical activity is associated with increased mortality risk.[56–59]

No study, to date, has examined the independent contributions of visual impairment, hearing impairment, peripheral neuropathy, dysfunctional balance and physical inactivity on all-cause mortality risk. In addition, no study has examined the potential combined effects of these parameters on all-cause mortality risk. As a result, the purpose of this study was to examine the potential independent and combined effects of each of these 5 parameters on all-cause mortality risk.

Methods

Design and Participants

Data from the 2003–2004 National Health and Nutrition Examination Survey (NHANES) were extracted for the current study; only available cycle inclusive of all data studied herein. Participants

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from the 2003–2004 NHANES were tracked through December 31, 2011 for mortality assessment. All study procedures were approved by the National Center for Health Statistics Ethics Review Board, with consent obtained from all participants before data collection. NHANES employs a representative sample of noninstitutionalized Americans, using a multistage, complex probability study design. Further details of NHANES can be found elsewhere (http://www.cdc.gov/nchs/nhanes.htm). In the current study, 1658 adults (age 40–85 yrs) provided data for analysis.

Mortality Assessment

The number of individuals deceased during the follow-up period (between 2003–2011) was calculated by comparing the participant's personal identification information with the National Center for Health Statistics' National Death Index. Positive matches were then examined manually for further validation, whereas individuals who had no signs of mortality were considered living at the time of census.

Balance Assessment

Balance assessment of NHANES has been described in previous work.[55] Briefly, balance testing consisted of using the modified Romberg Test of Standing Balance on firm and compliant support surfaces. This test evaluated the participants ability to stand unassisted under 4 different conditions (ordering in increasing levels of difficulty) designed to test sensory inputs from the vestibular system, vision, and proprioception: test 1-eyes open, firm surface; test 2-eyes closed, firm surface; test 3-eyes open, compliant surface; and test 4-eyes closed, compliant surface. Participants were allowed 2 trials for each condition. For all tests, balance was scored as pass or fail. With tests 1 and 2 lasting 15 seconds and tests 3 and 4 lasting 30 seconds, test failure was defined as the participants needing to open their eyes, moving their arms or feet in increase stability, or beginning to fall or requiring assistance to maintain balance. Similar to others,[60] participants were classified as having dysfunctional balance if they failed any of the 4 test conditions. Functional balance, in contrast, was operationally defined as successful completion of all 4 of the test conditions.

Physical Activity Assessment

Assessment of accelerometer-determined physical activity has been described in previous NHANES work.[23,61,62] Physical activity assessed using the ActiGraph 7164 accelerometer. The ActiGraph 7164 accelerometer is a small activity monitor (size of a wrist watch) that was worn on the waist to measure the frequency, intensity and duration of physical activity over a 7-day period. SAS (version 9.2) was used to reduce accelerometry data to those with ≥ 4 days of ≥ 10 hr/day of monitored data and integrate it into 1 minute time intervals. Nonwear time was identified as ≥ 60 consecutive minutes of 0 activity counts, with allowance for 1 to 2 minutes of activity counts between 0 and 100. Activity counts/min ≥ 2020[63] was used as the threshold to determine time spent at moderate-to-vigorous physical activity (MVPA) across the valid days (ie, days with at least 10+ hrs of monitoring). The average MVPA level across these valid days was calculated for each participant.

Vision Assessment

Assessment of visual acuity has been described in previous NHANES work.[22,55,64–66] Briefly, presenting visual acuity was assessed for each eye. In eyes with a presenting visual acuity of 20/30 or worse, corrected lenses were removed (if worn) and objective refraction was measured using an autorefractor (ARK-760; Marco) in the mobile examination center. Visual acuity of the better-seeing eye was used to classify participants given that sight in the better eye is the most relevant to disability in numerous visual disorders. Participants with presenting better-eye visual acuity of 20/40 or better were considered to have normal sight. Participants with presenting visual acuity worse than 20/40 but postrefraction visual acuity in either eye of 20/40 or better were considered to have uncorrected refractive error. Participants with visual acuity worse than 20/40 after autorefraction or who self-reported not being able to see light with both eyes open were considered to have vision impairment. Participants with missing data for presenting acuity in both eyes or with visual acuity worse than 20/40 in both eyes with no autorefraction in either eye were excluded from the analysis because they were considered to have incomplete visual acuity data. Thus, a 3-level visual acuity variable was created, including normal vision, uncorrected refractive error and visual impairment.

Hearing Assessment

For hearing assessment, and as described in previous NHANES work,[67] participants were asked whether their hearing was good, a little trouble, a lot of trouble, or deaf. For these analyses, this hearing variable was dichotomized into 'a lot of trouble or worse' vs. good/little trouble. Although a limitation of this study, we chose not to use the objectively-measured audiometry data in our analyses because the audiometry assessments were conducted on a limited sample of 2003–2004 participants (ie, only one-half sample of those between 20 to 69 years). This self-report hearing variable has, however, demonstrated some evidence of convergent validity by associating with depression symptoms and mobility function.[67]

Peripheral Neuropathy Assessment

Described in previous NHANES work,[68] participants aged 40 years and older completed the peripheral neuropathy exam except when they refused testing or met 1 of the following exclusion criteria: 1) bilateral amputation, 2) weight over 400 pounds, 3) presence of conditions (eg, casts) that interfered with testing, or 4) inability to understand the test instructions. Briefly, participants assumed supine position on an exam table while a trained health technician applied slight pressure (approximately 10-g filament force) to the bottom of each foot while using a standard monofilament (5.07 Semmes-Weinstein nylon monofilament). In a nonsequential order, pressure was applied at 3 sites on each foot: the plantar-first metatarsal head, the plantar-fifth metatarsal head, and the plantar hallux. A site was considered insensate if the participant incorrectly determined when the monofilament was applied to the foot on at least 2 of 3 applications.[69] Participants were defined as having peripheral neuropathy if the examination determined at least 1 insensate area in either foot[69] based on prior work showing that this level of sensory loss is predictive of ulcers and amputations, and has demonstrated high sensitivity and specificity.[70,71]

Calculation of Combined Sensory, Balance, and Activity Index

A 5-level index variable was calculated based on the participant's degree of sensory impairment, dysfunctional balance and physical inactivity. Those with visual impairment were given a score of 1; those with a lot or worse hearing trouble were scored as 1; those with peripheral neuropathy were scored as 1; those with dysfunctional balance were scored as 1; and those below the median level of MVPA

(< 10 min/day) were given a score of 1. Thus, the range for this index variable was 0 to 5, with higher scores indicating a worse score.

Covariates

Covariates included were age (continuous; yrs), gender, race-ethnicity (Mexican American, other Hispanic, non-Hispanic white, non-Hispanic black, and multiracial), glycosylated hemoglobin (A1C) levels (continuous; %), measured waist circumference (continuous; cm), and medications used to treat dizziness or balance problems (yes/no).

Data Analyses

Analyses were computed using Stata (v. 12) and accounted for the complex survey designed employed in NHANES. A multivariable Cox proportional hazard model was used to examine the independent associations of sensory impairment, balance and physical activity on all-cause mortality risk.

Results

Among the 1658 participants, 228 died during the median follow-up period of 92 months (IQR = 87 to 100 months). In the sample, 147,995 person-months occurred with a mortality incidence rate of 1.54 deaths per 1000 person-months. Characteristics of the study variables across mortality status is shown in Table 1.

Table 2 displays the adjusted Cox proportion hazard results. Hearing (Hazard Ratio [HR] = 1.18; $P = .40$), vision (HR = 1.17; $P = .58$) and peripheral neuropathy (HR = 1.06; $P = .71$) were not independently associated with all-cause mortality. For every 1 min/day increase in MVPA, participants had a 3% reduced risk of all-cause mortality (HR = 0.97; $P = .01$). Similarly, after adjustments, those with functional balance (vs. dysfunctional balance) had a 41% reduced risk of all-cause mortality (HR = 0.59; $P = .03$). Figure 1 displays the Kaplan-Meier survival curve across balance status.

Another Cox proportional hazard model was evaluated that examined the combined effects of sensory impairment, balance and activity (ie, the Index variable) on all-cause mortality risk. After adjusting for age, gender, race-ethnicity, A1C, waist circumference, balance-related medications and difficulty with falls in the past year, there was evidence of dose-response relationship for this Index variable. Compared with those with an index score of 0, the Hazard Ratios (95% CI) for those with an index score of 1 to 3, respectively, were 1.20 (0.46–3.13), 2.63 (1.08–6.40) and 2.88 (1.36–6.06). Figure 2 displays the Kaplan-Meier survival curve across this Index score.

Table 1 Study Variable Characteristics Across Mortality Status (N = 1658)

Variables	Alive at censor (n = 1430)	Not alive at censor (n = 228)
Age, mean years	55.1 (0.4)	70.6 (1.3)
% female	52.6	46.6
Race/ethnicity, %		
Mexican American	4.7	4.1
Other Hispanic	2.6	1.2
Non-Hispanic White	79.3	78.7
Non-Hispanic Black	8.8	12.2
Other race	4.7	3.8
Glycosylated hemoglobin (A1C), mean %	5.59 (0.03)	5.78 (0.05)
Waist circumference, mean cm	98.2 (0.3)	99.9 (1.1)
Waist circumference for men, mean cm	102.6 (0.6)	102.6 (0.8)
Waist circumference for women, mean cm	94.3 (0.4)	96.8 (1.8)
Moderate-to-vigorous physical activity, min/day	21.2 (0.9)	8.0 (1.1)
Falling problems in the past year, % yes	3.4	10.6
Difficulty with hearing, % yes	3.7	13.9
Visual impairment, % yes	0.9	6.3
Peripheral neuropathy, % yes	11.5	25.4
Off balance due to medication, % yes	3.4	7.6
Functional balance, % yes	62.0	26.9
Combined Sensory, Balance, and Activity Index, %		
0	38.1	9.8
1	36.6	18.7
2	20.1	45.8
3+	5.2	25.7

Table 2 Multivariable Cox Proportion Hazard Model Examining the Association Between Sensory Impairment, Balance, and Physical Activity With All-cause Mortality Risk (N = 1658)

Variables	Hazard ratio	95% CI	*P*-value
Difficulty with hearing vs. not	1.18	0.77–1.78	0.40
Visual impairment vs. not	1.17	0.63–2.14	0.58
Peripheral neuropathy vs. not	1.06	0.75–1.50	0.71
MVPA, 1 min/day increase	0.97	0.94–0.99	0.01
Functional balance vs. not	0.59	0.37–0.94	0.03
Covariates			
Age, 1 yr increase	1.08	1.06–1.09	<0.001
Female vs. male	0.54	0.35–0.84	0.009
Race/ethnicity			
Mexican American vs. white	1.32	0.76–2.25	0.29
Other Hispanic vs. white	0.66	0.23–1.89	0.41
Black vs. white	1.97	1.34–2.88	0.002
Other vs. white	1.02	0.32–3.21	0.97
Glycosylated hemoglobin (A1C), 1% increase	1.07	0.92–1.23	0.31
Waist circumference, 1 cm increase	0.99	0.98–1.01	0.93
Balance medication, yes vs. no	1.53	0.91–2.57	0.09
Problems with falling in past year, yes vs. no	1.62	0.82–3.19	0.14

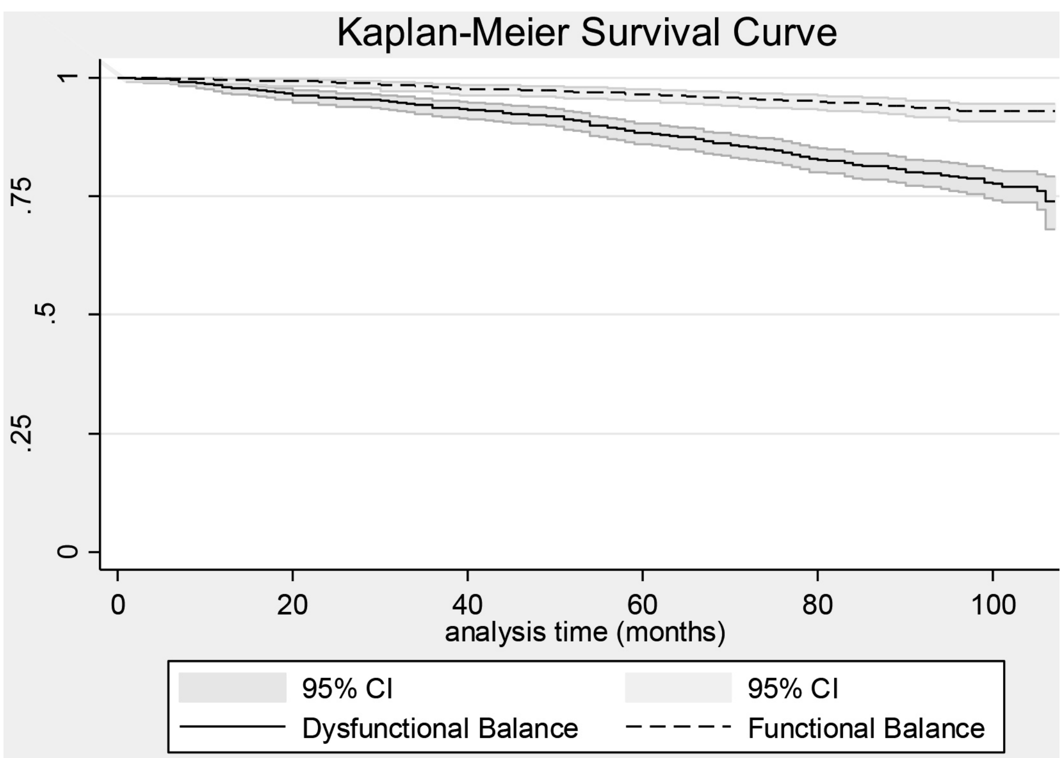

Figure 1 — Kaplan-Meier survival curve across balance status.

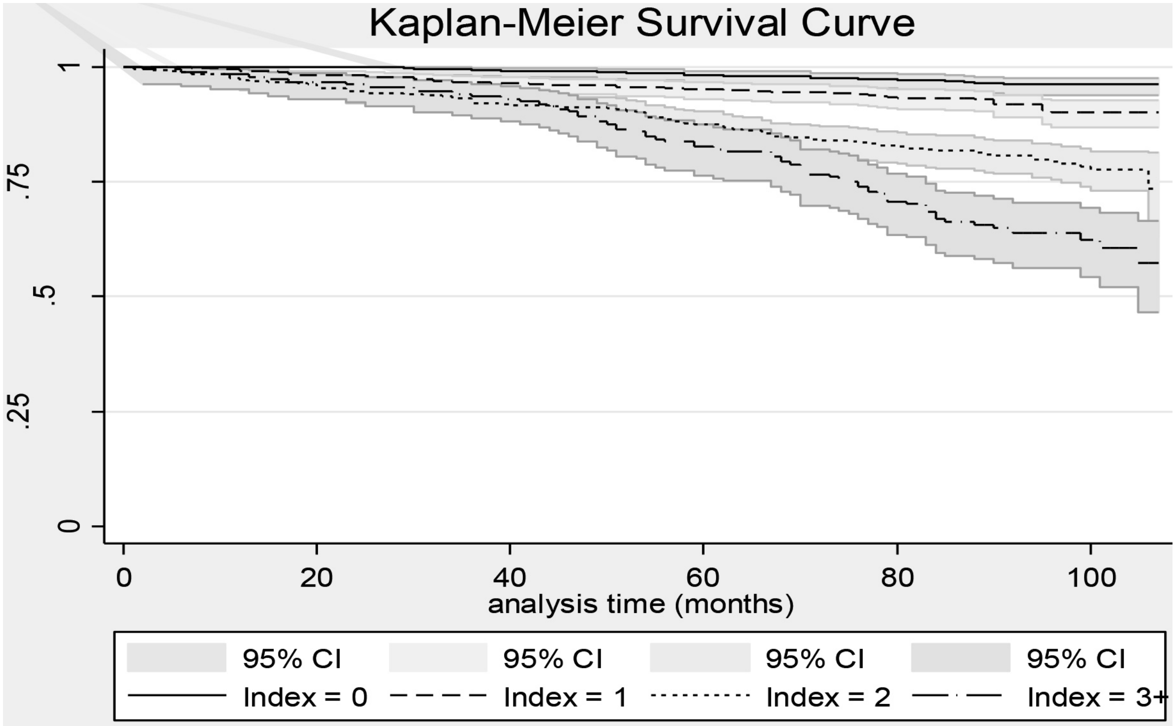

Figure 2 — Kaplan-Meier survival curve across the combined index score. One point was given to those with visual impairment, a lot of hearing difficulty, peripheral neuropathy, dysfunctional balance, and below the median level of moderate-to-vigorous physical activity (< 10 min/day). Thus, the range for this index variable was 0 to 5, with higher scores indicating a worse score.

Discussion

Previous research demonstrates independent contributions of visual impairment, hearing impairment and peripheral neuropathy on all-cause mortality risk. This, however, was not confirmed in the current study, possibly as a result of the limited sample size for these impairments. Previous work also demonstrates that sensory impairment is associated with reduced physical activity and worse balance, with the current study demonstrating that these 2 parameters (physical activity and balance) were independently associated with all-cause mortality risk.

The current study also highlights the potential dose-response association of sensory impairment, balance and physical activity on mortality risk. Promotion of physical activity may be one viable health promotion strategy as not only is physical activity independently associated with mortality,[72] but it is also associated with visual acuity,[20–24] hearing sensitivity,[48–50] peripheral neuropathy[68] and functional balance.[55] Functional balance may be particularly important to focus on, as dysfunctional balance is associated with decreased physical activity,[55] which is an important contributor of all-cause mortality risk.[72] Thus, the present findings, coupled with previous work in the literature, suggest that physical activity may play an important role in preventing premature mortality, likely through a variety of mechanisms, some of which may include improving balance and reducing sensory-related impairment. To increase physical activity in impaired populations, Rimmer and Schiller[73] created a model using the main components of access, participation, adherence, and health and function. Such a model has been shown to help facilitate accessibility and availability of physical activity for those with sensory impairments.

Limitations of this study include the relatively short follow-up period, the subjective assessment of hearing impairment, and common in observational studies, assessment of the independent variables only at 1 time period (baseline). Strengths of this study include the national sample, prospective study design and the objective assessments of physical activity, balance, peripheral neuropathy and visual impairment.

In conclusion, the current study suggests a potential dose-response association between sensory impairment and all-cause mortality risk. In particular, physical activity and functional balance were independent contributors to survival. These findings underscore the importance of promoting safe and progressive forms of physical activity. Such activities should aim to facilitate balance, and among those with sensory impairment, should be tailored to minimize fall risk.

Future confirmatory work on this topic is encouraged, and in particular, future work would benefit by examining the prospective interrelationships of physical activity, balance and sensory impairment, and collectively how these changes influence mortality risk.

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