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ORIGINAL ARTICLE

# Determinants of cognitive health in the elderly: a comprehensive analysis of demographics, health status, and lifestyle factors from NHANES

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**Abstract**
This study analyzes data from the National Health and Nutrition Examination Survey (NHANES) to identify factors influencing cognitive performance among the elderly, as measured by the Digit Symbol Substitution Test (DSST). Employing multivariable linear regression, we evaluated the impact of demographic, lifestyle, and health-related factors on cognitive function in U.S. adults aged 60 and older. Our findings indicate that advanced age, particularly in those aged 70–79 and 80 + years, is associated with lower DSST scores. Male gender is linked with reduced cognitive performance, while higher educational attainment appears protective. Lifestyle factors, including current smoking and higher alcohol consumption, negatively impact cognitive outcomes, and excessive sleep duration (over 9 h) is also detrimental. Among health conditions, diabetes, chronic heart failure, and a history of stroke were associated with cognitive declines. Furthermore, increasing severity of depression correlates with lower cognitive function. These results underline the need for comprehensive public health strategies that integrate lifestyle modifications and chronic disease management to maintain cognitive health in older adults.

**Keywords** Cognitive performance · DSST · Aging · NHANES

## Introduction

As global populations age, cognitive decline in the elderly emerges as a critical public health challenge with profound implications for healthcare systems, policy makers, and families [1]. Understanding the determinants of cognitive health is essential for devising effective interventions that can enhance quality of life and maintain functional independence among older adults. This study employs the Digit Symbol Substitution Test (DSST), a measure of executive function and processing speed [2], to investigate cognitive performance across a spectrum of demographic, lifestyle, and health-related factors. DSST is not only valuable for identifying cognitive impairments but also for tracking changes over time, making it a useful tool in both clinical and public health interventions for aging populations [2].

Demographic variables such as age, gender, and education level are well-recognized in their association with cognitive performance [3–5]. However, their interactions with lifestyle choices—specifically smoking status, alcohol consumption, and sleep patterns—remain underexplored in neurocognitive and gerontological research. Moreover, health-related conditions, including Body Mass Index (BMI), hypertension, diabetes, history of stroke, chronic heart failure, and the severity of depressive symptoms, are hypothesized to influence cognitive trajectories yet the compound effects of these factors are not fully understood [6–10].

This comprehensive analysis utilizes data from the National Health and Nutrition Examination Survey (NHANES) to parse the individual and combined impacts

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of these predictors on cognitive function among the elderly. By integrating a broad array of variables, this study aims to elucidate the complex interplays and provide a holistic view of the factors that contribute to cognitive decline. Such insights are important for developing targeted, multifaceted interventions and informing public health strategies that address the nuances of cognitive aging and contribute to the broader goals of sustaining cognitive resilience in aging populations.

## Methods

### Study design and data source

This study employs a cross-sectional analysis of data from the NHANES for the years 2013-2014[11]. Conducted by the National Center for Health Statistics (NCHS) under the Centers for Disease Control and Prevention (CDC), NHANES assesses the health and nutritional status of the civilian noninstitutionalized U.S. population through combined interviews and physical examinations [11].

### Population and sampling

The subset analyzed comprised participants aged 60 years and older who completed the Digit Symbol Substitution Test (DSST), enabling an assessment of cognitive function.

### Outcome measures

The primary outcome was the DSST score, which measures executive function, processing speed, and attention. The DSST score is based on the number of correct symbol-number pairings made by participants within 120s. The score ranges from 0 to 100, with higher scores indicating better cognitive performance. This test is a validated measure of cognitive function in older adults, widely used in epidemiological studies and clinical assessments [2].

### Explanatory variables

Age, a key demographic variable, was categorized into three groups: 60–69 years, 70–79 years, and 80 + years. Gender was recorded as male or female based on self-report, and educational attainment was classified as high school or below versus college or above, with higher education serving as a proxy for cognitive reserve. Lifestyle variables included smoking status, categorized into never smokers, former smokers (those who had quit), and current smokers, while alcohol consumption was self-reported as the number of alcoholic drinks consumed over the past year, treated as a continuous variable. Sleep duration was also self-reported and categorized into three groups: less than 7 h, 7–9 h (reference group), and more than 9 h per night. Health-related variables included body mass index (BMI), calculated as weight in kilograms divided by height in meters squared ($kg/m^2$), and treated as a continuous variable. Hypertension was defined as either a self-reported physician diagnosis or measured systolic blood pressure $\geq 140$ mmHg or diastolic blood pressure $\geq 90$ mmHg during physical examination. Diabetes was defined by self-reported physician diagnosis or fasting glucose levels $\geq 126$ mg/dL. The presence of chronic heart failure and history of stroke were both based on self-reported physician diagnoses. Depression severity was assessed using the Patient Health Questionnaire-9 (PHQ-9), categorizing participants into five levels: no depressive symptoms (score 0–4), mild (5–9), moderate (10–14), moderately severe (15–19), and severe (20–27).

### Statistical analysis

Univariate linear regression models were first used to evaluate the unadjusted association between each explanatory variable and DSST score. Multivariable linear regression was then performed to assess the adjusted associations while controlling for all the other variables.

The complex survey design of NHANES was accounted for by incorporating sampling weights, primary sampling units, and strata into the analyses to ensure nationally representative estimates and appropriate variance calculations. Standard diagnostic tests were conducted to evaluate model assumptions. All statistical analyses were conducted using Stata (version 18.0, Stata Corp LP, College Station, TX, USA) [12]. A two-sided $P$ value of less than 0.05 was prespecified as statistically significant.

### Ethical considerations

The study utilized publicly available, de-identified NHANES data, adhering to ethical research standards. The dataset's use was reviewed and approved to ensure compliance with ethical guidelines focused on privacy and confidentiality.

## Results

### Results from the National Health and Nutrition Examination Survey

In the study, the population of 1,589 elderly participants, were categorized into three age groups: 60–69 years ($N = 844$), 70–79 years ($N = 479$), and 80 + years ($N = 266$). The mean DSST scores differed significantly across age groups, with participants aged 60–69 years achieving higher cognitive performance (mean score 56.2, SD ± 0.9) compared to those in the 70–79 years group (mean score 47.8, SD ± 0.8), and the 80 + years group scoring the lowest (mean score 40.2, SD ± 1.0).

Table 1 presents the baseline demographic , lifestyle and health-related factors stratified by age groups.

## Demographics

The gender distribution showed a slightly higher proportion of females across all age groups, with the percentage increasing with age: 52.5% in the 60–69 years group, 54.6% in the 70–79 years group, and 58.5% in the 80 + years group. Educational attainment also varied, with 65.0% of the 60–69 age group having attended college or above, compared to 60.8% in the 70–79 age group and 59.5% in the 80 + age group.

## Lifestyle factors

Alcohol Consumption (number of alcohol drinks in the past year) was highest among the 60–69-year group (mean 10.6, SD ± 4.0), decreasing sharply in the older groups (2.7, SD ± 0.2 in the 70–79 years group and 3.1, SD ± 0.3 in the 80 + years group). Smoking Status showed that current smoking decreased with age from 13.7% in the 60–69 years group to 8.1% in the 70–79 years group and to 1.5% in the 80 + years group. The data demonstrates a consistent sleep pattern among participants, with most individuals across

**Table 1** Baseline participant characteristics by Age categories, NHANES, 2013–2014

| Characteristics | 60–69 years ($N$ = 844) | 70–79 years ($N$ = 479) | 80 + years ($N$ = 266) | Total ($N$ = 1589) |
|---|---|---|---|---|
| **Gender** | | | | |
| Female | 440(52.5%) | 252(54.6%) | 136(58.5%) | 828(54%) |
| Male | 404(47.5%) | 227(45.4%) | 130(41.5%) | 761(46%) |
| **Digit Symbol Score**, mean ± SD | 56.2 ± 0.9 | 47.8 ± 0.8 | 40.2 ± 1 | 53.3 ± 0.8 |
| **Body Mass Index (kg/m²)**, mean ± SD | 29.8 ± 0.4 | 29.0 ± 0.3 | 27.0 ± 0.3 | 29.2 ± 0.3 |
| **Educational Level** | | | | |
| High School or Below | 413(35.0%) | 230(39.2%) | 115(40.5%) | 758(37.1%) |
| College or above | 431(65.0%) | 249(60.8%) | 151(59.5%) | 831(62.9%) |
| **Alcohol Consumption (past 1 year)**, mean ± SD | 10.6 ± 4.0 | 2.7 ± 0.2 | 3.1 ± 0.3 | 7.2 ± 2.4 |
| **Smoking Status** | | | | |
| Never | 386(46.6%) | 243(51.0%) | 156(59.1%) | 785(49.8%) |
| Former | 305(39.7%) | 196(40.9%) | 106(39.4%) | 607(40.0%) |
| Current | 153(13.7%) | 39(8.1%) | 4(1.5%) | 196(10.2%) |
| **Sleep Category** | | | | |
| 7–9 h | 498 (68.1%) | 312(70.9%) | 178(67.4%) | 988(68.8%) |
| < 7 h | 310(27.9%) | 149(25.5%) | 68(24.9%) | 527 (26.8%) |
| > 9 h | 36(4.0%) | 18(3.6%) | 20(7.7%) | 74(4.4%) |
| **Depression Severity** | | | | |
| No depressive symptoms | 589(74.5%) | 348(76.9%) | 192(73.8%) | 1129(75.1%) |
| Mild depressive symptoms | 140(14.9%) | 79 (16.0%) | 41(17.1%) | 260(15.6%) |
| Moderate depressive symptoms | 63(7.3%) | 28(4.2%) | 15(5.2%) | 106(6.1%) |
| Moderately severe depressive symptoms | 31(2.2%) | 10 (2.1%) | 6(2.5%) | 47(2.3%) |
| Severe depressive symptoms | 8(1.04%) | 4(0.7%) | 2(1.3%) | 14(1.0%) |
| **Hypertension** | | | | |
| No | 199 (27.4%) | 87(20.6) | 33(12.0%) | 319(23.1%) |
| Yes | 636(72.6%) | 385(79.4) | 230(88.0%) | 1251 (73.9%) |
| **Diabetes Diagnosis** | | | | |
| No | 593(79.6%) | 334(77.2%) | 204(82.7%) | 1131(79.4%) |
| Yes | 199(20.4%) | 120(22.8%) | 509(17.3%) | 369 (20.6%) |
| **Congestive Heart Failure** | | | | |
| No | 808(96.5%) | 435(90.8%) | 229(87.4%) | 1472(93.4%) |
| Yes | 34(3.5%) | 42(9.2%) | 36(12.6%) | 112(6.6%) |
| **History of Stroke** | | | | |
| No | 807(95.4%) | 438(91.7%) | 231(87.8%) | 1476(93.2%) |
| Yes | 37(4.7%) | 39(8.3%) | 34(12.2%) | 110(3.8%) |

The percentages and means presented in this table are survey weighted. N, number of participants; SD, standard deviation each age group reporting 7–9 h of sleep per night, indicating little variation in sleep duration with aging.

## Health-related factors

The mean BMI showed a decreasing trend with age: 29.8 kg/m² (SD ± 0.4) in the 60–69 years group, 29.0 kg/m² (SD ± 0.3) in the 70–79 years group, and 27.0 kg/m² (SD ± 0.3) in the 80 + years group. The prevalence of hypertension increased with age, from 72.6% in the 60–69 years group to 79.4% in the 70–79 years group and 88.0% in the 80 + years group. 20.4% of the youngest group (60–69 years) reported having diabetes, this was less prevalent in the oldest group (80 + years) (17.3%). The incidence of congestive heart failure and history of stroke increases with increasing age groups. Regarding mental health, the percentage of participants with no depressive symptoms and varying depressive symptoms were similar across age groups group.

Table 2 presents the univariable and multivariable linear regression coefficients. Being male was associated with a significant decrease in the outcome variable, with a univariable coefficient of -3.56 (95% CI: -5.28 to -1.84, $P = 0.001$) and a multivariable coefficient of -6.23 (95% CI: -7.60 to -4.87, $P < 0.001$). Compared to the reference group (60–69 years), individuals aged 70–79 years showed a significant decrease in the outcome, both in univariable (-8.39, 95% CI: -10.39 to -6.40, $P < 0.001$) and multivariable analyses (-7.73, 95% CI: -9.95 to -5.52, $P < 0.001$). Similarly, individuals 80 years and older exhibited even greater decreases in univariable (-15.96, 95% CI: -17.83 to -14.08, $P < 0.001$) and multivariable analyses (-14.84, 95% CI: -16.88 to -12.80, $P < 0.001$). Having an education level of college or above was associated with an increase in the outcome variable with a univariable coefficient of 11.77 (95% CI: 8.72 to 14.82, $P < 0.001$) and a multivariable coefficient of 9.47 (95% CI: 6.78 to 12.16, $P < 0.001$).

BMI showed no significant association in the multivariable analysis (-0.08, 95% CI: -0.21 to 0.05, $P = 0.195$). Current smokers had a significant decrease in the outcome in multivariable analysis (-5.03, 95% CI: -9.37 to -0.69, $P = 0.026$). A decrease in DSST was observed with every 10

**Table 2** Univariable and Multivariable Linear regression analysis of factors affecting DSST scores

| Predictor | Univariable Coef. | 95% CI | *P*-value | Multivariable Coef. | 95% CI | *P*-value |
|---|---|---|---|---|---|---|
| **Gender (Male)** | -3.56 | (-5.28, -1.84) | **0.001** | -6.23 | (-7.60, -4.87) | **< 0.001** |
| **Age Category** | | | | | | |
| 60–69 (Reference) | | | | | | |
| 70–79 | -8.39 | (-10.39, -6.40) | **< 0.001** | -7.73 | (-9.95, -5.52) | **< 0.001** |
| 80+ | -15.96 | (-17.83, -14.08) | **< 0.001** | -14.84 | (-16.88, -12.80) | **< 0.001** |
| **Education Level** | | | | | | |
| Below College (Ref) | | | | | | |
| College or above | 11.77 | (8.72, 14.82) | **< 0.001** | 9.47 | (6.78, 12.16) | **< 0.001** |
| **BMI** | -0.01 | (-0.16, 0.14) | 0.861 | -0.08 | (-0.21, 0.05) | 0.195 |
| **Smoking Status** | | | | | | |
| Non-smoker (Ref) | | | | | | |
| Former | -1.46 | (-4.40, 1.47) | 0.305 | -0.15 | (-2.23, 1.93) | 0.883 |
| Current | -4.38 | (-8.56, -0.20) | **0.041** | -5.03 | (-9.37, -0.69) | **0.026** |
| **Alcohol Consumption (Per 10 Bottles in the Last Year)** | -0.06 | (-0.11, -0.00) | **0.034** | -0.14 | (-0.21, -0.07) | **0.001** |
| **Sleep Duration** | | | | | | |
| 7–9 h (Ref) | | | | | | |
| < 7 h | -2.92 | (-5.47, -0.37) | **0.028** | -0.98 | (-2.87, 0.91) | 0.286 |
| > 9 h | -8.99 | (-13.38, -4.60) | **0.001** | -5.74 | (-11.42, -0.06) | **0.048** |
| **Depression Severity** | | | | | | |
| None (Ref.) | | | | | | |
| Mild | -4.99 | (-8.21, -1.77) | **0.005** | -4.08 | (-6.67, -1.50) | **0.004** |
| Moderate | -6.84 | (-12.28, -1.41) | **0.017** | -5.07 | (-9.46, -0.68) | **0.026** |
| Moderately Severe | -14.69 | (-21.24, -8.14) | **< 0.001** | -8.97 | (-15.62, -2.33) | **0.012** |
| Severe | -10.60 | (-27.87, 6.67) | 0.210 | -2.97 | (-9.63, 3.70) | 0.358 |
| **Hypertension** | -5.67 | (-8.32, -3.02) | **< 0.001** | -2.30 | (-4.60, 0.00) | 0.050 |
| **Diabetes** | -6.75 | (-9.01, -4.49) | **< 0.001** | -3.54 | (-5.54, -1.54) | **0.002** |
| **Chronic Heart Failure** | -10.45 | (-13.77, -7.13) | **< 0.001** | -3.32 | (-6.13, -0.52) | **0.023** |
| **History of Stroke** | -10.72 | (-13.63, -7.80) | **< 0.001** | -5.44 | (-9.03, -1.86) | **0.006** |

Note: Regression coefficients presented are weighted for both univariate and multivariate models bottles consumed in the past year in multivariable analysis (-0.14, 95% CI: -0.21 to -0.07, $P=0.001$).

In univariable analysis, sleeping less than 7 h was associated with a decrease (-2.92, 95% CI: -5.47 to -0.37, $P=0.028$), although this was not significant in the multivariable analysis. Sleeping more than 9 h showed significant decreases in DSST in both univariable (-8.99, 95% CI: -13.38 to -4.60, $P=0.001$) and multivariable analyses (-5.74, 95% CI: -11.42 to -0.06, $P=0.048$).

Increasing severity of depression was significantly associated with decreases in the outcome variable, with coefficients ranging from -4.08 for mild depression to -8.97 for moderately severe depression in the multivariable analysis.

Chronic conditions such as diabetes, chronic heart failure, and history of stroke showed significant negative impacts on the mean DSST scores in multivariable analysis -3.54 (-5.54, -1.54), -3.32 (-6.13, -0.52), -5.44 (-9.03, -1.86) respectively.

## Discussion

This cross-sectional analysis of data from the National Health and Nutrition Examination Survey (NHANES) identified several demographic, lifestyle, and health-related factors associated with cognitive performance in U.S. adults aged 60 years and older, as measured by the Digit Symbol Substitution Test (DSST). The study found significant associations between advanced age, male gender, a history of stroke, and chronic conditions such as depression, diabetes, and chronic heart failure with lower cognitive scores. Higher educational attainment was linked to better cognitive outcomes, while lifestyle factors like smoking, alcohol consumption, and long sleep duration were associated with cognitive decline.

Age was a prominent factor associated with cognitive decline, with participants aged 80 years and older experiencing the most significant reductions in DSST scores compared to those aged 60–69 years. This finding is consistent with existing literature, which identifies aging as a key factor in cognitive deterioration, likely influenced by neurobiological processes such as neuronal loss and reduced synaptic plasticity [1]. Male gender was also independently associated with poorer cognitive function, consistent with some research suggesting women may preserve cognitive function better with age [4]. However, findings on gender and cognition vary, with other studies showing minimal or reversed differences [3]. This highlights the need for further research to explore the complex interplay of biological and sociocultural factors influencing cognitive aging. Higher educational attainment, which reflects cognitive reserve, appeared protective, supporting theories that education may buffer against age-related cognitive decline and contribute to brain health [5].

A history of stroke was associated with significantly lower DSST scores, in line with well-established links between stroke-related vascular damage and cognitive impairment [6]. This finding highlights the importance of stroke prevention, and management strategies aimed at reducing long-term cognitive decline and supporting brain health in stroke survivors.

Lifestyle factors also played a considerable role in cognitive outcomes. Current smoking and higher alcohol consumption were linked to poorer cognitive performance, consistent with research that associates smoking and chronic alcohol use with neurotoxic effects and cognitive decline [13, 14].

In terms of sleep patterns, long sleep duration (> 9 h) remained independently associated with lower DSST scores, even after accounting for multiple comparisons, while short sleep duration (< 7 h) was not significantly related to cognitive outcomes. The negative association with prolonged sleep is well established and may reflect underlying health conditions or disruptions in sleep architecture, which could contribute to cognitive decline [15]. The non-significant relationship with short sleep duration could be influenced by several factors. Short sleep duration alone may not fully capture the complexities of sleep quality. Sleep fragmentation, disturbances, and efficiency (how restorative sleep is) are critical aspects that affect brain health and cognitive function. It is possible that some individuals in the < 7-hour sleep group had good sleep quality, which offset the negative effects typically associated with short sleep duration. There is also the possibility that healthier participants or those with protective factors offset the effects of short sleep. The complex relationship between sleep and brain health warrants further investigation, particularly in the context of aging populations.

Chronic health conditions, including depression, diabetes, and heart failure, were strongly associated with cognitive decline consistent with current body of knowledge [7–9]. Depression demonstrated a stepwise relationship, with increasing severity of depressive symptoms linked to progressively lower DSST scores. However, the lack of statistical significance for severe depression in our sample, despite the observed trend, may be due to the very small representation of individuals with severe depression (only 1% of participants). This limitation likely reduced the power to detect a significant association. Larger studies with greater representation of severely depressed individuals are needed to further explore this relationship.

Interestingly, BMI and hypertension were not significantly associated with cognitive performance in the multivariable analysis. This contrasts with some studies that have linked these conditions to cognitive decline [7, 10]. A plausible explanation for the lack of significant associations between BMI, hypertension, and cognitive performance could be that the effect of these conditions on cognition is more indirect or accumulates over a longer period, making it difficult to detect in a cross-sectional analysis.

Although the minimal clinically important differences (MCIDs) for the DSST have not been well defined, small changes in scores may still have meaningful implications, especially in older adults. Studies, such as Jehu et al., indicate that even modest declines in executive function could reduce functional independence, suggesting that the cognitive changes observed in our study could have real-world implications for daily functioning and brain health in aging populations [16].

The study has limitations, primarily its cross-sectional design, which limits our ability to infer causal relationships. Additionally, even though we accounted for NHANES' complex sampling design, the participants who completed the DSST may not fully represent the broader NHANES population, raising concerns about potential selection bias. This could limit the generalizability of our findings, as individuals with better cognitive function may have been more likely to complete the test. We were also unable to account for the duration or control status of chronic conditions such as diabetes and hypertension, which may affect their associations with cognitive outcomes. Longitudinal studies are needed to explore these relationships over time and assess the impact of targeted interventions on cognitive and brain health in aging populations.

Despite these limitations, the study's strengths include the use of a large, nationally representative sample and a comprehensive evaluation of demographic, lifestyle, and health-related factors. The multivariable analysis helped account for potential confounders, offering a robust examination of the factors associated with cognitive aging and brain health.

In conclusion, our findings highlight the multifaceted nature of cognitive aging and brain health, with significant associations between modifiable risk factors and cognitive performance. Addressing lifestyle factors such as smoking, alcohol consumption, and sleep patterns, as well as managing chronic conditions like depression, stroke, diabetes, and heart failure, may help maintain cognitive function in older adults. Future longitudinal studies will be essential to further understand these associations and to develop interventions aimed at promoting cognitive resilience and brain health in older populations.

## Declarations

**Ethics approval and consent to participate** The data used in this study were obtained from the National Health and Nutrition Examination Survey (NHANES), an open-source dataset publicly available for research purposes. As this study involved secondary analysis of publicly available, de-identified data, it did not require ethical approval or informed consent.

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