Association of Balance Function With All-Cause and Cause-Specific Mortality Among US Adults

Chao Cao, MPH; W. Todd Cade, PT, PhD; Shengxu Li, MD, PhD, MPH; Jacqueline McMillan, MD, MSc; Christine Friedenreich, PhD; Lin Yang, PhD

**IMPORTANCE** Difficulty maintaining balance is common among individuals aged 40 years or older and increases the risk of falls. However, little is known about the association of balance function with long-term mortality outcomes in adults.

**OBJECTIVE** To investigate the association of balance function with all-cause and cause-specific mortality among US adults.

**DESIGN, SETTING, AND PARTICIPANTS** A prospective, population-based cohort study of a nationally representative sample of 5816 adults (weighted population, 92,260,641) from the US National Health and Nutrition Examination Survey was conducted from 1999 to 2004. Individuals aged 40 years or older who completed the modified Romberg Test of Standing Balance on Firm and Compliant Support Surfaces were included. Participants were linked to mortality data from the test date through December 31, 2015. Data analysis was conducted from February 1 to June 1, 2020.

**EXPOSURES** The modified Romberg Test of Standing Balance on Firm and Compliant Support Surfaces was used to measure balance function and define balance disorder according to sensory input.

**MAIN OUTCOMES AND MEASURES** Mortality associated with all causes, cardiovascular disease (CVD), and cancer.

**RESULTS** A total of 5816 adults (weighted mean [SE] age, 53.6 [0.2] years; 2897 [49.8%] women) were included in this cohort study. During up to 16.8 years of follow-up (median, 12.5 years; 1530 deaths occurred, including 342 associated with CVD and 364 associated with cancer. Participants with balance disorder were at a higher risk of death from all causes, CVD, and cancer. After adjusting for sociodemographic characteristics, lifestyle factors, and chronic conditions, the hazard ratios (HRs) among participants with balance disorder compared with those without balance disorder were 1.44 (95% CI, 1.23-1.69) for all-cause mortality, 1.65 (95% CI, 1.17-2.31) for CVD mortality, and 1.37 (95% CI, 1.03-1.83) for cancer mortality. Furthermore, vestibular balance disorder was associated with increased mortality from all causes (HR, 1.31; 95% CI, 1.08-1.58), CVD (HR, 1.59; 95% CI, 1.12-2.27), and cancer (HR, 1.39; 95% CI, 1.04-1.86).

**CONCLUSIONS AND RELEVANCE** In this nationally representative sample of US adults, balance disorder was associated with an increased risk of all-cause, CVD, and cancer mortality. Further studies are needed to confirm these findings and evaluate whether the observed associations represent a causal biological phenomenon and, if so, whether the effect is modifiable with a multicomponent exercise program.
Falls are the most common cause of serious injuries in older adults and increase the risk of hospitalization. In the US, falls were responsible for an estimated 2.8 million emergency department visits and cost the health care system more than $49.5 billion in 2015. The most prominent predisposing risk factor for falls among US adults is deficits in balance. An estimated 40% of the US population experience dizziness or balance difficulty through their lifetime. Previous observational studies provided limited evidence suggesting that poor balance performance, measured as part of physical function or physical capacity assessment, was associated with a higher risk of death from all causes and cardiovascular disease (CVD). To our knowledge, no study to date has assessed mortality associated with balance function specific to sensory input.

Maintaining balance involves a complex set of sensorimotor control systems. Balance depends on correct inputs from the vestibular, visual, and proprioceptive systems; an integration of sensory inputs by the central nervous system; and then responses to the integrated signals by the musculoskeletal system (motor output). Hence, balance disorders could be non-specific sequelae of numerous impairments, including deficits in vision, proprioception, vestibular, autonomic, and/or musculoskeletal function. Particularly, balance disorder attributed to the inner ear vestibular system is associated with metabolic syndrome, CVD, and neurologic disorders. Although vestibular balance disorder is prevalent, affecting approximately 69 million US adults aged 40 years or older, it cannot be captured by assessing balance performance in physical function testing.

The multiple factors associated with balance function, including an underlying role of metabolic health, combined with the notable prevalence of balance disorder in adults, necessitates an in-depth investigation on the role of balance function in long-term health among adults of all ages. To address these knowledge gaps, the present study evaluated associations of overall and sensory-specific balance disorder with all-cause and cause-specific mortality in a nationally representative sample of the US adult population. This knowledge could open new avenues for research informing clinical practice in screening and managing balance disorders.

Methods

Study Population

The National Health and Nutrition Examination Survey (NHANES), a major program of the National Center for Health Statistics, is designed to monitor the health and nutritional status of the US national, civilian, noninstitutionalized population using a continuous, complex, multistage probability sampling design in 2-year cycles since 1999. Participants were required to complete an in-person interview and undergo physical examinations and laboratory tests in a mobile examination center. All NHANES protocols were approved by the National Center for Health Statistics ethics review board. Written informed consent was provided by each participant. Data on sociodemographic characteristics, lifestyle behaviors, and medical conditions in adults aged 40 years or older who completed the balance function test during the 3 cycles of NHANES from 1999 to 2004 were analyzed. This modeling investigation was exempt from human subjects review because it was based on published data and nationally representative, de-identified data sets that included no personally identifiable information. Data analysis was conducted from February 1 to June 1, 2020. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Balance function was assessed using the modified Romberg Test of Standing Balance on Firm and Compliant Support Surfaces (modified Romberg test herein) performed by trained health technicians. The modified Romberg test procedure was detailed on the NHANES website. In brief, to ensure safety, participants who could not stand on their own, had a leg brace, or felt dizzy or lightheaded were ineligible for the balance function test. The modified Romberg test examines participants’ ability to stand unassisted under 4 test conditions with increasing difficulty. In test condition 1, the participant stands making use of all the sensory inputs that contribute to balance, including the central vestibular system, vision, and proprioception (leg muscle position sense). Test condition 2 tests balance when only vestibular and proprioceptive information are available (the participant closes their eyes to eliminate visual input). In test condition 3, the participant must maintain their balance on a foam-padded surface, which reduces the proprioceptive input, leaving only visual and vestibular cues. In test condition 4, the participant stands on a foam pad with closed eyes (visual input is removed) and maintains balance using only the vestibular system. Each participant is eligible for an initial test and 1 retest to pass a specific test condition.

Overall balance disorder was defined with binary response (no/yes) by whether participants successfully completed the 4 test conditions (no) or were unsuccessful at any condition (yes). Sensory-specific balance disorders were further classified as visual/proprioceptive (ending the test at conditions 1-3) and vestibular balance disorder (ending the test at condition 4). The severity of vestibular balance disorder was defined by the time that condition 4 was unsuccessful (20 to <30, 10 to <20, and 0 to <10 seconds) (Figure 1).

The National Center for Health Statistics provided mortality data that were linked to the National Death Index through...
December 31, 2015. The International Statistical Classification of Diseases, 10th Revision (ICD-10) was used to record the underlying cause of death. Cardiovascular disease mortality was classified as death caused by heart disease (ICD-10 codes I00-I09, I11, I13, and I20-I51) or cerebrovascular diseases (ICD-10 codes I60-I69) and cancer mortality as malignant neoplasms (ICD-10 codes C00-C97). The duration of follow-up was defined as the interval (months) from the balance function testing date to the date of death or to December 31, 2015, for those who were censored. To reduce the probability of reverse causation, deaths that occurred during the first 24 months of follow-up were excluded.

Self-reported sociodemographic characteristics included sex, race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, and other), educational attainment (less than high school, high school, and above high school), and family income (ratio of family income to the federal poverty level: <1.30, 1.30-3.49, or ≥3.5). Lifestyle factors included leisure-time physical activity (inactive vs active, defined as engaging in no or any moderate to vigorous physical activities during the past 30 days at leisure-time), body mass index (calculated as weight in kilograms divided by height in meters squared: underweight, <18.5; normal weight, 18.5-24.9; overweight, 25.0-29.9; and obese ≥30.0), smoking status (never, former <20 pack-years, former ≥20 pack-years, former with unknown pack-year, current <20 pack-years, and current ≥20 pack-years), alcohol consumption (derived from 24-hour dietary recall interviews: 0, 0.1-4.9, 5.0-14.9, 15.0-29.9, and ≥30.0 g/d), and the Healthy Eating Index-2010 (derived from 24-hour dietary recall interviews). The Healthy Eating Index-2010 indicates the overall dietary quality with a score ranging from 0 (worst-quality diet) to 100 (best-quality diet).

Hypertension was determined by participants receiving a diagnosis from a health professional or NHANES-measured blood pressure greater than or equal to 130 mm Hg systolic or greater than or equal to 80 mm Hg diastolic. Hypercholesterolemia was determined by participants receiving a diagnosis from a health professional or NHANES-measured total cholesterol level greater than or equal to 240 mg/dL (to convert to millimoles per liter, multiply by 0.0259). History of chronic diseases (heart disease, stroke, cancer, and diabetes) was determined by participants receiving these diagnoses from health professionals or if participants were instructed to take prescribed medications for these conditions.

Statistical Analysis
Following the NHANES analytic guidelines, all analyses were conducted using sample weights, stratification, and cluster-
ing of the complex sampling design to account for the unequal probability of selection, oversampling of certain subpopulations, and nonresponse adjustments. Sample sizes, weighted prevalence of balance disorder, and 95% CIs were calculated overall and according to participants’ sociodemographic characteristics and lifestyle factors. Multivariable Cox proportional hazards regression models were applied to estimate hazard ratios (HRs) and 95% CIs for the associations of overall and sensory-specific balance disorder with mortality. For cause-specific mortality, participants who reported a relevant history of each analyzed disease outcome were excluded (eg, previous cancer diagnoses for cancer mortality). Two-stage multivariable models were adjusted for age, sex, race/ethnicity, educational attainment, family poverty ratio in the first stage, and leisure-time physical activity, alcohol consumption, body mass index, smoking status and intensity, diagnosis of hypertension, hypercholesterolemia, diabetes, CVD, and/or cancer and family history of diabetes and/or CVD in the second stage. In addition, survival curves were produced using Stata, version 15.1 (StataCorp LLC) to illustrate the association between sensory-specific balance disorder and all-cause mortality, which was fully adjusted for sociodemographic and other covariates.

Furthermore, stratified analyses and interaction analyses were conducted to examine whether the detected association differed by age, sex, physical activity, body mass index, smoking status, and/or chronic disease diagnoses. In addition, a series of sensitivity analyses were performed by (1) excluding participants with a baseline history of CVD or cancer, (2) examining vestibular balance disorder severity (unsuccessful test time) while excluding participants with visual/proprioceptive disorder, and (3) restricting the analyses to participants with existing diagnoses of chronic diseases (diabetes, CVD, and cancer) at baseline. All analyses were done using Stata, version 15.1 (StataCorp LLC). Statistical tests were 2-sided and statistical significance was set at P < .05.

Results

Participant Characteristics

After excluding deaths that occurred during the first 24 months of follow-up (n = 88), 5816 adults (weighted mean [SE] age, 53.6 [0.2] years; 2897 [49.8%] women) were included in the analyzed cohort. A total of 2509 participants had a balance disorder at baseline. During up to 16.8 years of follow-up (median, 12.5 years; 68 919 person-years), 1530 deaths occurred, including 342 from CVD, 364 from cancer, 38 from accidents, and 786 from other causes. Table 1 presents sample sizes and weighted prevalence of balance disorder at baseline according to participant characteristics. The prevalence of a balance disorder, increased with age, was present in 18.2% of adults aged 40 to 49 years, 33.5% of adults aged 50 to 64 years, and 61.9% of those aged 65 years or older. Participants with lower levels of economic status, educational attainment, physical activity, and chronic diseases were more likely to experience balance disorders.

Balance Disorder and Mortality

Participants with balance disorder were at a higher risk of death from all causes, cardiovascular disease, and cancer (Figure 2). After adjusting for sociodemographic characteristics, lifestyle factors, and chronic conditions, HRs comparing participants with vs those without a balance disorder were 1.44 (95% CI, 1.23-1.69) for all-cause mortality, 1.65 (95% CI, 1.17-2.31) for those with CVD mortality, and 1.37 (95% CI, 1.03-1.83) for those with cancer mortality. In addition, balance disorder was associated with increased risks of mortality from accidents (HR, 2.32; 95% CI, 0.54-10.0) and other causes (HR, 1.17; 95% CI, 0.89-1.54). Results were similar after excluding participants with a baseline history of CVD and/or cancer (eFigure 1 in the Supplement).

These associations remained consistent in most subgroups. The association between balance disorder and all-cause mortality was stronger among physically active participants (HR, 1.53; 95% CI, 1.21-1.95) compared with their counterparts (HR, 1.16; 0.97-1.38) (Figure 3). The association between balance disorder and CVD mortality was stronger among those with a lower vs higher body mass index (HR, 2.80; 95% CI, 1.33-5.92 vs HR, 1.12; 95% CI, 0.67-1.86) and living with vs without chronic diseases (HR, 5.07; 95% CI, 2.47-10.4 vs HR, 1.21; 95% CI, 0.85-1.71) (Figure 3).

Sensory-Specific Balance Disorder and Mortality

At baseline (N = 5816), 4.2% of participants (n = 242) had visual/proprioceptive disorder and 39.0% of participants (n = 2267) had vestibular balance disorder (eTable 1 in the Supplement). During the follow-up period, participants with visual/proprioceptive and vestibular balance disorders had increased mortality risks compared with those without balance disorder (eFigure 2 in the Supplement; Table 2). After fully adjusting for sociodemographic characteristics, lifestyle factors, and chronic conditions, participants with visual/proprioceptive disorders had a higher mortality risk from all causes (HR, 1.95; 95% CI, 1.56-2.43), CVD (HR, 2.39; 95% CI, 1.48-3.88), accidents (HR, 8.68; 95% CI, 1.81-41.6), and other causes (HR, 1.39; 95% CI, 1.02-1.89) compared with those without any balance disorder (Table 2). Participants with vestibular balance disorders had an elevated mortality risk from all causes (HR, 1.31; 95% CI, 1.08-1.58), CVD (HR, 1.59; 95% CI, 1.12-2.27), and cancer (HR, 1.39; 95% CI, 1.04-1.86) compared with those without any balance disorder (Table 2). Similar results were observed when participants with a history of CVD or cancer at baseline were excluded (eTable 2 in the Supplement). With respect to the severity of vestibular balance disorder, dose-response associations were observed between failure time at the fourth testing point (specific to vestibular balance disorder) and all-cause, CVD, and cancer mortality risks (eTable 3 in the Supplement).

Discussion

In this prospective cohort of US nationally representative adults with up to 16.8 years of follow-up, balance disorder was associated with an increased risk of death from all causes, CVD, and
cancer in adults aged 40 years or older. Although vestibular balance disorder is a less severe presentation of balance disorder compared with that due to visual or proprioceptive input, vestibular balance disorder was associated with higher mortality from all causes, CVD, and cancer. These associations, despite being small, were significant and persisted after adjusting for sociodemographic characteristics, lifestyle factors, and chronic conditions.

To our knowledge, this study is the first to prospectively investigate the association of overall and sensory-specific balance disorder with all-cause and cause-specific mortality. Heterogeneous crude measures of balance ability used in previous studies precluded arrival at a firm conclusion. A meta-analysis summarizing evidence from 5 observational studies of adults older than 70 years found inconsistent associations between poorer performance in standing balance with a higher risk of all-cause mortality. In the same meta-analysis, studies examining the association of gait speed and mortality were considerably larger, with 16 estimates from 11 different populations demonstrating a strong association (HR, 2.87; 95% CI, 2.2-3.72) between gait speed and mortality. There was some evidence that standing balance time was more strongly associated with mortality than other measures of physical capability, including grip strength and chair rise speed. Cooper and colleagues found that participants who maintained a 1-legged stance with their eyes closed for a longer time had an approxi-

| Table 1. Baseline Characteristics of Study Participants According to Balance Disorder* |
|-------------------------------|-----------------|-----------------|-----------------|
| Characteristic               | No. of participants (Weighted %) | Balance Disorder | No. of participants (Weighted %) | Weighted prevalence, % (95% CI) |
| Overall                      | 5816 (100)      | 2509 (100)      | 31.6 (29.5-33.8) |
| Sex                          |                 |                 |                               |
| Male                         | 2919 (47.8)     | 1248 (46.4)     | 31.0 (28.6-33.3) |
| Female                       | 2897 (52.2)     | 1261 (53.6)     | 32.3 (29.5-35.0) |
| Age group, y                 |                 |                 |                               |
| 40-49                        | 1683 (38.7)     | 346 (20.4)      | 18.2 (15.8-20.6) |
| 50-64                        | 2051 (37.9)     | 767 (36.6)      | 33.5 (30.4-36.7) |
| ≥65                          | 2082 (37.4)     | 1396 (43.0)     | 61.9 (58.1-65.7) |
| Race/ethnicity               |                 |                 |                               |
| Non-Hispanic White           | 3233 (78.1)     | 1433 (77.2)     | 30.9 (28.3-33.4) |
| Non-Hispanic Black           | 1048 (9.2)      | 402 (8.9)       | 31.9 (28.1-35.6) |
| Hispanic                     | 1367 (8.8)      | 604 (9.7)       | 35.4 (31.0-39.8) |
| Other                        | 168 (3.9)       | 70 (4.2)        | 36.7 (27.4-46.1) |
| Family poverty ratio         |                 |                 |                               |
| <1.3                         | 1287 (14.7)     | 676 (20.0)      | 43.1 (39.7-46.6) |
| 1.3 to <3.5                  | 2479 (37.8)     | 1158 (43.4)     | 35.8 (32.7-39.0) |
| ≥3.5                         | 2050 (47.5)     | 675 (36.6)      | 25.3 (22.5-28.1) |
| Educational level            |                 |                 |                               |
| <High school                 | 1805 (18.4)     | 947 (25.8)      | 44.3 (40.9-47.7) |
| High school                  | 1407 (26.2)     | 645 (29.3)      | 35.4 (31.8-39.1) |
| >High school                 | 2604 (55.4)     | 917 (44.9)      | 25.9 (23.4-28.5) |
| Weight status (BMI)c         |                 |                 |                               |
| <25                          | 1604 (29.5)     | 780 (32.0)      | 33.9 (30.3-37.6) |
| 25 to <30                    | 2332 (39.1)     | 1021 (40.6)     | 33.2 (30.2-36.3) |
| ≥30                          | 1803 (30.3)     | 661 (25.8)      | 27.5 (24.6-30.4) |
| Leisure-time physical activity |             |                 |                               |
| Inactive                     | 2604 (37.3)     | 1264 (45.1)     | 38.5 (35.7-41.4) |
| Active                       | 3212 (62.7)     | 1245 (54.9)     | 27.7 (25.1-30.2) |
| Diabetes                     |                 |                 |                               |
| No                           | 5070 (90.9)     | 2072 (86.2)     | 33.6 (31.2-35.9) |
| Yes                          | 746 (9.1)       | 437 (13.8)      | 53.6 (49.0-58.3) |
| Cardiovascular disease       |                 |                 |                               |
| No                           | 4953 (88.4)     | 1978 (80.9)     | 32.4 (30.1-34.7) |
| Yes                          | 863 (11.6)      | 531 (19.1)      | 58.0 (53.7-62.3) |
| Cancer                       |                 |                 |                               |
| No                           | 5305 (92.0)     | 2227 (89.1)     | 34.3 (31.9-36.6) |
| Yes                          | 511 (8.0)       | 282 (10.9)      | 48.2 (43.2-53.3) |

* Sample size was weighted to be nationally representative. Balance disorder was defined as no (success with the Romberg test) vs yes (unsuccess with the Romberg test).

b No. of participants within each group may not sum to equal the unweighted number due to missing data. Weighted percentage may not sum to 100% due to missing data.

c Weight status was defined by body mass index (BMI, calculated as weight in kilograms divided by height in meters squared).

d Leisure-time physical activity level was defined by engaging in no (inactive) or any (active) moderate or vigorous recreational physical activity over the past 30 days.
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The present findings on the association of vestibular balance disorder with mortality risk could be further explained through a metabolic pathway. Emerging evidence from animal experiments and epidemiologic studies reported that vestibular balance disorder was associated with microvascular and macrovascular diseases and metabolic syndrome. Metabolic syndromes induce structural and functional changes in the vestibular system in animal models. Clinical research, balance disorder has been hypothetized as a marker of metabolic disorder. Specifically, diabetes has been postulated to be vestibulotoxic owing to its microangiopathic effects, which leads to ischemia of the vestibular structures. Likewise, reduced somatosensation associated with diabetic neuropathy appears to hinder standing balance. In support of this possibility, a higher prevalence of vestibular balance disorder was found in adults with diabetes than in those without diabetes (70%), and was particularly notable in patients with diabetes with a longer duration of disease and poor glucose regulation. Moreover, impaired metabolism has been proposed to alter the metabolism of inner ear fluids, which leads to vestibular disorder causing severe dizziness (vertigo), tinnitus, and hearing loss. Considering the strong evidence base indicating that metabolic syndrome increased the risk of CVD and common cancers, the underlying altered metabolism of vestibular balance disorder might partly explain its association with mortality caused by CVD and cancer observed in the present study.

Future research to elucidate the underlying biological pathways between balance disorder and mortality is needed to inform clinical practice. Exercise is a preferred management strategy for fall prevention. However, neither the multifactorial assessment and management of risk factors for falls nor fall prevention exercise programs currently consider the metabolic system. Few interventions exist with strong efficacy to improve balance function. Future research should evaluate the causality of vestibular balance disorder and its associated altered metabolic system with the risk of future falls and mortality and whether a multicomponent exercise program additionally targeting metabolic health at a younger age could improve balance function and long-term health outcomes.

Strengths and Limitations
A strength of this study is the nationally representative sample from the NHANES and the availability of a comprehensive list of potential confounders, which increase the generalizability of these results. In addition, several stratified and sensitivity analyses were conducted to examine consistencies across subpopulations. The study also has limitations. First, sensory-specific balance disorders were not assessed by diagnostic instruments, such as posturography or vestibular-evoked myogenic potentials. However, the modified Romberg test has been developed and used as a screening tool in both clinical and research settings and is feasible with minimal operational requirements. Moreover, compared with other crude balance measurements (eg, 1-leg standing test), the modified Romberg test can provide additional information on vestibular function. Second, because of the observational nature of the study design, causality could not be determined.
Figure 3. Stratified Hazard Ratios and 95% CIs for All-Cause and Cause-Specific Mortality According to Balance Disorder

### All-cause mortality

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Hazard ratio (95% CI)</th>
<th>Favors decreased risk of mortality</th>
<th>Favors increased risk of mortality</th>
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<tbody>
<tr>
<td><strong>Age, y</strong></td>
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<tr>
<td>40-49</td>
<td>0.99 (0.50-1.97)</td>
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<td>50-64</td>
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<td>≥65</td>
<td>1.37 (1.06-1.76)</td>
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<td><strong>Sex</strong></td>
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<tr>
<td>Male</td>
<td>1.45 (1.16-1.81)</td>
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<td>Female</td>
<td>1.22 (0.93-1.58)</td>
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<td><strong>Leisure time physical activity</strong></td>
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<td>Active</td>
<td>1.53 (1.21-1.95)</td>
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<td><strong>BMI</strong></td>
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<td>&lt;27.5</td>
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<td>≥27.5</td>
<td>1.49 (1.14-1.96)</td>
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<td><strong>Smoking status</strong></td>
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<td>Ever</td>
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<td>Any</td>
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### Cardiovascular disease mortality

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<th>Favors increased risk of mortality</th>
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<td><strong>Age, y</strong></td>
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<td>40-49</td>
<td>1.36 (0.46-4.06)</td>
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<td>≥65</td>
<td>1.42 (0.93-2.15)</td>
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<td><strong>Sex</strong></td>
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<tr>
<td>Male</td>
<td>1.53 (0.85-2.77)</td>
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<tr>
<td>Female</td>
<td>1.68 (1.00-2.84)</td>
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</tr>
<tr>
<td><strong>Leisure time physical activity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inactive</td>
<td>1.81 (1.06-3.08)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>Active</td>
<td>1.46 (0.81-2.65)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;27.5</td>
<td>2.80 (1.33-5.92)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>≥27.5</td>
<td>1.12 (0.67-1.86)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td><strong>Smoking status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>1.55 (0.95-2.54)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>Ever</td>
<td>1.73 (0.99-2.99)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td><strong>Chronic diseases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1.21 (0.85-1.71)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>Any</td>
<td>5.07 (2.47-10.4)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
</tbody>
</table>

### Cancer mortality

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Hazard ratio (95% CI)</th>
<th>Favors decreased risk of mortality</th>
<th>Favors increased risk of mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age, y</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-49</td>
<td>0.51 (0.22-1.16)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>50-64</td>
<td>1.58 (0.98-2.55)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>≥65</td>
<td>1.70 (1.02-2.81)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1.31 (0.89-1.92)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>Female</td>
<td>1.41 (0.88-2.26)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td><strong>Leisure time physical activity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inactive</td>
<td>1.51 (0.97-2.34)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>Active</td>
<td>1.22 (0.74-2.02)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;27.5</td>
<td>0.98 (0.66-1.45)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>≥27.5</td>
<td>1.81 (1.23-2.66)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td><strong>Smoking status</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>1.32 (0.81-2.17)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>Ever</td>
<td>1.41 (0.98-2.05)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td><strong>Chronic diseases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1.09 (0.72-1.64)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
<tr>
<td>Any</td>
<td>2.63 (1.46-4.72)</td>
<td><img src="image" alt="Favors decreased risk of mortality" /></td>
<td><img src="image" alt="Favors increased risk of mortality" /></td>
</tr>
</tbody>
</table>

All-cause, cardiovascular disease–specific, and cancer-specific mortality. BMI indicates body mass index (calculated as weight in kilograms divided by height in meters squared). Balance disorder was defined as no (successful Romberg test) vs yes (unsuccessful Romberg test). The models were adjusted for age (5-year intervals), sex (male or female), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, and other), education attainment (less than high school, high school graduate, above high school), family poverty status (ratio of family income to the federal poverty level: <1.30, 1.30-3.49, or $\geq 3.5$), leisure-time physical activity (inactive or active), alcohol consumption (0, 0.1-4.9, 5-14.9, 15-29.9, or $\geq 30$ g/d), body mass index BMI (<18.5, 18.5-24.9, 25.0-29.9, and $\geq 30.0$), smoking status (never, former $<$20 pack-years, former $\geq 20$ pack-years, and current $>$20 pack-years), hypertension (yes or no), hypercholesterolemia (yes or no), history of diabetes (yes or no), history of cardiovascular disease (CVD) (yes or no), history of cancer (yes or no), family history of diabetes (yes or no), and family history of CVD (yes or no), except the corresponding subgroup variate.

a Leisure-time physical activity level was defined by engaging in no (inactive) or any (active) moderate or vigorous recreational physical activity over the past 30 days.

b Chronic diseases included CVD (not included in CVD mortality), cancer (not included in cancer mortality), and diabetes.
Table 2. Association of Different Sensory Input Balance Disorders With All-Cause and Cause-Specific Mortality Among US Adults

<table>
<thead>
<tr>
<th>Mortality outcome</th>
<th>Death/No.</th>
<th>Weighted death (%)</th>
<th>Hazard ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Model 1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>All-cause</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>526/3307</td>
<td>6 205 210 (9.8)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Vestibular&lt;sup&gt;c&lt;/sup&gt;</td>
<td>846/2267</td>
<td>6 631 921 (24.1)</td>
<td>1.41 (1.19-1.66)</td>
</tr>
<tr>
<td>Visual/proprrioceptive&lt;sup&gt;d&lt;/sup&gt;</td>
<td>158/242</td>
<td>750 524 (46.4)</td>
<td>1.95 (1.56-2.43)</td>
</tr>
<tr>
<td>Cardiovascular disease&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>62/2975</td>
<td>666 432 (1.1)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Vestibular&lt;sup&gt;c&lt;/sup&gt;</td>
<td>116/1819</td>
<td>897 875 (3.9)</td>
<td>1.71 (1.23-2.38)</td>
</tr>
<tr>
<td>Visual/proprrioceptive&lt;sup&gt;d&lt;/sup&gt;</td>
<td>27/159</td>
<td>145 530 (12.9)</td>
<td>3.00 (1.76-5.13)</td>
</tr>
<tr>
<td>All cancer&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>109/3078</td>
<td>1 812 790 (3.1)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Vestibular&lt;sup&gt;c&lt;/sup&gt;</td>
<td>155/2016</td>
<td>1 557 762 (6.2)</td>
<td>1.50 (1.12-2.02)</td>
</tr>
<tr>
<td>Visual/proprrioceptive&lt;sup&gt;d&lt;/sup&gt;</td>
<td>15/211</td>
<td>79 635 (5.8)</td>
<td>1.34 (0.68-2.65)</td>
</tr>
<tr>
<td>Accident</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>12/3307</td>
<td>174 674 (0.3)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Vestibular&lt;sup&gt;c&lt;/sup&gt;</td>
<td>22/2267</td>
<td>214 746 (0.8)</td>
<td>2.64 (0.68-10.3)</td>
</tr>
<tr>
<td>Visual/proprrioceptive&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4/242</td>
<td>14 318 (0.9)</td>
<td>5.93 (1.15-30.5)</td>
</tr>
<tr>
<td>Other cause</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>272/3307</td>
<td>2 931 221 (4.6)</td>
<td>1 [Reference]</td>
</tr>
<tr>
<td>Vestibular&lt;sup&gt;c&lt;/sup&gt;</td>
<td>430/2267</td>
<td>2 959 212 (10.7)</td>
<td>1.21 (0.93-1.56)</td>
</tr>
<tr>
<td>Visual/proprrioceptive&lt;sup&gt;d&lt;/sup&gt;</td>
<td>84/242</td>
<td>321 183 (19.9)</td>
<td>1.66 (1.23-2.24)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Adjusted for age (5-year intervals), sex (male or female), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, and other), educational attainment (less than high school, high school graduate, above high school), family poverty status (ratio of family income to the federal poverty level: <1.30, 1.30-3.49, or ≥3.50), smoking status (never, former <20 pack-years, current <20 pack-years, former with unknown pack-years, current ≥20 pack-years), hypertension (yes or no), hypercholesterolemia (yes or no), family history of diabetes (yes or no), family history of cardiovascular disease (CVD) (yes or no), history of diabetes (yes or no), history of cancer (yes or no).

<sup>b</sup> Additionally adjusted for leisure-time physical activity (inactive or active), alcohol consumption (0, 0.1-4.9, 5-14.9, 15-29.9, or ≥30 g/d), body mass index (calculated as weight in kilograms divided by height in meters squared: <18.5, 18.5-24.9, 25-29.9, and ≥30), smoking status (never, former <20 pack-years, former ≥20 pack-years, former with unknown pack-years, current <20 pack-years, current ≥20 pack-years), hypertension (yes or no), hypercholesterolemia (yes or no), family history of diabetes (yes or no), family history of cardiovascular disease (CVD) (yes or no), history of diabetes (yes or no), history of cancer (yes or no).

<sup>c</sup> Vestibular balance disorder was defined as ending the modified Romberg balance test at test condition 4 (the participant stands on a foam pad with closed eyes [visual input is removed] and maintains balance using only the vestibular system).

<sup>d</sup> Visual/proprrioceptive disorder was defined as ending the modified Romberg balance test at test conditions 1 to 3 (i: participant stands making use of all the sensory inputs that contribute to balance, including the central vestibular system, vision, and proprioception; 2: participant closes their eyes to eliminate visual input; and 3: participant must maintain their balance on a foam-padded surface).

<sup>e</sup> Excluded participants with a history of CVD at baseline.

<sup>f</sup> Excluded participants with a history of cancer at baseline.

Conclusions

In this nationally representative sample of US adults, balance disorder was associated with an increased risk of all-cause, CVD, and cancer mortality. This association appeared to be stronger among individuals with chronic diseases. Further studies are needed to confirm these findings and evaluate whether the observed associations represent a causal biological phenomenon and, if so, whether the effect is modifiable with a multicomponent exercise program.

ARTICLE INFORMATION

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Author Contributions: Mr Cao and Dr Yang had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Concept and design: Cao, Yang. Acquisition, analysis, or interpretation of data: All authors. Drafting of the manuscript: Cao, Yang. Critical revision of the manuscript for important intellectual content: All authors.


Conflict of Interest Disclosures: None reported.

REFERENCE

2. Florence CS, Bergen G, Atherly A, Burns E, Stevens J, Drake C. Medical costs of fatal and