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Balance Disorders in Young and Middle-Aged Adults: NHANES, 2001–2004 and 2021–2023

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ABSTRACT

Objectives: To estimate the prevalence of balance disorders in young and middle-aged adults, examine associations with risk factors, and changes over the past 20 years.

Methods: The National Health and Nutrition Examination Survey (NHANES) is a cross-sectional complex random sample of the civilian, non-institutionalized United States population. In 2001–2004 and 2021–2023, NHANES included questions about balance, dizziness, and falls in the past 12 months. The modified Romberg test (MRT) was used to examine vestibular balance function. Logistic regression models were used to assess risk factor associations with balance disorders.

Results: Among 4525 middle-aged adults 40–69 years in 2001–2004, 21.5% (95% confidence interval [CI]: 19.1%, 23.9%) reported difficulty with balance and dizziness, and 29.7% (27.3%, 32.1%) failed to pass four MRT (MRT-4) conditions. Among 3986 middle-aged adults in 2021–2023, 36.2% (34.5%, 37.8%) reported specific balance and dizziness problems (BDP), and 25.9% (23.2%, 28.6%) failed the MRT-4. An enhanced MRT with a fifth condition (MRT-5) increased the discrimination of adults at risk of balance problems and falls. Risk factors for vestibular balance disorders, including age, education, income, cigarette smoking, physical activity, hypertension, diabetes, trouble hearing, and severe headaches/migraines, remained consistent. Reported functional disabilities (hearing, mobility, and vision) were significantly associated with BDP and MRT. In 2021–2023, comparisons of 2084 young adults 20–39 years with middle-aged adults showed increased age-specific prevalences of BDP and falls.

Conclusion: Middle-age-specific MRT-4 results in 2021–2023 improved. Balance disorders are associated with other health conditions, increased risk of falls, and need for medical services.

Level of Evidence: 3.

1 | Introduction

Balance problems are multifactorial and often associated with vestibular disorders and other sensory impairments which can occur at any age [1–3]. They increase risk of falling and injury and negatively impact health and quality of life [4–8]. Balance disorders have been reported by 11% to 15% of U.S. adults [9]. Medical expenditures for individuals with dizziness and vertigo exceed \$48 billion annually [10]. The economic burden is significant; for example, hospitalization for traumatic injury costs more than hospitalization due to congestive heart failure, pneumonia, stroke, and myocardial infarction [11].

Balance depends on complex sensorimotor systems, vestibular, visual, and somatosensory/proprioceptive, requiring accurate sensory inputs, sensory integration by the central nervous system, and coordination by the musculoskeletal system. Every sensory system declines with age [12–13]. Deficits in sensory inputs may cause impaired balance and falls, traumatic injury, increased risk of hospitalization, and death—particularly in older adults [6, 14–20]. Although understanding balance problems is important for improving health and quality of life, few reports provide population-based estimates for balance disorders and associated risk factors.

This study analyzed self-reported balance disorders and modified Romberg standing balance test (MRT) results of participants in the National Health and Nutrition Examination Survey (NHANES) for the 2001–2004 and 2021–2023 survey periods. The objectives were to: (1) provide updated estimates of balance function, (2) evaluate sociodemographic and health risk associations with balance disorders, and (3) examine changing prevalence of balance disorders over the past 20 years.

2 | Materials and Methods

The National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention (CDC) conducts NHANES, a cross-sectional, multifaceted health interview and examination study that uses a complex, stratified, multistage probability survey design to obtain nationally-representative random samples of the civilian, noninstitutionalized U.S. population. Weights adjust for differential selection from oversampling (e.g., older adults, African American, and Hispanic), lack of coverage, and nonresponse, to generate population estimates. Participants first complete home interviews, then visit mobile exam centers for physical examinations and laboratory specimen collection [21, 22].

NHANES used the MRT [23] to assess vestibularly-mediated balance function. MRT was chosen after consultation with experts [24, 25] who also considered computerized dynamic posturography [26, 27] but rejected it due to the need for servicing to maintain strict quality control as equipment is transported frequently to different geographic test sites. MRT requires no servicing and is a standard balance assessment that has been used for many years by providers across healthcare settings [28, 29].

2.1 | Design and Participants

Participants across the age range categories shown in Table 1 were all administered the same NHANES balance protocols for their respective time periods, 2001–2004 and 2021–2023. Age ranges differed, however, during survey periods 2001–2004 (individuals aged 40+ years) and 2021–2023 (individuals aged 20–69 years). Comparative analyses of the balance component between survey periods were therefore limited to middle-aged adults (40–69 years), as both survey periods included this age range (4525 middle-aged adults in 2001–2004 and 3986 in 2021–2023).

Participants provided written informed consent. The study was approved by the CDC's Institutional Review Board.

2.2 | Balance Questions and Testing

The NHANES 2001–2004 questions asked about difficulty with balance, dizziness, and falling in the past 12 months. The 2021–2023 questions asked about balance and dizziness problems (BDP), including vertigo, blurring of vision with head movement (oscillopsia), unsteadiness or off-balance (disequilibrium), feeling light-headed and faint, and the number of falls in the past 12 months.

Prior to performing MRT, participants were interviewed to determine eligibility. In 2001–2004 ineligible subjects were either: (i) protocol violations (limited time; equipment failure; weight > 125 kg; amputation of feet or legs; assistance needed because of visual impairment; illness or emergency, other limitations), or (ii) refusals and safety exclusions (unable to stand or leg brace needed to stand unassisted; dizziness sufficient to cause unsteadiness). In 2021–2023 ineligible subjects were either: (i) protocol violations (as in 2001–2004; except body weight > 143 kg and pregnancy), or (ii) refusals and safety exclusions (as in 2001–2004); or (iii) recent injury or surgery to foot, leg, or hip; balance problems past 24 h; history of falling past 12 months due to dizziness/balance problems; not feeling okay to begin MRT; neck pain sufficient to cause unsteadiness.

The MRT consisted of four conditions (MRT-4) for the 2001–2004 survey, and five conditions (MRT-5) for the 2021–2023 survey, of increasing difficulty [30–32]. Scored as pass/fail, it was designed to assess the individual's use of sensory inputs that contribute to balance, specifically the vestibular system, vision, and proprioception. Since each successive condition is progressively more challenging, testing ended when an individual failed a test condition after two attempts.

Research performed after the 2001–2004 survey showed that adding head movement conditions to MRT improved sensitivity of the test [33, 34]. Therefore, in the 2021–2023 survey the MRT included a fifth condition for subjects if they successfully passed the MRT-4. Additional eligibility criteria were required before subjects were allowed to attempt the fifth condition. About one-fifth (21%) of the 1837 individuals who successfully completed MRT-4 did not attempt MRT-5 due to safety concerns and other reasons: neck pain (15%); neck surgery (3%); cervical range of motion in yaw < 30° (0.7%); fell due to dizziness in past 12 months (1.4%); refusal, equipment failure/error, and "other" (1.4%).

For MRT, participants stood with shoes removed, feet together, and arms crossed at the chest. Condition 1: on the floor (hard surface), eyes open; condition 2: on floor, eyes closed; condition 3: on compliant surface (7.6 cm medium density foam pad with waterproof slipcover), eyes open; condition 4: on foam pad, eyes

TABLE 1 | Participants in the NHANES 2021–2023 and 2001–2004 Balance Examinations and Interviews.

	NHANES 2021–2023 N = 6070			NHANES 2001–2004 N = 6785		
Characteristics	**Age 20–39 wt'd %* (*n*)**	**Age 40–59 wt'd %* (*n*)**	**Age 60–69 wt'd %* (*n*)**	**Age 40–59 wt'd %* (*n*)**	**Age 60–69 wt'd %* (*n*)**	**Age 70+ wt'd %* (*n*)**
Overall	100.0 (2084)	100.0 (2221)	100.0 (1765)	100.0 (3012)	100.0 (1513)	100.0 (2260)
Sex						
Male	49.8 (907)	49.3 (992)	47.8 (796)	49.7 (1513)	46.3 (732)	40.8 (1081)
Female	50.2 (1177)	50.7 (1229)	52.2 (969)	50.3 (1499)	53.7 (781)	59.2 (1179)
Race/ethnicity[a]						
Non-Hispanic white	52.4 (997)	57.6 (1215)	68.7 (1122)	74.5 (1551)	79.2 (724)	83.8 (1598)
Non-Hispanic black	12.1 (322)	11.4 (297)	10.3 (223)	10.8 (668)	10.0 (330)	7.2 (251)
Hispanic/Mexican American	21.5 (477)	18.0 (426)	10.9 (238)	10.0 (673)	6.3 (406)	5.9 (357)
Other	14.0 (288)	12.9 (283)	10.1 (182)	4.7 (120)	4.4 (53)	3.1 (54)
Education: > high school	66.0 (1419)	64.1 (1445)	61.1 (1082)	60.6 (1553)	49.9 (609)	36.8 (740)
Poverty income ratio (PIR)[b]						
< 1.00	16.8 (355)	12.1 (300)	12.1 (236)	10.2 (424)	7.8 (206)	11.6 (317)
1.00–1.99	22.2 (380)	16.5 (338)	17.5 (288)	14.0 (574)	21.0 (365)	34.0 (748)
2.00–3.99	28.0 (478)	29.2 (512)	27.2 (394)	28.0 (762)	34.8 (422)	32.2 (587)
≥ 4.00	33.0 (520)	42.2 (704)	43.2 (577)	47.8 (1067)	36.4 (391)	22.3 (394)
Smoking status						
Never	71.3 (1462)	59.4 (1264)	53.1 (917)	46.5 (1397)	41.5 (646)	50.9 (1116)
Past	14.9 (321)	22.2 (490)	30.5 (537)	27.3 (760)	42.0 (591)	41.9 (955)
Current	13.8 (289)	18.4 (457)	16.4 (308)	26.2 (849)	16.5 (271)	7.3 (180)
Alcohol use, ever[c]	92.2 (1240)	93.0 (1371)	92.8 (1233)	90.9 (2376)	82.4 (1109)	78.7 (1442)
Physical activity, moderate, or vigorous[d]	88.1 (1804)	81.9 (1786)	78.8 (1358)	64.7 (1757)	55.9 (747)	44.1 (903)

(Continues)

TABLE 1 | (Continued)

	NHANES 2021–2023			NHANES 2001–2004		
	N = 6070			*N* = 6785		
Characteristics	**Age 20–39 wt'd %* (*n*)**	**Age 40–59 wt'd %* (*n*)**	**Age 60–69 wt'd %* (*n*)**	**Age 40–59 wt'd %* (*n*)**	**Age 60–69 wt'd %* (*n*)**	**Age 70+ wt'd %* (*n*)**
Medical history						
Body mass index (BMI)[e]						
Underweight (< 18.5)	2.4 (30)	1.0 (23)	1.1 (15)	1.0 (30)	0.7 (9)	1.6 (30)
Normal (18.5–24.9)	30.8 (464)	21.9 (391)	22.6 (335)	27.3 (709)	23.9 (316)	31.8 (564)
Overweight (25–29.9)	31.2 (467)	30.6 (505)	35.6 (497)	36.8 (1041)	38.4 (513)	41.2 (747)
Obese (30+)	35.6 (577)	46.4 (791)	40.7 (613)	35.0 (1028)	37.0 (533)	25.4 (425)
Hypertension	12.3 (280)	36.9 (861)	56.2 (1016)	29.2 (919)	51.8 (805)	57.2 (1277)
Diabetes	2.2 (48)	12.1 (295)	19.4 (348)	7.9 (290)	15.9 (302)	16.4 (399)
Arthritis	5.5 (117)	26.4 (605)	48.7 (852)	24.1 (714)	45.0 (651)	53.0 (1164)
Congestive heart failure	0.1 (3)	1.9 (55)	5.9 (114)	1.7 (64)	4.6 (75)	10.6 (239)
Stroke	0.5 (11)	2.8 (72)	5.9 (114)	1.7 (60)	5.1 (86)	10.1 (251)
Cancer	1.9 (40)	7.1 (168)	22.9 (389)	7.6 (190)	17.8 (208)	25.9 (538)
Severe headaches/migraines[f]	12.8 (282)	12.5 (289)	8.7 (165)	23.8 (728)	12.1 (195)	9.2 (201)
Hearing[g] (self-report)						
Excellent or good	87.1 (1837)	79.2 (1751)	67.3 (1196)	72.7 (2257)	63.1 (997)	49.4 (1089)
Excellent	45.9 (1003)	33.5 (760)	25.6 (454)	-—	-—	-—
Good	41.3 (834)	45.7 (991)	41.6 (742)	72.7 (2257)	63.1 (997)	49.4 (1089)
Little or moderate trouble	12.3 (235)	18.7 (420)	28.3 (492)	24.3 (666)	29.9 (412)	34.9 (781)
Little trouble	9.2 (181)	13.4 (295)	19.0 (332)	24.3 (666)	29.9 (412)	34.9 (781)
Moderate trouble	3.1 (54)	5.3 (125)	9.3 (160)	-—	-—	-—
A lot of trouble	0.5 (10)	1.9 (44)	4.2 (71)	2.9 (85)	6.6 (98)	14.3 (352)
Deaf	0.1 (2)	0.2 (5)	0.3 (5)	0.1 (3)	0.4 (5)	1.3 (33)

(Continues)

TABLE 1 | (Continued)

Characteristics	NHANES 2021–2023 $N = 6070$ Age 20–39 wt'd %* (*n*)	NHANES 2021–2023 $N = 6070$ Age 40–59 wt'd %* (*n*)	NHANES 2021–2023 $N = 6070$ Age 60–69 wt'd %* (*n*)	NHANES 2001–2004 $N = 6785$ Age 40–59 wt'd %* (*n*)	NHANES 2001–2004 $N = 6785$ Age 60–69 wt'd %* (*n*)	NHANES 2001–2004 $N = 6785$ Age 70+ wt'd %* (*n*)
Functional disability (self-report)						
Seeing even with glasses						
Little/no difficulty	73.9 (1523)	56.7 (1240)	55.6 (950)	-—	-—	-—
Some difficulty	23.9 (502)	39.0 (857)	39.9 (724)	-—	-—	-—
A lot of difficulty	2.2 (55)	4.3 (118)	4.5 (90)	-—	-—	-—
Hearing even with hearing aids						
Little/no difficulty	86.6 (1817)	80.4 (1774)	70.3 (1240)	-—	-—	-—
Some difficulty	12.2 (236)	17.2 (386)	26.6 (464)	-—	-—	-—
A lot of difficulty	1.2 (22)	2.4 (51)	3.1 (58)	-—	-—	-—
Following conversation with noise						
Little/no difficulty	77.9 (1629)	72.8 (1608)	63.4 (1117)	-—	-—	-—
Some difficulty	13.1 (263)	15.0 (330)	19.4 (339)	-—	-—	-—
A lot of difficulty	9.1 (187)	12.2 (279)	17.2 (305)	-—	-—	-—
Walking or climbing stairs						
Little/no difficulty	89.1 (1840)	72.8 (1551)	59.2 (1019)	-—	-—	-—
Some difficulty	9.3 (205)	20.6 (496)	28.1 (496)	-—	-—	-—
A lot difficulty	1.6 (37)	6.6 (170)	12.7 (246)	-—	-—	-—
Feel worried/nervous/anxious						
Never	13.6 (295)	16.1 (356)	20.8 (373)	-—	-—	-—
Some	36.7 (736)	43.1 (897)	45.4 (785)	-—	-—	-—
Often	49.6 (1047)	40.8 (959)	33.9 (606)	-—	-—	-—
Feel depressed						
Never	32.7 (651)	38.8 (794)	43.7 (748)	-—	-—	-—
Some	50.4 (1062)	45.0 (1001)	40.9 (733)	-—	-—	-—

(Continues)

TABLE 1 | (Continued)

Characteristics	NHANES 2021–2023 *N* = 6070			NHANES 2001–2004 *N* = 6785		
	Age 20–39 wt'd %* (*n*)	**Age 40–59 wt'd %* (*n*)**	**Age 60–69 wt'd %* (*n*)**	**Age 40–59 wt'd %* (*n*)**	**Age 60–69 wt'd %* (*n*)**	**Age 70+ wt'd %* (*n*)**
Often	16.9 (361)	16.2 (415)	15.4 (278)	-—	-—	-—
Balance						
Difficulty with balance or dizziness[h] (self-report)	-—	-—	-—	20.5 (642)	25.4 (384)	35.4 (808)
Difficulty with falls[i] (self-report)	-—	-—	-—	4.2 (137)	5.8 (89)	13.5 (311)
Balance and dizziness problems (BDP)[h] (self-report)	27.8 (599)	34.3 (809)	40.0 (731)	-—	-—	-—
Modified Romberg test, MRT-4						
Failed to pass all four conditions	7.9 (101)	17.5 (265)	43.4 (481)	24.4 (623)	49.1 (596)	74.7 (1107)
Passed all four conditions	92.1 (1217)	82.5 (1135)	56.7 (702)	75.6 (1759)	50.9 (590)	25.3 (325)
Condition #4, time (sec) stance maintained—Mean [95% CI]	28.6 [28.1, 29.0]	26.5 [25.8, 27.3]	21.0 [20.1, 21.9]	25.3 [24.7, 25.8]	20.1 [19.2, 21.0]	13.5 [12.7, 14.4]
Modified Romberg test, MRT-5						
Failed to pass all five conditions	26.8 (314)	48.9 (583)	76.4 (739)	-—	-—	-—
Passed all five conditions	73.3 (871)	51.2 (600)	23.6 (268)	-—	-—	-—
Condition #5: time (sec) stance maintained—mean [95% CI]	26.1 [25.6, 26.6]	22.7 [21.7, 23.8]	18.7 [16.7, 20.8]	-—	-—	-—

Note: -- not calculated. Test conditions #1 and #2: 15 s required to pass; conditions #3, #4, and #5: 30 s required to pass.
*Wt'd % are United States population-based estimates of percent prevalence based on the national sampling weights provided by NHANES to account for the complex sample design.
[a]Hispanic/Mexican American combines Mexican American with Other Hispanic for both survey periods. Other race/ethnicity includes non-Hispanic Asian and Other, including multiracial, for 2021–2023.
[b]Poverty income ratio is the ratio of family income to poverty level. Department of Health and Human Services' poverty guidelines specific to family size, year, and state of residence were used.
[c]Alcohol use included different questions for alcohol use: for 2001–2004, "Have you had at least 12 alcohol drinks in any one year? (Y/N)" and for 2021–2023, "Ever had alcohol? (Y/N)."
[d]Physical activity included different questions: for 2001–2004, "Moderate or vigorous activity in past 30 days?" and for 2021–2023, "What is frequency of your moderate or vigorous leisure time physical activity?"
[e]From the NHANES Mobile Exam Center (MEC) data sample.
[f]Severe headaches/migraines are based on different questions: for 2001–2004, "During the past 3 months, did you have severe headaches or migraines? (Y/N)" and for 2021–2023, "During the past 12 months, were your {balance difficulty} episodes accompanied by migraine/severe headache? (Y/N)."
[g]Hearing was based on responses to questions: for 2001–2004, hearing was categorized as "good, a little trouble, a lot of trouble, or deaf," and for 2021–2023, hearing was categorized as "excellent, good, a little trouble, moderate trouble, a lot of trouble, or deaf."
[h]Balance difficulties were different from each survey period: for 2001–2004, balance difficulties were based on the question "In the past 12 months, have you had dizziness, difficulty with balance, or difficulty with falling?" and for 2021–2023, the question "In the past 12 months, have you had problems with {ask each one: vertigo, blurring of vision when you move your head, unsteadiness, light-headedness/fainting}?"
[i]Falls questions from each survey period were different: in 2001–2004, the question was "In the past 12 months, have you had difficulty with falling?" The age-specific percentages for 2001–2004 are shown here (Table 1). The falls question in 2021–2023 was "During the past 12 months, how many times have you fallen?" Age-specific percentages of numbers of falls in 2021–2023 are shown in Table 2.

closed; and condition 5: on foam pad, eyes closed and head rotating slowly side-to-side at 1 Hz controlled by a metronome. Passing criteria: conditions 1–2, perform for 15 s; conditions 3–5, perform for 30 s. These durations ensured consistency between survey periods 2001–2004 and 2021–2023. Failure criteria: moving feet, significant arm movement, opening eyes (conditions 2, 4, or 5), or examiner's intervention due to excessive motion. MRT success was scored as yes/no based on whether participants completed all 4 (or 5, where appropriate) test conditions. Time to failure in seconds was recorded and analyzed for conditions 4 and 5.

2.3 | Sociodemographic and Health Related Risk Variables

Demographic characteristics were self-reported. Body mass index was categorized as underweight, normal, overweight, or obese. Systolic and diastolic blood pressures were calculated by averaging three successive measurements. Hypertension was defined by prior medical diagnosis, measured blood pressure, and use of hypertension medication. Additional health history and disability conditions were determined from questionnaire responses. Severe headaches/migraines were determined in 2001–2004 by: "Were severe headaches/migraines present in the last three months?"; in 2021–2023 by: "Did severe headaches/migraines accompany balance difficulties during the past 12 months?" Participants were asked about their overall hearing ability and about their understanding of conversations with background noise. They were also asked if they were ever told by a physician or health professional that they had conditions such as arthritis, diabetes, etc. Functional disability was evaluated from the 2021–2023 interviews. Questions asked about difficulty in the past 12 months with: (i) seeing even with glasses, (ii) hearing even with hearing aids, (iii) walking or climbing stairs, (iv) feeling worried, nervous, or anxious, and (v) feeling depressed.

2.4 | Statistical Analysis

All analyses used survey procedures in SAS, version 9.4, (SAS Institute, Cary, North Carolina, USA) following NCHS guidelines [35–37] to account for sample weights, stratification, and clustering in the NHANES complex sample design (e.g., PROC SURVEY with NCHS-provided variables for WEIGHT, STRATA, and CLUSTER), and the Taylor series (linearization) method was used to estimate sample variance for 95% confidence intervals (CIs) and statistical testing. Prevalence of self-reported measures (including for balance and dizziness) and MRT success or times to failure were calculated for the 2001–2004 and 2021–2023 samples. Multivariable logistic regression models, adjusted for age and sex, estimated relative risk (RR) and statistical significance for associations of balance disorders between survey cycles and with sociodemographic, health conditions, and functional disabilities within survey periods. Prevalence ratios were used to assess RR because they more directly measure the likelihood of an event for common outcomes (> 10%), wherein odds ratios from logistic regression do not provide as good an approximation [38, 39]. Obtaining adjusted prevalence ratio RR estimates requires additional calculation compared to odds ratios but is an available option in SAS, calculated as a nonlinear function of parameters from the logistic model [40]. All *p*-values and CIs were two-sided.

3 | Results

Characteristics of the NHANES participants are shown in Table 1, including the number of individuals in each survey period, arranged by age category (ordered youngest to oldest) and, alongside, the weighted percent estimates (since the sample numbers in each cell represent a percentage of the U.S. population in each time period). The first three left-hand columns provide these data for the most recent survey period, 2021–2023, since information on young adults aged 20–39 were only collected in the most recent survey. The three right-hand columns 4 to 6 provide data for NHANES 2001–2004, which collected information on adults aged 40+ (including older adults aged 70+). Age-specific comparisons are available for middle-aged adults, 40–69 years. Compared to 2001–2004, the 2021–2023 middle-aged adults were more educated, physically active, and more likely to have hypertension or diabetes; they were less likely to be non-Hispanic whites, smokers, or have trouble hearing (Table 1).

The participant flowchart (Figure 1) illustrates success/failure through the test conditions for both cohorts. Time able to maintain stance on condition 4 improved significantly between the two survey periods (Table 1). After adjusting for age and sex, the relative risk of failing MRT-4 for middle-aged adults in 2001–2004 (compared to 2021–2023) was 36% higher (RR = 1.36, 95% confidence interval [CI]: 1.22, 1.52; $p < 0.01$). In 2021–2023, 36.2% (34.5%, 37.8%) reported BDP (40–59 years: 34.3% [32.2%, 36.5%]; 60–69 years: 40.0% [36.0%, 44.0%]). In 2001–2004, the phrasing "difficulty with balance, dizziness, or falling" was sufficiently different from the specific BDP conditions asked about in 2021–2023 that it precluded direct comparisons of dizziness, balance, and falls across the two survey periods.

In 2001–2004, 29.7% (27.3%, 32.1%) failed MRT-4 (40–59 years: 24.4% [22.0%, 26.8%]; 60–69 years: 49.1% [45.1%, 53.2%]), whereas in 2021–2023, 25.9% (23.2%, 28.6%) failed MRT-4 (40–59 years: 17.5% [14.1%, 20.9%]; 60–69: 43.4% [39.1%, 47.6%]), a significant age-specific improvement ($p < 0.01$ in adjusted logistic regression models; Table 1). Time maintaining stance on MRT-4 in 2021–2023 compared to 2001–2004 was significantly longer (Figure 2). In 2001–2004, the mean was 24.2 s (23.7, 24.7) for middle-aged adults, but in 2021–2023, it increased modestly to 24.8 s (24.1, 25.4) ($p < 0.01$ in age- and sex-adjusted models). Younger individuals aged 20–39 years in 2021–2023 had longer mean time, 28.6 s [28.1, 29.0], maintaining stance on condition 4 and higher probability of success, since only 7.9% failed while 92.1% successfully passed the MRT-4.

Figure 3 depicts the relative risk of failing MRT-4, adjusted for age and sex. For middle-aged adults in 2021–2023, older age, less education, poverty income ratio, cigarette smoking, less physical activity, hypertension, diabetes, congestive heart failure or stroke, severe headaches/migraines, trouble hearing, and history of falling were all associated with failing MRT-4. In 2001–2004, Hispanic and non-Hispanic black race/ethnicity and arthritis were also associated with failing MRT-4. Comparisons between

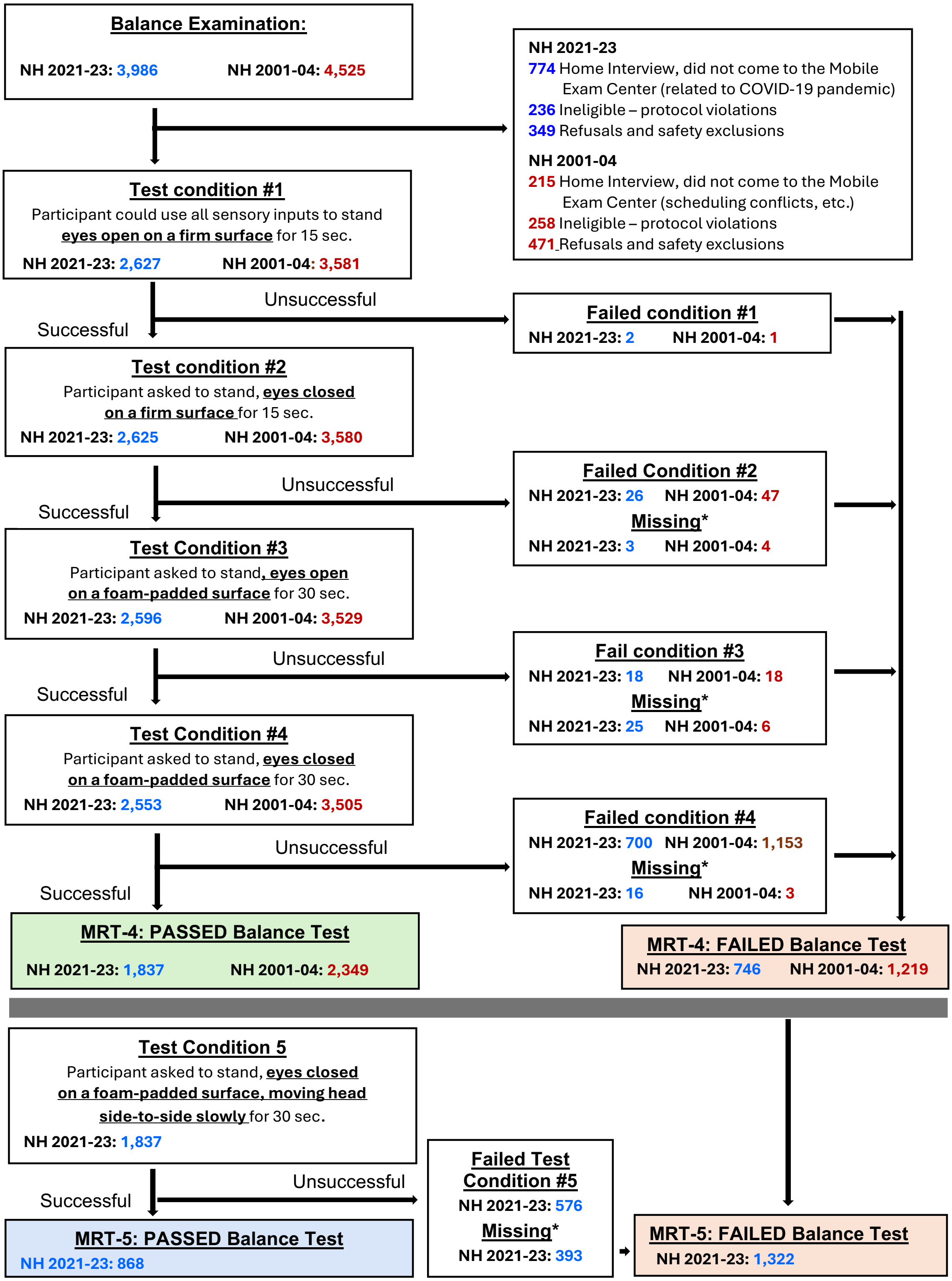

FIGURE 1 | Flow chart for NHANES (NH) 2021–2023 and 2001–2004: Modified Romberg Test (MRT) balance assessments for middle-aged adults (40–69 years).

relative risks across survey periods suggested only race/ethnicity and smoking were different (both $p<0.01$). In Figure 4 for 2021–2023 middle-aged adults, all measures of functional disability with "some or more difficulty" were associated with self-reported BDP. Significant associations for functional disabilities with failing MRT-4 were: difficulty hearing even with hearing aids, difficulty following conversations in noisy environments, walking or climbing stairs, and falling ≥ 3 times in the past 12 months. No association was found with failing MRT-4 and reported problems with anxiety or depression, however.

Prevalences of the BDP conditions of vertigo and unsteadiness increased with age in 2021–2023. Feeling light-headed or faint and oscillopsia, however, both showed small, inconsistent

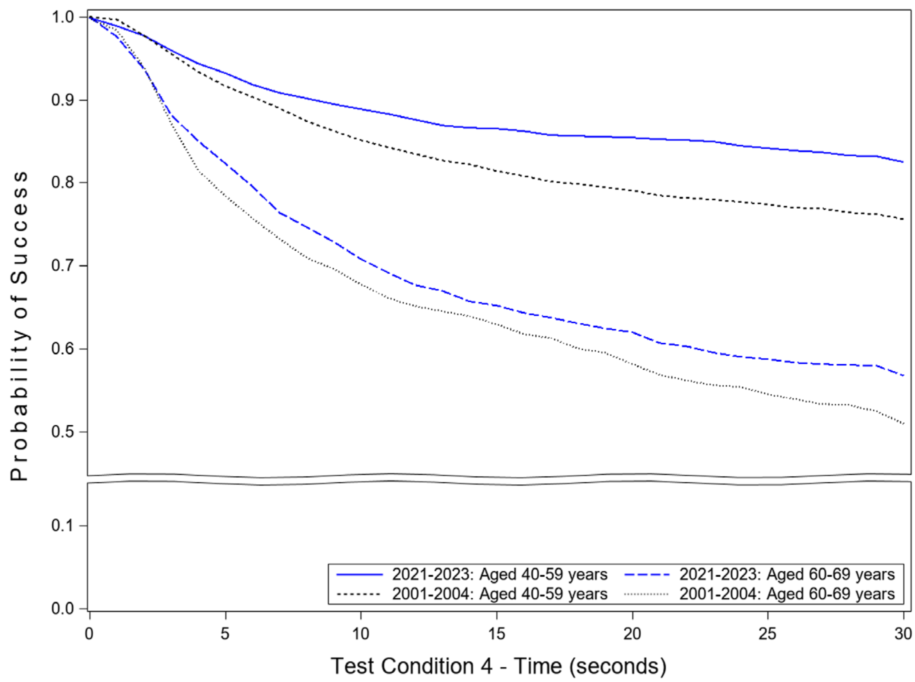

FIGURE 2 | Modified Romberg Test with four conditions (MRT-4): Probability of maintaining stance on test condition 4 by age* and survey periods, NHANES 2021–2023 and 2001–2004. *p-value < 0.01 for all pairwise comparisons based on log rank statistical test with adjustment for multiple comparisons for survey period and age.

changes in prevalence across the age range 20–69 (Table 2A). Unsteadiness or feeling off-balance (disequilibrium) increased the most, nearly doubling in prevalence, rising from 15.5% (12.9%, 18.2%) for young adults aged 20–39, to 29.6% (25.5%, 33.8%) for older adults aged 60–69. The combination of any BDP increased approximately six percentage points across the three age categories, for example, for age 20–39, 27.8% (25.2%, 30.4%); age 40–59, 34.3% (32.2%, 36.5%); and age 60–69, 40% (36.0%, 44.0%). When participants were asked which of the four BDP conditions bothered them the most in the past 12 months, young adults were most bothered by feeling light-headed or faint, 47.5% ([41.7%, 53.4%]; see Table 2B). Of these young adults, most reported being mildly bothered, while one-fourth indicated they were moderately or more seriously bothered. Vertigo was the most bothersome BDP for about 25% of the adults across the age range 20–69 and one-fourth of them reported that vertigo was a moderate or worse concern. Older adults aged 60–69 reported being most bothered by unsteadiness, 41.0% (35.9%, 46.1%) and more than one-third reported their unsteadiness problem was a moderate or worse concern.

Younger adults were more likely to report nausea/vomiting (31.5% vs. 26.7% and 15.2%) or severe headaches/migraines (46.3% vs. 36.8% and 22.1%) accompanied their BDP (95% CIs provided in Table 2C). Younger adults were also less likely to have seen a health professional or to have attempted treatment for their balance difficulties (Table 2G). Except for the larger relative risk association of failed MRT-4 with the most bothersome condition of feeling light-headed or faint for young adults, older adults (60–69 years) had larger relative risks for failed MRT-4 (and failed MRT-5) with most bothersome BDP conditions and also with falls (Table 3).

A sensitivity analysis was conducted to evaluate whether exclusions prior to administering MRT-4 in the two time periods could account for better MRT-4 performance in 2021–2023. We distinguished between protocol violations (limited time, equipment failure, etc.) and refusal or safety exclusions (unable to stand or leg brace needed to stand unassisted; dizziness sufficient to cause unsteadiness, etc.). Individuals excluded for protocol violations were not included in the sensitivity analysis. We investigated whether re-coding adults who either refused or were excluded for safety concerns as "failed MRT-4" could account for better performance in 2021–2023. For this worst-case scenario, the relative risk of failed MRT-4 in 2001–2004 (compared to 2021–2023) was 23% higher (RR = 1.23, 95% CI: 1.13–1.33; $p < 0.01$). The sensitivity analysis yielded a reduced estimate, RR = 1.23 (after re-coding) compared to RR = 1.36 (before re-coding). Better performance on MRT-4 in 2021–2023 was confirmed; however, since, regardless of recoding, both relative risk estimates were significant.

4 | Discussion

Two nationwide health examination surveys of adult balance disorders were compared for successful completion of MRT-4 and health risk factors across a 20-year period, 2001–2004 to 2021–2023. The adults available for comparison were middle-aged, 40–69 years, subdivided into 40–59 and 60–69 age groups. Older adults aged 70+ years were available only in 2001–2004. Inclusion of young adults in 2021–2023, however, allowed three age-group (20–39, 40–59, and 60–69 years) comparisons of the prevalence of the four BDP conditions, namely, vertigo, blurred vision with head movement (oscillopsia), unsteadiness or feeling off-balance (disequilibrium), or feeling light-headed or faint. For self-reported BDP in the past 12 months, we examined severity, accompanying conditions (nausea/vomiting, severe headaches/migraines, activity limitations, injuries, and falls), and whether health professionals were consulted and treatments tried (Table 2). In 2021–2023, unsteadiness or feeling off-balance (disequilibrium) was more prevalent in older adults and increased in linear fashion across the three age groups, young adults aged 20–39, adults aged 40–59, and older adults aged 60–69.

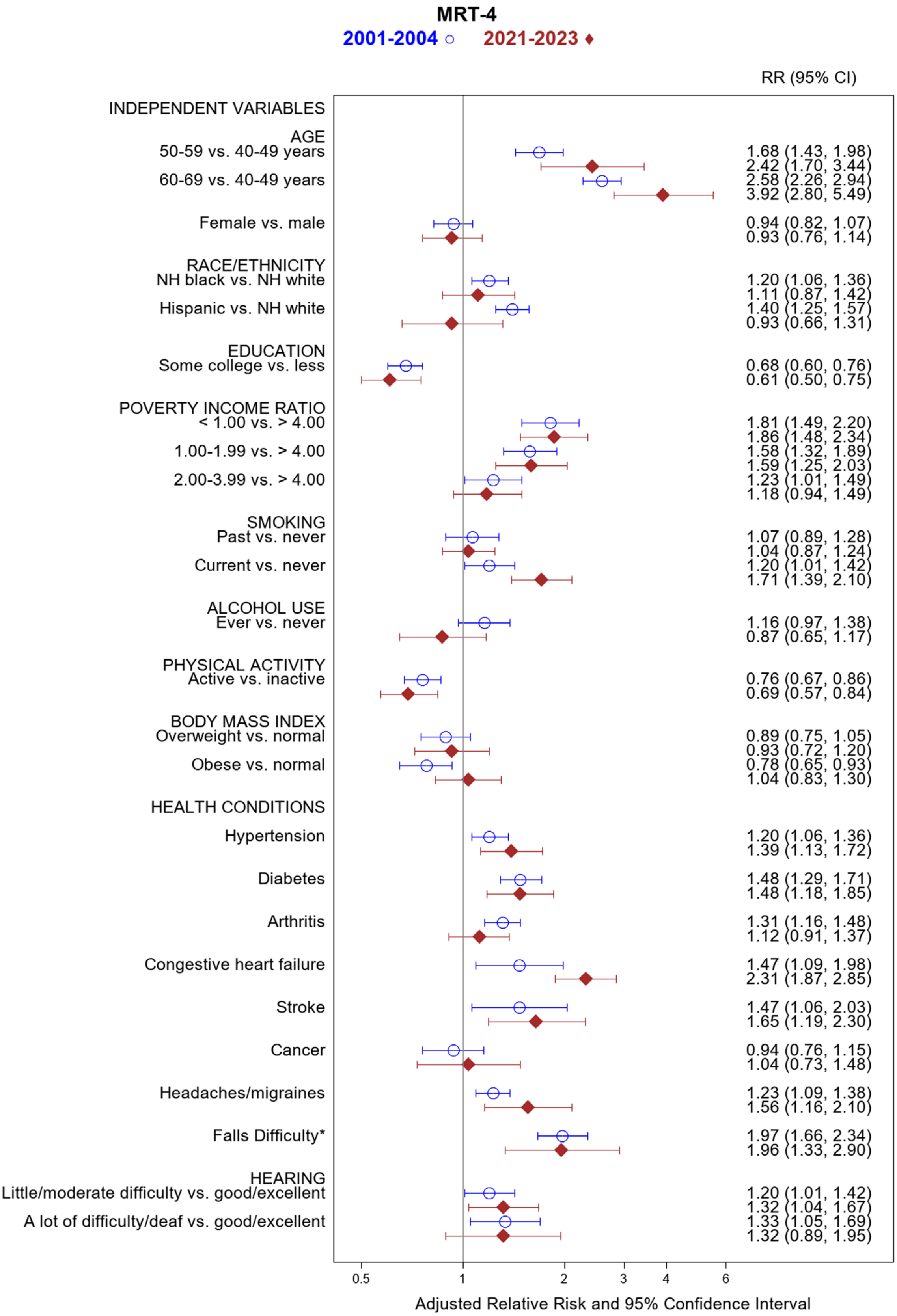

FIGURE 3 | Legend on next page.

FIGURE 3 | Modified Romberg Test with four conditions (MRT-4): Balance disorders by sociodemographic and health risks for middle-aged adults (40–69 years), NHANES 2001–2004 and 2021–2023. RR = relative risk; 95% CI = 95% confidence interval. Represents the relative risk of failing MRT-4 for each comparison group compared to each reference group, adjusted for age and sex. For example, the relative risk of failing to successfully pass all four Modified Romberg Test (MRT-4) conditions for female compared to male participants in NHANES 2021–2023 was RR = 0.94 (95% CI: 0.82, 1.07). Confidence intervals that cross the vertical reference line (x-axis = 1.00) indicate the relative risk is not statistically significant ($p > 0.05$). *Falls difficulty in NHANES 2001–2004 was defined as the report of "difficulty with falls in the past 12 months" and, in NHANES 2021–2023 was defined by the report of "falling 5 or more times in the past 12 months."

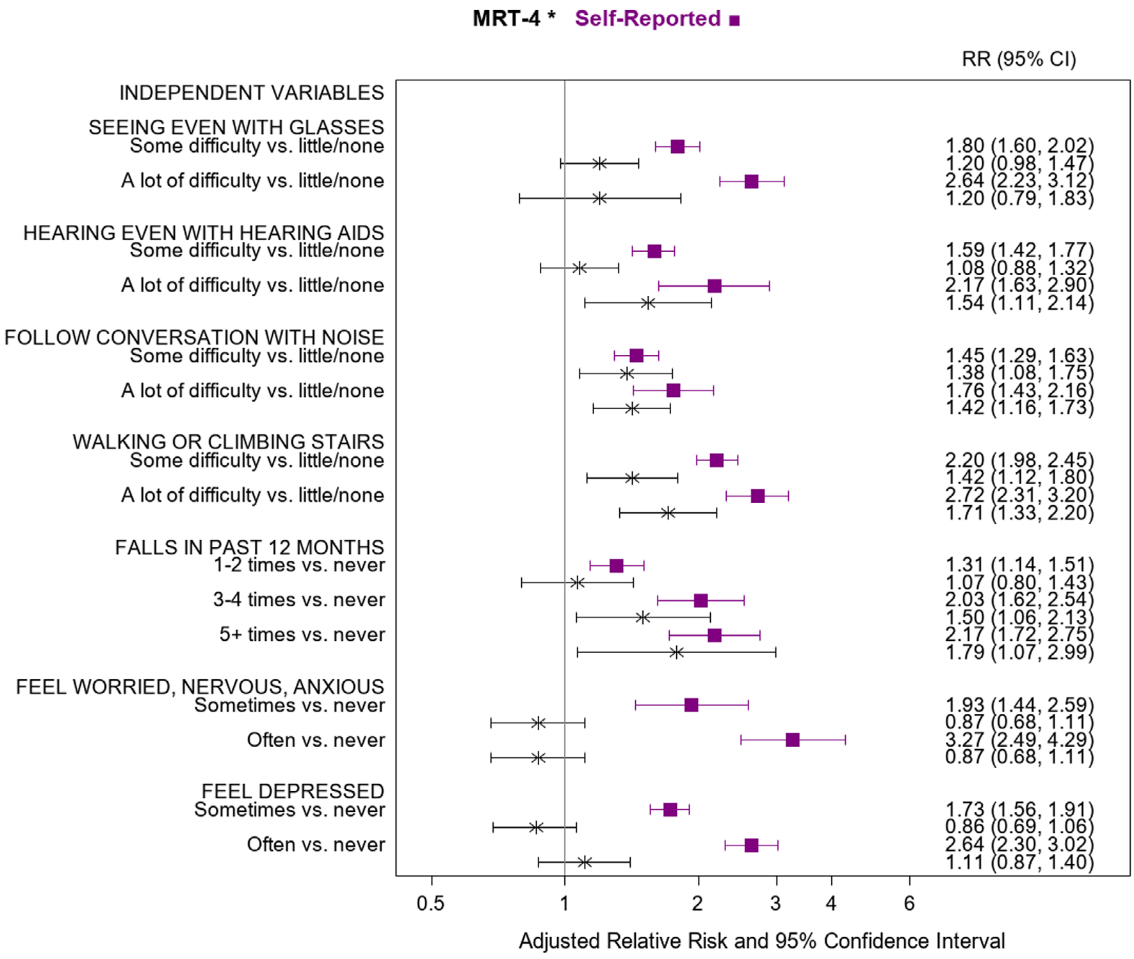

FIGURE 4 | Balance disorders by functional disability for middle-aged adults (40–69 years), NHANES 2021–2023. MRT-4 = balance difficulty during Modified Romberg Test–4 test conditions. Self-reported = Self-reported balance difficulty. RR = relative risk; 95% CI = 95% confidence interval. Represents the relative risk of (i) failing the MRT-4, or (ii) reporting balance and dizziness problems for each of the functional disabilities; each comparison group is compared to the reference group (e.g., "little/none" or "never"), adjusting for age and sex. Hence, the relative risk of failing the MRT-4 for participants with some difficulty seeing compared to participants with no difficulty seeing is 1.20 (95% CI: 0.98, 1.47). Confidence intervals that do not cross the vertical reference line (1.00) are statistically significant.

MRT balance performance test results improved over the two decades between surveys. The age-specific prevalence of successfully completing MRT-4 improved significantly by 6.9 percentage points for individuals aged 40–59, from 75.6% to 82.5%, and by 5.8 percentage points for individuals aged 60–69 years, from 50.9% to 56.7%, in 2001–2004 and 2021–2023, respectively. In addition, participants maintained balance on MRT-4 longer in 2021–2023, demonstrating age-specific improvements over time. This trend of better age-specific balance function in middle-aged adults is consistent with age-specific temporal trends reported in other sensory modalities (hearing and vision) and health conditions, such as cardiovascular disease, dementia, and ischemic stroke [41–47]. These trends suggest generally improved health outcomes in the U.S. population.

Comparison of sociodemographic and health factors associated with failed MRT-4 indicated similar relationships and strengths of associations in 2001–2004 and 2021–2023. Three exceptions were: (i) the association of Hispanic and non-Hispanic blacks with failed MRT (vs. non-Hispanic whites) was statistically significant in 2001–2004, whereas no association was observed in 2021–2023; (ii) the risk associated with current smoking (vs. never) increased significantly in 2021–2023 compared to 2001–2004; (iii) congestive heart failure emerged as one of the

TABLE 2 | Responses to balance and falls questions asked during home interview for adults aged 20–69 years, NHANES 2021–2023.

Balance and falls questions	NHANES 2021–2023		
	20–39 years (N = 2084) Wt'd %* (95% CI)	**40–59 years (N = 2221) Wt'd %* (95% CI)**	**60–69 years (N = 1765) Wt'd %* (95% CI)**
(A) In the past 12 months, did you have problems with balance and dizziness problems (BDP):			
Vertigo	14.8 (12.3, 17.2)	18.3 (16.7, 19.9)	21.9 (19.3, 24.6)
Blurred vision when head is moving head (oscillopsia)	8.8 (7.2, 10.5)	11.4 (9.7, 13.1)	10.3 (7.8, 12.9)
Unsteadiness or feeling off-balance (disequilibrium)	15.5 (12.9, 18.2)	22.9 (20.6, 25.3)	29.6 (25.5, 33.8)
Light-headedness feeling or about to faint (presyncope) or fainting (syncope)	19.0 (16.4, 21.5)	19.4 (17.3, 21.5)	17.6 (14.2, 21.0)
Any balance or dizziness problems (one or more of the above)	27.8 (25.2, 30.4)	34.3 (32.2, 36.5)	40.0 (36.0, 44.0)
(B) Among participants who reported BDP during the past 12 months, which problem bothered you the most? How much of a problem was it?			
Vertigo:			
Mild problem	19.8 (15.5, 24.1)	18.7 (16.0, 21.3)	20.6 (14.0, 27.2)
Moderate problem	3.4 (1.6, 5.2)	4.6 (2.5, 6.6)	4.2 (2.6, 5.8)
Big or very big problem	3.1 (1.2, 5.0)	2.4 (1.3, 3.6)	2.6 (1.7, 3.5)
Blurred vision when head is moving (oscillopsia):			
Mild problem	7.0 (4.7, 9.3)	8.3 (6.2, 10.4)	5.9 (4.4, 7.5)
Moderate problem	1.5 (0.6, 2.5)	1.8 (0.6, 3.1)	2.0 (0.8, 3.1)
Big or very big problem	0.6 (0.1, 1.8)	1.8 (0.6, 3.1)	0.5 (0.1, 1.1)
Unsteadiness or feeling off-balance (disequilibrium):			
Mild problem	13.0 (11.2, 14.7)	19.2 (15.3, 23.2)	26.2 (21.3, 31.1)
Moderate problem	2.8 (0.8, 4.9)	6.2 (3.7, 8.7)	9.3 (6.7, 11.8)
Big or very big problem	1.2 (0.1, 2.3)	4.3 (2.5, 6.0)	5.5 (4.0, 7.0)
Light-headedness feeling or about to faint (presyncope) or fainting (syncope):			
Mild problem	35.4 (29.4, 41.4)	23.8 (19.2, 28.3)	16.2 (13.4, 18.9)
Moderate problem	10.2 (7.3, 13.2)	6.5 (5.0, 8.0)	5.6 (3.0, 8.2)
Big or very big problem	1.9 (0.5, 3.3)	2.4 (1.1, 3.7)	1.4 (0.4, 2.4)
(C) When you had balance or dizziness problems in the past 12 months, did you have:			
Episodes or symptoms accompanied by nausea or vomiting	31.5 (26.1, 37.0)	26.7 (22.6, 30.8)	15.2 (12.3, 18.1)
Episodes or symptoms accompanied by migraines or severe headaches	46.3 (41.2, 51.5)	36.8 (32.3, 41.3)	22.1 (17.2, 27.1)
Episodes or symptoms that prevented you from doing things you would otherwise do, such as work, school, or other scheduled activities	30.2 (25.8, 34.6)	33.5 (28.2, 38.8)	35.5 (30.1, 40.8)

(Continues)

Balance and falls questions	NHANES 2021–2023		
	20–39 years (*N* = 2084) Wt'd %* (95% CI)	**40–59 years (*N* = 2221) Wt'd %* (95% CI)**	**60–69 years (*N* = 1765) Wt'd %* (95% CI)**
(D) In the past 12 months, how many times have you fallen?			
1–2 times	18.2 (15.2, 21.2)	21.3 (20.1, 22.5)	24.2 (21.0, 27.4)
3–4 times	3.1 (2.0, 4.2)	2.7 (1.7, 3.8)	4.0 (2.8, 5.2)
5 or more times	2.7 (1.8, 3.5)	2.7 (2.0, 3.3)	4.1 (2.6, 5.6)
(E) During the past 5 years, how many times have you fallen?			
Never	58.9 (54.9, 41.2)	57.0 (54.3, 59.7)	46.6 (42.9, 50.5)
Once per year or fewer (but more than never)	37.9 (34.7, 41.2)	39.8 (37.0, 42.5)	49.4 (46.1, 52.6)
About every month	1.9 (0.9, 2.9)	2.3 (1.5, 3.1)	2.9 (1.8, 4.0)
About every week	0.8 (0.4, 1.3)	0.7 (0.1, 1.2)	0.5 (0.1, 0.9)
Daily or constantly	0.5 (0.1, 0.9)	0.2 (0.1, 0.4)	0.6 (0.1, 1.1)
(F) Among individuals who reported falls:			
Have you had an injury that resulted from falling?	27.0 (20.2, 33.8)	35.9 (30.9, 41.0)	36.3 (31.4, 41.2)
(G) Healthcare			
Have you seen a doctor or other health professional about your problems with balance, blurred vision (oscillopsia), or light-headedness and fainting?	10.6 (8.6, 12.6)	15.9 (14.3, 17.4)	21.0 (18.2, 23.7)
Among individuals who reported balance difficulties*: have you ever tried to treat your problem(s) with balance, blurred vision [oscillopsia], or light-headedness and fainting?	35.7 (31.9, 39.6)	42.2 (39.0, 45.4)	43.1 (37.4, 48.8)

Note: * Wt'd % are United States population-based estimates of percent prevalence based on the national sampling weights provided by NHANES to account fpr the complex sample design.

strongest risk factors, in 2021–2023, RR = 2.31 (1.87, 2.85) for failed MRT-4, second only to associations with age. These differences suggest underlying changes in population composition, lifestyle factors (e.g., nutrition, exercise, smoking, etc.), and improved treatments (e.g., to lower blood pressure, anticoagulant medications, etc.) for chronic health conditions such as congestive heart failure [48–51].

For NHANES 2021–2023, we compared associations between functional disabilities and BDP and also with failed MRT-4 during the past 12 months. The report of BDP was more strongly associated with functional disabilities. While self-reported BDP and MRT-based assessment of balance showed different association magnitudes, they generally did not conflict. The exception was for feelings of anxiety and depression, which were not associated with failed MRT-4 but were moderately strong related to self-reported BDP.

Differences between self-report and exam-based measures are not surprising. Self-report represents subjective opinions regarding sensations and performance, while exam-based measures provide controlled snapshots of responses to focused stimuli. Both kinds of data provide useful information. Several reports have examined the association between anxiety and subjective versus objective measures [52–55]. Reports across other sensory domains have provided insights regarding discrepancies in association patterns for disability outcomes based on self-report compared to objective behavioral measures [56–58].

The finding in 2021–2023 of more self-reported BDP and more actual performance balance dysfunction with increasing age, from 20–39 to 40–59 to 60–69 years, supports and extends previous evidence from smaller samples. Many participants accurately perceived that their balance ability had decreased. This finding is particularly notable with MRT-5. Condition 5 is more challenging because it involves active head movement, so the test subject concentrates on performing head movements rather than simply on what the feet are doing on the unstable foam pad. Shaking the head may also make the labyrinthine sensation and cervical proprioception less reliable measures of head

TABLE 3 | Associations between Modified Romberg Balance Tests (MRT-4 & MRT-5), balance disorders, and falls by age, NHANES 2021–2023.

	Balance and dizziness problems (BDP) and falls (past 12 months)				
Age (years)	Vertigo adj RR [95% CI]	Oscillopsia adj RR [95% CI]	Unsteadiness adj RR [95% CI]	Light-headedness/ fainting adj RR [95% CI]	Falls adj RR [95% CI]
(A) Relative risk[1] of failing to pass MRT-4					
20–39	1.57 (0.86, 2.87)	1.43 (0.74, 2.74)	1.43 (0.88, 2.31)	**1.83 (1.13, 2.97)***	0.88 (0.47, 1.61)
40–59	**1.50 (1.00, 2.26)***	1.41 (0.88, 2.26)	**1.80 (1.22, 2.66)****	1.18 (0.75, 1.85)	**1.60 (1.13, 2.27)***
60–69	1.14 (0.95, 1.38)	**1.40 (1.07, 1.84)***	**1.27 (1.06, 1.52)***	**1.21 (1.05, 1.41)***	**1.28 (1.06, 1.54)***
(B) Relative risk[1] of failing to pass MRT-5					
20–39	1.19 (0.86, 1.65)	1.35 (0.88, 2.05)	1.12 (0.77, 1.61)	1.24 (0.95, 1.62)	1.04 (0.80, 1.35)
40–59	1.21 (0.99, 1.47)	1.17 (0.93, 1.46)	**1.30 (1.15, 1.49)****	1.13 (0.92, 1.37)	**1.36 (1.16, 1.58)****
60–69	**1.13 (1.02, 1.26)***	**1.20 (1.10, 1.30)****	**1.15 (1.03, 1.28)***	**1.15 (1.03, 1.27)***	**1.08 (1.00, 1.18)***

Note: Statistically significant results are bolded; *indicates $p < 0.05$ and **indicates $p < 0.01$.
Abbreviations: MRT-4 = Modified Romberg Test, 4 test conditions; MRT-5 = Modified Romberg Test, 5 test conditions.
[1]Represents the relative risk of failing to pass MRT for individuals reporting balance symptoms or falls during the past 12 months compared to individuals who did not report balance symptoms or falls during the past 12 months; adj RR = adjusted relative risk; 95% CI = 95% confidence interval; adjusted for sex.

orientation. This head movement challenge adds a component of dual task performance to the MRT. This simple modification to the already-simple MRT clinical test improves test sensitivity, using a 30-s time interval to assess, without the need to measure postural sway. Because it improves sensitivity, we recommend use of MRT-5 in future epidemiologic studies as well as in clinical screening.

Prior studies have documented increased prevalence of BDP (vertigo, dizziness, disequilibrium) with disability and other health conditions, including sociodemographic factors and psychosomatic conditions. Much of the literature has focused on risks for older age adults where falls contribute to greater morbidity and motality [59]. Balance and dizziness problems are important factors for transitioning from independent to assisted living. A study of association between regular episodes of dizziness/balance problems with disability assessed by three common Activities of Daily Living and physical functioning scales found that associations were not changed after controlling for other health conditions (e.g., orthostatic hypotension, poor visual acuity, prescription medicines, etc.). The other health conditions, when controlled for, did not confound the strong association of dizziness/balance problems with disability [60].

A systematic review and meta-analysis reported that dizziness is significantly associated with falls and even more strongly associated with recurrent falls [61]. The prevalence of fall-related injuries for young (18–44 years), middle-aged (45–64 years), and older (≥65 years) adults, based on the 2008 National Health Interview Survey and CDC injury statistics reporting, showed that about one-third of falls occurred in each age group and balance problems and falls are common across the adult lifespan [62]. Therefore, balance/dizziness problems are important risk factors for falls and suitable interventions should be implemented [63–65]. Another national study found > 60% decrease in quality-adjusted life years (QALYs) associated with report of balance and walking problems and about a 50% decrease in QALYs associated with falls in the past 12 months [66].

This study has some limitations and unique strengths. It relied upon self-report of BDP and other measures, including functional disability, during structured home interviews. Eligibility exclusions for MRT-4 could have affected the results, but a sensitivity analysis showed the estimate of better balance performance in 2021–2023 compared to 2001–2004 remained similar in magnitude and statistically significant. An important strength of the study was the ability to compare risk factor associations with the MRT-4, a direct physical performance measure, across the two time periods.

NHANES 2001–2004 and 2021–2023 were cross-sectional surveys that ascertained different representative samples of the U.S. population but did not include prospective longitudinal comparisons. Over the past 20 years, however, the National Center for Health Statistics has used carefully constructed, standard procedures with vigilant monitoring of adherence to examination protocols in order to provide national estimates of health trends with a high degree of precision for the U.S. population. One may ask, which observed differences in this study are clinically significant versus statistically significant? Although this question is important, the determination of statistical versus clinical significance can be complicated and depends on one's scientific perspective. Studies on large, nationally representative cohorts (population-based samples of adults) provide the broad view of the total population, which are essential for long-term planning and for health care. Those studies necessarily lose the level of detail possible in studies of smaller, clinical samples of affected individuals. Thus, the two kinds of approaches complement each other and together provide valuable scientific and therapeutic insights.

5 | Conclusion

Prior studies of balance disorders have typically used clinic-based patient samples and community-based cohorts. Few studies have provided nationally-representative estimates. This study presents results from two national surveys, NHANES 2001–2004 and 2021–2023. Estimates based on the MRT-4 screening protocol for balance function demonstrated significantly better age-specific performance in 2021–2023. Specifically, the prevalence of balance dysfunction based on MRT-4 decreased over the past two decades among middle-aged adults. A higher percentage of adults in the age ranges 40–59 and 60–69 years successfully passed the MRT-4. Nevertheless, risk factor associations with failed MRT-4 outcomes, after controlling for demographic factors in the U.S. population, have not changed markedly in the past two decades. Using the 2021–2023 self-report measures of BDP to compare with failed MRT-4 outcomes for a comparison of associations with self-reported functional disabilities, we found similar patterns of significance for sensory measures (i.e., hearing even with hearing aids and difficulty following conversations in noisy environments), mobility measures (i.e., walking and climbing stairs), and falls in the past 12 months.

While age-specific prevalence of balance function based on the MRT-4 improved, as people live longer, more older adults will live with disabilities associated with vestibular balance disorders and other sensory impairments. This trend will add to the need for multidisciplinary approaches to care, integrating fall risk screening into evaluations that assess auditory, cognitive, physical, and psychological factors. Health care providers can inform their patients of the consequences of untreated BDP and associated risk factors to advocate for proactive multidisciplinary management, which may include referral to medical specialists (neurotologists, gerontologists) and intervention services from physical and occupational therapists to assist patients in maintaining physical activity and quality of life.

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Conflicts of Interest

One author (C.C.D.S.) holds an equity interest in Labyrinth Devices, LCC. He has been a consultant to Cochlear Corporation, MED-EL GmbH, and Novartis. The terms of these arrangements are managed in accordance with the Johns Hopkins School of Medicine policies. All other authors declare they have no conflicts of interest. This submission has not been published anywhere previously and it is not simultaneously being considered for any other publication.

Data Availability Statement

The data that support the findings of this study are openly available in NCHS/NHANES Public Use Data at https://wwwn.cdc.gov/nchs/nhanes/Default.aspx.

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