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RESEARCH ARTICLE

Associations of the Lifestyle for Brain Health (LIBRA) index with cognitive functioning across adulthood: Variation by sex and socioeconomic status in the German National Cohort (NAKO)

Susanne Röhr[1,2,3] | Felix Wittmann[2] | Melanie Luppa[2] | Sebastian Köhler[4] | Kay Deckers[4] | Colin Rosenau[4] | Philine Betker[5] | Patricia Bohmann[6,7] | Hermann Brenner[8] | Agnes Flöel[9,10] | Jana-Kristin Heise[5] | André Karch[11] | Thomas Keil[12,13,14] | Michael Leitzmann[6] | Wolfgang Lieb[15] | Claudia Meinke-Franze[9] | Rafael Mikolajczyk[16,17] | Ute Mons[18] | Katharina Nimptsch[19] | Cara Övermöhle[15] | Annette Peters[20] | Tobias Pischon[19] | Tamara Schikowski[21,22] | Matthias B. Schulze[23,24] | Oliver Tüscher[17,25] | Stefan N. Willich[12] | Luca Kleineidam[26,27] | Michael Wagner[26,27] | Klaus Berger[11] | Alexander Pabst[2] | Steffi G. Riedel-Heller[2]

Correspondence
Susanne Röhr, Centre for Healthy Brain Ageing (CHeBA), Discipline of Psychiatry and Mental Health, School of Clinical Medicine, Faculty of Medicine and Health, UNSW Sydney, Randwick, NSW, Australia.
Email: s.roehr@unsw.edu.au

Susanne Röhr and Felix Wittmann shared first authorship.

Alexander Pabst and Steffi G. Riedel-Heller shared last authorship.

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Abstract

INTRODUCTION: The Lifestyle for Brain Health (LIBRA) index evaluates modifiable dementia risk, mainly in midlife and older adults. We examined the frequency of LIBRA factors and their individual and combined associations with cognitive functioning across adulthood (20–75 years), considering age, sex, and socioeconomic status (SES).

METHODS: Data came from the population-based German National Cohort (NAKO baseline; $n = 149{,}948$). We calculated proportions for LIBRA factors, tested frequency trends, and analyzed cross-sectional associations with cognitive functioning using cluster-adjusted regression controlling for confounders.

RESULTS: Behavioral and psychosocial risks (smoking, physical inactivity, depression) were more common in younger adults, while cardiovascular risks (hypertension, coronary heart disease, hypercholesterolemia) predominated in older age. Men had higher LIBRA scores. Higher scores were consistently linked to lower cognitive functioning and lower SES across age groups.

DISCUSSION: Dementia risk factors were frequent and already associated with poorer cognition in younger adults, underscoring the need for early, targeted, and equity-oriented prevention.

KEYWORDS
adulthood, aging, cognitive functioning, cohort study, dementia, dementia risk, German National Cohort, lifespan, lifestyle, Lifestyle for Brain Health, prevention, risk factor, risk reduction, younger adults

Highlights

- Higher Lifestyle for Brain Health (LIBRA) scores were consistently associated with lower cognitive functioning across adulthood spanning from 20 to 75 years of age.
- Behavioral and psychosocial LIBRA factors (smoking, physical inactivity, depression) were more frequent in younger adults; cardiovascular factors (hypertension, coronary heart disease, hypercholesterolemia) more among older adults.
- The study is the first to demonstrate LIBRA's usefulness in younger adults (20–39 years).
- Lower socioeconomic status (SES) groups had higher LIBRA scores.
- Sex/gender and SES disparities call for targeted prevention strategies.

1 | BACKGROUND

A growing body of research highlights considerable potential for reducing the risk of cognitive decline and dementia through modifiable health and lifestyle factors.[1] Up to 45% of all dementia cases could theoretically be prevented if 14 modifiable risk factors were eliminated: less education in early life; hearing loss, traumatic brain injury, hypertension, diabetes, high cholesterol, excessive alcohol consumption, physical inactivity, depression, smoking, and obesity in midlife; social isolation, air pollution, and untreated vision loss in later life.[1] Notably, these factors contained in the "Lancet life course model" do not form an exhaustive list but rather represent those with the most robust evidence for being risk factors for cognitive decline and dementia available up to 2024.

The Lifestyle for Brain Health (LIBRA) index constitutes an approach to assess potential for improving brain health or reducing dementia risk based on individual-level modifiable risk and protective factors.[2,3] It is a weighted composite score developed in 2013 through a systematic literature review and refined by a Delphi expert panel.[2] LIBRA's quantification method specifically focusing on the individual is useful, for example, in characterizing risk profiles, monitoring and evaluating intervention outcomes in dementia trials, studying pathways to dementia in association with non-individual (e.g., social, environmental, or economic determinants of health) and non-modifiable factors (e.g., age, genetics), and in helping people to understand their potential for brain health improvement.[4–7] Thus, LIBRA has applications for the development, evaluation, and implementation of strategies aimed at dementia prevention and intervention. Sharing many factors with the Lancet model, the LIBRA index contains 12 modifiable risk and protective factors for dementia. Its applicability has been comprehensively studied and confirmed in relation to cognitive functioning, cognitive decline, and prevalent and incident cognitive impairment and dementia in diverse midlife to older populations.[5,8–14] Recently, an updated LIBRA index (LIBRA2) has been suggested to reflect novel evidence on emerging modifiable risk and protective factors, which led to the addition of three more factors (sleep disturbances, low social participation, hearing impairment).[15] Notably, LIBRA remains valid despite the development of the updated version. Studies have shown that both versions effectively predict dementia risk, with similar performance metrics.[16]

Having reliable tools for quantifying potential for brain health improvement is particularly relevant in the context of the rise of dementia due to population aging and increases in cardiovascular and metabolic risk factors.[17,18] Germany, a country with one of the oldest populations globally, expects an increase of people with dementia from 1.7 million in 2023 to 3 million by 2060 or 2070.[19] Annual total societal costs in Germany accumulated to 73 billion Euro in 2016 and are projected to increase to 195 billion Euro in 2060.[20] The dementia prevention potential in Germany is estimated to be substantial: 38% of dementia cases in Germany were associated with 11 Lancet risk factors.[21] Yet, this opportunity remains largely untapped, both in Germany and globally.

Furthermore, investigations into risk and protective factors for brain health tend to focus on adults from midlife to late life, assumingly missing opportunities for brain health maintenance and promotion in earlier life. Cognitive functioning develops in early childhood, shaped by the individual's living conditions and broader environment.[22]

Lifestyle behaviors particularly form in the adolescent stage, manifesting in early adulthood.[23] Given the growing emphasis on a life course approach to brain health, research on modifiable risk and protective factors for dementia in young adulthood may offer additional prevention potential.[24] Moreover, the increasing recognition of the social determinants of health, that is, the conditions in which people are born, grow, work, live, and age,[25] in shaping lifestyle factors for brain health warrants targeted research to inform more equitable strategies for dementia prevention.[6, 26]

Thus, the study aimed to investigate (1) the occurrence of LIBRA risk and protective factors and (2) their individual and combined associations with cognitive functioning across adulthood (20–75 years) in a large sample of community-dwelling individuals from Germany. Additionally, (3) stratified analyses by age group, sex, and socioeconomic status (SES) were conducted to investigate whether the distribution of modifiable dementia risk factors and their associations with cognitive functioning differed across key demographic and social dimensions known to shape these patterns.[2] Analyses were repeated using LIBRA2 to assess whether observed age group, sex, and socioeconomic patterns in modifiable dementia risk are robust to differences in risk-factor composition and weighting.

RESEARCH IN CONTEXT

1. **Systematic review**: A literature search using conventional data sources (e.g., MEDLINE, Google Scholar) was conducted to retrieve studies that investigated the Lifestyle for Brain Health (LIBRA) index in relation to cognitive outcomes. The literature showed that the LIBRA index is well validated for predicting dementia risk, cognitive functioning, and decline, and guiding preventive strategies, particularly in mid- to early late-life (40–75 years). In addition to the original LIBRA index, a recent update introduced three additional risk factors. We identified a gap in the literature regarding the validity of the LIBRA index in younger adults (< 40 years).
2. **Interpretation**: Our findings confirm that higher (worse) LIBRA scores are associated with lower cognitive functioning in midlife and later adulthood and demonstrate that this also applies to younger adults. This study suggests that the LIBRA index is also useful in younger adults (20–39 years), a demographic group that remains overlooked in dementia risk research. The observed sex/gender and socioeconomic disparities in cognitive functioning underline the compounded disadvantages faced by lower socioeconomic status (SES) groups and women across adulthood.
3. **Future directions**: More research is needed on modifiable health and lifestyle factors in relation to cognition and dementia risk in earlier life stages to better understand life-course dynamics. The links with sex/gender and SES warrant increased emphasis on the social determinants of health in shaping lifestyle for brain health across the life course. Eventually, this can inform effective individual-level and population-based prevention strategies.

2 | METHODS

2.1 | Study design and population

The "NAKO Gesundheitsstudie" (German National Cohort; NAKO) is a population-based cohort with the objective to investigate major diseases, their etiological pathways, early detection, risk prediction modeling, and links with regional and socioeconomic disparities; it is described in detail elsewhere.[27] At baseline, NAKO targeted 200,000 participants aged 20 to 70 years, who were randomly selected from the compulsory resident registry offices in 16 study regions by 18 study centers across Germany, comprising urban, industrial, and rural areas. Baseline recruitment started between March and September 2014 and was completed between October 2018 and September 2019. A total of 205,415 participants were recruited, exceeding the target. The age ranged from 19 to 75 years. Assessments were completed by 204,739 participants. The response rate at baseline varied from 9% to 32% between study centers, averaging 17%. NAKO baseline characteristics are presented elsewhere.[28]

The study presented here is a population-based, cross-sectional analysis using baseline data from NAKO.

2.2 | Ethics

The NAKO Code of Ethics[29] determines general ethical rules and principles for the collection and use of study data in adherence to the Declaration of Helsinki.[30] The study documents have been approved by all responsible local ethical committees of the study centers.

2.3 | Assessment procedures and measures

The study centers invited participants for on-site standardized assessments, which comprised a computer-assisted face-to-face interview, biomedical examinations, bio samples, self-completed questionnaires, and whole-body magnetic resonance imaging (MRI) of a subsample. Certified study personnel, who obtained comprehensive training, conducted the assessments, which comprised a basic examination program (level 1) and a detailed program (level 2). In the following, assessments relevant for this study are described.

2.4 | Cognitive functioning and cognitive status

All participants completed a neuropsychological assessment comprising a battery of six tasks that measured core domains of cognitive

functioning, that is, episodic memory, working memory, executive control, and processing speed. Specifically, the tasks included semantic fluency (naming as many animals as possible in 1 minute),[31] immediate and delayed recall (recalling as many words as possible from a digitally recorded 12-word list),[32] Stroop color-word task 1 (naming the color of 36 patches) and Stroop color-word task 2 (incongruent condition),[33] and digit span backward (recalling number sequences of increasing length from three to nine digits in reverse order).[34] The scores of the tasks were combined using confirmatory factor analysis in a procedure described in Kleineidam et al.[35] Two cognitive domain scores were derived, one for memory (tasks: immediate recall trial 1, immediate recall trial 2, and delayed recall trial 3) and one for executive function (tasks: semantic fluency task, Stroop task 1, Stroop effect [task 2-1], digit span backward). A global cognitive functioning score was then calculated as the arithmetic mean of the memory and executive function domain scores. Subsequently, all scores were *z* standardized (mean = 0, standard deviation [SD] = 1) using the mean and SD from the baseline assessment, such that higher values indicate higher cognitive functioning. The standardized global cognitive functioning score was used as the outcome in this study.

As NAKO is a population-based cohort, cognitive status was not clinically adjudicated at baseline and thus, does not explicitly exclude participants based on cognitive impairment or a prior dementia diagnosis. However, participants with severe cognitive impairment that precluded informed consent or completion of study procedures were not eligible to participate. Moreover, participation required attendance at the study center and completion of extensive assessments, which likely limits inclusion of individuals with moderate to severe cognitive impairment. Consequently, the cohort predominantly represents community-dwelling adults with preserved functional capacity, and individuals with manifest dementia are expected to be rare.

2.5 | LIBRA score

We computed the original LIBRA score for all participants with available data across the relevant factors. The original LIBRA score contains up to 12 modifiable health and lifestyle factors for dementia.[8] Information on 10 of them was available at NAKO baseline: chronic kidney disease, coronary heart disease, depression, diabetes, hypercholesterolemia, hypertension, low-to-moderate alcohol consumption, obesity, physical inactivity, and smoking (current). Information on high cognitive activity was not assessed, and information on healthy diet was unavailable at the time of our study. The risk and protective factors forming LIBRA were derived from a systematic literature review and agreed upon in a Delphi consensus.[2] The calculation of LIBRA is based on standardized weights assigned to each factor, whereby each weight reflects a factor's meta-analytic relative risks for dementia. The weights are added and their sum forms the LIBRA score. Higher scores indicate poorer LIBRA or higher modifiable dementia risk (total theoretical range: LIBRA: −5.9 to +12.7; LIBRA2: −6.1 to +25.8). For supplementary analysis, we also computed the LIBRA2, which was updated comprising three additional risk factors: sleep disturbances, low social participation, and hearing impairment, two-factor reclassifications (from physical inactivity to physical inactivity, from low-to-moderate alcohol intake to high alcohol intake), and reassessed weights.[15] Information on sleep disturbances and low social participation was available for the full NAKO sample, while information on hearing impairment was only available for a subsample (< 25%), and therefore, was not considered. Table 1 details the operationalization of the LIBRA and LIBRA2 scores in NAKO.

2.6 | Covariates

Age and sex were self-reported by the participants. Age groups were categorized into decade bands (20–29 years, 30–39 years, 40–49 years, 50–59 years, 60–69 years, 70–75 years). Education was assessed according to the International Standard Classification of Education 97 (ISCED-97)[43] and categorized into three levels of education: low (ISCED-97 Level 1/2: primary and lower secondary education), moderate (ISCED-97 Level 3/4: upper secondary and post-secondary non-tertiary education), and high (ISCED-97 Level 5/6: tertiary education).[44] SES was based on the International Socio-Economic Index of Occupational Status (ISEI-08).[45] ISEI-08 uses the occupational codes of the International Standard Classification of Occupations (ISCO) and regression analyses to estimate levels of education and income associated with occupational categories. This informs the calculation of the ISEI-08 composite score, ranging from 10 to 90 with higher scores indicating higher SES. For stratification, the ISEI-08 score was categorized into low, moderate, and high SES based on tertiles according to sample distribution, which approximated normality and equal group sizes.

Employment status denotes a participant as employed, unemployed, or non-employed (e.g., retired). Marital status differentiated whether a participant was either married/in a partnership or single/separated/divorced/widowed. Furthermore, the number of people living in the household was recorded. Migration status (yes/no) denotes a participant with a personal or familial immigration history, irrespective of birthplace (in Germany or elsewhere). German language proficiency was categorized according to self-report and differentiated between native speakers, bilingual speakers, and the level of German language abilities among non-native speakers (native speaker, bilingual, very good, good, fair, poor, very poor—the latter three categories were collapsed due to low responses). The demographic and socioeconomic indicators were included given their established associations with both lifestyle exposures and cognitive functioning.

2.7 | Statistical analysis

Sample characteristics were inspected for the total sample and regarding age groups, using chi-squared (χ^2) tests for categorical variables and *t* tests or analysis of variance for continuous variables. Mean LIBRA scores were calculated with respect to age group, sex, and SES. The frequency of each LIBRA factor was calculated as the proportion of

TABLE 1 Operationalization of the Lifestyle for Brain Health (LIBRA and LIBRA2) indices in the German National Cohort (NAKO; *N* = 204,739).

LIBRA factor	Assessment	Operationalization	*N* (number of missing values)	LIBRA weight	LIBRA2 weight
(Coronary) Heart disease	Self-reported response to standardized medical questionnaire: Have you ever been diagnosed by a doctor with any of the following cardiovascular diseases: heart attack, angina pectoris, heart failure, cardiac arrhythmia (yes/no/don't know response)	Responding yes to any of: heart attack, angina pectoris, heart failure, cardiac arrhythmia	204,739 (2263)	+1.0	+2.6
Diabetes	Self-reported response to standardized medical questionnaire: Have you ever been diagnosed by a doctor with any of the following metabolic diseases: diabetes mellitus (yes/no/don't know response)	Responding yes	204,149 (590)	+1.3	+2.2
Hypercholesterolemia	Self-reported response to standardized medical questionnaire: Have you ever been diagnosed by a doctor with any of the following metabolic diseases: increased blood fats or cholesterol or triglycerides (yes/no/don't know response)	Responding yes	202,616 (2123)	+1.1	+2.6
Hypertension	Objectively measured blood pressure: two repeated measures, right arm, seated; using the average of the systolic blood pressure and diastolic blood pressure measures, respectively. Or self-reported response to standardized medical questionnaire: Have you ever been diagnosed by a doctor with any of the following cardiovascular diseases: high blood pressure or hypertension (yes/no/don't know response)	According to World Health Organization (WHO) guidelines[36]: mean systolic blood pressure ≥ 140 mm H; or diastolic blood pressure ≥ 90 mm Hg, or answering yes to self-reported history if blood pressure was not available	204,646 (93)	+1.6	+1.1
Depression	Current self-reported depressive symptoms/depression measured by the Patient Health Questionnaire-9 (PHQ-9),[37] an established nine-item screening instrument for depression assessing the presence of depressive symptoms corresponding to Criterion A of the Diagnostic and Statistical Manual of Mental Disorders 4th edition (DSM-IV; American Psychiatric Association 1994) in the last 2 weeks on a 4-point rating scale (0, not at all; 1, several days; 2, more than half the days; 3, nearly every day). Total scores ≥ 10 indicate a moderate to severe depressive symptomatology.[38] Or self-reported response to standardized medical questionnaire: Have you ever been diagnosed by a doctor or psychotherapist with any of the following neurological or psychiatric illnesses? Depression (lifetime) (yes/no/don't know response)	PHQ-9 score ≥ 10, or yes to depression history if PHQ score was not available	204,311 (428)	+2.1	+4.1
Obesity	Based on study-personnel led standardized measurement of height (in meters) and weight (in kilograms) during assessment. Calculation of the body mass index (BMI; weight [kg]/height [m]^2) and subsequent categorization according to the WHO:[39] underweight: BMI < 18.5; normal weight: BMI 18.5–24.9; overweight: BMI 25.0–29.9; obesity: class 1 (moderate): BMI 30.0–34.9; class 2 (severe): BMI 35.0–39.9; class 3 (very severe or morbid obesity): BMI ≥ 40.0	BMI ≥ 30	203,725 (1014)	+1.6	+2.2

(Continues)

TABLE 1 (Continued)

LIBRA factor	Assessment	Operationalization	*N* (number of missing values)	LIBRA weight	LIBRA2 weight
Smoking (current)	Self-reported response to interview question: Have you ever smoked cigarettes, cigars, cigarillos, pipes, or other tobacco products? If you have NOT smoked except for very rare attempts—or have smoked less than 100 cigarettes etc. in your lifetime—please select the answer option "I have never smoked." Please do NOT consider smoking a hookah. Answering options: I never smoked; yes, I still smoke to this day, yes, I used to smoke.	Responding "yes, I still smoke to this day"	196,033 (8706)	+1.5	+2.5
Low-to-moderate alcohol consumption	Self-reported response to two interview questions: Frequency: How often do you have an alcoholic drink, such as a glass of wine, beer, mixed drink, schnapps, or liqueur? Answering options: never, once per month or less, 2–4 times per month, 2–3 times per week, 4–6 times per week, once per day or more. Amount: If you drink alcohol, how many alcoholic drinks do you typically drink in a day? An alcoholic drink (standard drink) corresponds to a small bottle or glass of beer (0.33l), a small glass of wine or sparkling wine (0.125l), or a double shot of schnapps (4cl). (One such drink = 12 g/day.) Answering options: 1–2 beverages, 3–4 beverages, 5–6 beverages, 7–9 beverages, 10 or more beverages.	Estimate of consumed grams of alcohol per day; low-to-moderate drinking as any amount of up to 12 g/day for women, 24 g/day for men according to German guidelines[40]	195,131 (9608)	−1.0	N/A
Physical inactivity	Self-reported responses assessed using the Global Physical Activity Questionnaire (GPAQ), which measures moderate- and vigorous-intensity activity across work, transport, and leisure domains. Participants report frequency (days/week) and duration (minutes/day), which are converted to total metabolic equivalent of task (MET)-minutes per week using standard WHO scoring (4 METs for moderate and 8 METs for vigorous activity).[41]	GPAQ total MET < 600	189,082 (15,657)	+1.1	N/A
High cognitive activity	*NOT AVAILABLE*				
Healthy diet	*NOT AVAILABLE*				
Chronic kidney disease	Self-reported response to interview question: Have you ever been diagnosed by a doctor with impaired kidney function or chronic kidney failure? (yes/no/don't know response)	Responding yes	203,857 (882)	+1.1	+1.8
TOTAL LIBRA			**178,716 (26,023)**	**−1.0; +12.7**	
Added LIBRA2 factors					
Sleep disturbances	Self-reported response to interview question (single item from the German version of the Pittsburgh Sleep Quality Index/PSQI[42]): During the past month, how would you rate your sleep quality overall? Answering options were categories on a 4-point Likert scale from very good (1), pretty good (2) to fairly poor (3) and very poor (4). Or self-reported response to PHQ-9:[37] Over the last 2 weeks, how often have you had trouble falling or staying asleep, or sleeping too much? Answering options comprised: not at all (2), several days (11), more than half the days (12), nearly every day (13)	Scoring 3 (fairly poor) or 4 (very poor); if not available scoring 12 (on more than half of the days) or 13 (almost every day) on the PHQ-9 item	190,199 (14,540)		+1.1

(Continues)

TABLE 1 (Continued)

LIBRA factor	Assessment	Operationalization	*N* (number of missing values)	LIBRA weight	LIBRA2 weight
Low social participation	Self-reported response about participation in sports or other clubs or associations, occupational associations, church or religious gatherings, political groups or parties, self-help groups at least once per month, or none. Or self-reported response to questions on social network: low social participation was considered scoring in the lowest quartile for total number of relationships (children, relatives, close friends) multiplied by total number of monthly contacts (children, relatives, close friends).	No participation in social activities; if not available scoring in the low quartile of social participation	172,210 (32,529)		+2.1
High alcohol intake	Self-reported response to two questions: Frequency: How often do you have an alcoholic drink, such as a glass of wine, beer, mixed drink, schnapps or liqueur? Amount: If you drink alcohol, how many alcoholic drinks do you typically drink in a day? An alcoholic drink (standard drink) corresponds to a small bottle or glass of beer (0.33l), a small glass of wine or sparkling wine (0.125l), or a double shot of schnapps (4cl). (One such drink = 12 g/day)	Estimate of consumed grams of alcohol per day; high drinking as any amount of equal or more than 12 g/day for women, 24 g/day for men according to German guidelines[40]	195,131 (9608)		+1.0
Moderate-to-high physical activity	Self-reported responses assessed using the GPAQ;[41] total MET	GPAQ total MET ≥ 600	189,082 (15,657)		−1.9
Hearing impairment	*NOT AVAILABLE FOR FULL SAMPLE IN NAKO*				
TOTAL LIBRA2			**158,496 (46,243)**		**−1.9; +22.3**

participants who fulfilled the criteria for a factor as outlined in Table 1 and is presented for the total sample and by age groups. To examine the presence of linear trends in frequency of LIBRA risk and protective factors across age groups, we conducted the Cochran–Armitage test for trend. For each LIBRA factor, we calculated the chi-squared (χ^2) statistic, *p* value, and effect size (slope) to quantify the magnitude and direction of the trend.

Cluster-adjusted (for the study centers) linear regression analysis, after inspection of variable distributions, was used to assess the association of LIBRA scores with cognitive functioning. A hierarchical approach was chosen, in which cognitive functioning was first regressed on LIBRA scores in an unadjusted Model 1 and then adjusted for age, sex, education, SES, employment status, marital status, number of people in the household, migration status, and German language proficiency in Model 2. Covariates were included in the models as described in section 2.6. Additionally, we introduced a quadratic term for age to account for the non-linear relationship of age with cognitive functioning. The models were calculated for the total analytical sample and for each age group. Additionally, we ran Model 2 stratified for sex and SES.

The large size of the NAKO sample ensures high statistical power of the study, improving the ability to examine associations with greater precision and reducing the impact of random error. However, with large samples and multiple comparisons, the likelihood of false positive results increases. Therefore, we do not solely rely on coefficients and *p* values, but also report effect sizes for group differences, as well as explained variance (R^2) and the Bayesian information criterion (BIC) for regression models. All statistical analyses were carried out in Stata/SE 17.0.

2.7.1 | Supplementary analyses

In addition to the main analyses, the individual LIBRA factors were analyzed for their associations with cognitive functioning across the total sample and stratified for age groups, using linear regression with adjustment for the covariates as outlined above. All individual LIBRA factors were also entered simultaneously into multivariable models to examine their independent associations with cognitive functioning, overall and stratified by age group, adjusting for the same covariates as in the main analyses.

Moreover, we repeated the analyses using the LIBRA2 score, carrying out the same analytical steps as described above for the original LIBRA (hereafter LIBRA). Evaluating both versions, LIBRA (here 10/12 factors) and LIBRA2 (here 12/15 factors), provides insights into whether the updated version offers improved predictive power and added value through the inclusion of additional factors. We chose LIBRA for the main analyses due to the higher proportion of complete cases and reduced deviation from the NAKO baseline sample characteristics. All results of the analyses using the LIBRA2 index can be found in the supporting information.

3 | RESULTS

3.1 | Analytic sample

The analytic sample comprised 149,948 (73.2%) complete cases. We excluded 54,791 (27.8%) participants in total. Reasons for exclusion were missing values on LIBRA factors (n = 26,023), global cognitive

functioning ($n = 5097$), education ($n = 15,248$), SES ($n = 7467$), employment status ($n = 854$), marital status ($n = 24$), migration status ($n = 22$), German language proficiency ($n = 28$), and number of people living in a household ($n = 28$). One participant was excluded because of age < 20 years. Comparisons of key sample characteristics between included and excluded individuals suggested minimal differences, if any (Table S1 in supporting information). Sex (Cramér $V = 0.0013$), the LIBRA score (Cohen $d = -0.018$), and number of people living in the household (Cohen $d = -0.065$) showed very small effect sizes, indicating no difference between those included and excluded. Small effect sizes were observed for age group (Cramér $V = 0.129$), education (Cramér $V = 0.109$), employment status (Cramér $V = 0.104$), migration status (Cramér $V = 0.125$), marital status (Cramér $V = 0.046$), SES (Cohen $d = 0.285$), and cognitive functioning (Cohen $d = 0.130$).

3.2 | Sample characteristics

The analytic sample showed a nearly even distribution of sexes (50.4% women, 49.6% men). The mean age of the participants across the six age groups was 50.1 years (SD = 13.6). Education levels were high overall, with more than half of the sample (56.2%) having completed tertiary education. Overall cognitive functioning varied by age ($\eta^2 = 0.255$, $F[6, 149,941] = 7,637.10$, $p < 0.001$), with the highest mean score in the youngest group ($M = 0.71$, SD = 0.84, 20–29 years) and the lowest in the oldest group ($M = -0.91$, SD = 0.82, 70–75 years). Similarly, the mean LIBRA score differed across age groups ($\eta^2 = 0.111$, $F[6, 149,941] = 3342.83$, $p < 0.001$), indicating that older participants exhibited higher scores ($M = 2.28$, SD = 1.85) compared to younger groups ($M = 0.28$, SD = 1.46; observed LIBRA score range = −1.0; +12.7). Detailed sociodemographic metrics are presented in Table 2.

3.3 | Frequency of LIBRA risk and protective factors

The frequency of LIBRA risk and protective factors and their trends across age groups are summarized in Table 3. For most risk factors, there was a higher occurrence with higher age (Figure 1). Coronary heart disease rose from 3.5% in the youngest age group (20–29 years) to 30.6% in the oldest (70–75 years; $\chi^2[5] = 486.73$, $p < 0.001$; slope = 0.53). Similarly, diabetes showed a pronounced increase from 0.8% in the youngest group to 13.9% in the oldest, with results confirming a significant trend ($\chi^2[5] = 249.08$, $p < 0.001$; slope = 0.56). Hypercholesterolemia also showed a strong upward trend, rising from 3.3% to 43.8% with age ($\chi^2[5] = 786.89$, $p < 0.001$; slope = 0.57). Hypertension saw the steepest increase, from 13.5% to 74.4% ($\chi^2[5] = 1327.56$, $p < 0.001$; slope = 0.64).

In contrast, depression exhibited a decreasing trend with age, especially in ages 60+ years, declining from 8.6% in 50- to 59-year-olds to 4.0% in the oldest ($\chi^2[5] = 26.14$, $p < 0.001$; slope = −0.13). Likewise, the trend for smoking demonstrated a marked decrease in older age groups. It was highest in the youngest age group (20–29 years, 25.0%) and steadily decreased with age, reaching its lowest point in the oldest group (70–75 years, 8.4%; $\chi^2[5] = 234.12$, $p < 0.001$; slope = −0.38). The trend for physical inactivity showed an inverted *U*-shaped pattern across age groups. It was relatively low in the youngest age group (20–29 years, 9.6%), peaked in the middle-aged group (40–49 years, 14.5%), and then decreased steadily in older age groups, reaching its lowest proportion in the oldest group (70–75 years, 6.8%; $\chi^2[5] = 54.29$, $p < 0.001$; slope = −0.12).

Among protective factors, low-to-moderate alcohol consumption was highest in the youngest group (86.2%) and declined slightly with age, stabilizing in the older age groups ($\chi^2[5] = 61.74$, $p < 0.001$; slope = −0.14). The stacked proportion of LIBRA factors across age groups is shown in Figure 2.

3.4 | Association of LIBRA scores and cognitive functioning

Higher (worse) LIBRA scores were associated with lower cognitive functioning in the total sample and across all age groups. In the unadjusted Model 1, each 1-point increase in the LIBRA score was associated with −0.129 lower estimated standardized scores (95% confidence interval [CI] = −0.133, −0.125, $p < 0.001$, $R^2 = 0.067$) in cognitive functioning for the total sample. LIBRA showed an association with lower cognitive functioning of −0.076 (95% CI = −0.092, −0.061; $p < 0.001$) per additional LIBRA point (observed range: −1.0; +12.7) for individuals aged 20 to 29, while in the 70 to 75 age group, each 1-point increase in LIBRA was associated with −0.042 (95% CI = −0.060, −0.025; $p < 0.001$) lower performance. Model 2, which adjusted for age, age^2, sex, education, SES (continuous), employment status, marital status, household size, migration background, and German language proficiency, confirmed the findings, but they were more attenuated. In the total sample, each additional LIBRA point was associated with −0.027 (95% CI = −0.031, −0.024, $p < 0.001$, $R^2 = 0.349$) lower cognitive functioning. The age-stratified analyses yielded a similar pattern, with younger adults showing −0.034 (95% CI = −0.049, −0.020; $p < 0.001$) lower cognitive functioning per one LIBRA point increment for those aged 20 to 29, while oldest adults aged 70 to 75 showed a decrease of −0.026 (95% CI = −0.043, −0.008; $p < 0.001$). In the unadjusted model, LIBRA explained 6.7% of the variance in cognitive functioning ($R^2 = 0.067$). In the adjusted model, the total explained variance increased to 34.9% ($R^2 = 0.349$). The incremental contribution of LIBRA in the adjusted model was small (Cohen $f^2 = 0.012$). BIC values also indicated better fit for the Model 2 approach. The results are further detailed in Table 4.

3.5 | Mean LIBRA scores by age groups, sex, and level of SES

Higher (worse) LIBRA scores were consistently observed in individuals with low SES, regardless of age group or sex. Similar to the total sam-

TABLE 2 Characteristics of the analytic sample, total and according to age group ($n = 149{,}948$).

Variable	Total	20–29	30–39	40–49	50–59	60–69	70–75	Effect Size	Test Statistic	*p* value
Number of observations	149,948	11,503	17,085	40,721	41,124	36,562	2953			
Global cognitive functioning, *M* (SD)	0.03 (0.97)	0.71 (0.84)	0.56 (0.87)	0.29 (0.88)	−0.06 (0.87)	−0.56 (0.85)	−0.91 (0.82)	$\eta^2 = 0.255$	$F(6) = 7637.10$	< 0.001
LIBRA score, *M* (SD)[a]	1.36 (1.95)	0.28 (1.46)	0.53 (1.57)	0.99 (1.80)	1.61 (2.01)	2.14 (1.96)	2.28 (1.85)	$\eta^2 = 0.111$	$F(6) = 3342.83$	< 0.001
Sex, *n* (%)										
Female	75,601 (50.4)	5841 (50.8)	8662 (50.7)	20,465 (50.3)	20,950 (50.9)	18,318 (50.1)	1365 (46.2)	$V = 0.014$	$X^2(5) = 28.35$	< 0.001
Education, *n* (%)										
Low	2,909 (1.9)	170 (1.5)	234 (1.4)	647 (1.6)	824 (2.0)	931 (2.6)	103 (3.5)	$V = 0.039$	$X^2(10) = 464.87$	< 0.001
Moderate	62,790 (41.9)	5350 (46.5)	6,492 (38.0)	16,540 (40.6)	17,792 (43.3)	15,408 (42.1)	1208 (40.9)			
High	84,249 (56.2)	5,983 (52.0)	10,359 (60.6)	23,534 (57.8)	22,508 (54.7)	20,223 (55.3)	1642 (55.6)			
Socioeconomic status,[b] *M* (SD)	50.38 (15.32)	49.87 (14.44)	52.74 (15.34)	51.22 (15.43)	49.16 (15.30)	49.82 (15.05)	50.86 (15.03)	$\eta^2 = 0.006$	$F(6) = 186.19$	< 0.001
Socioeconomic status,[b] *n* (%)										
Low	52,359 (34.9)	4102 (35.7)	5,098 (29.8)	13,487 (33.1)	15,549 (37.8)	13,136 (35.9)	987 (33.4)	$V = 0.074$	$X^2(10) = 834.74$	< 0.001
Moderate	48,305 (32.2)	3850 (33.5)	5,139 (30.1)	12,894 (31.7)	13,365 (32.5)	12,060 (33.0)	997 (33.8)			
High	49,284 (32.9)	3551 (30.9)	6,848 (40.1)	14,340 (35.2)	12,210 (29.7)	11,366 (31.1)	969 (32.8)			
Employment status, *n* (%)										
Employed	118,902 (79.3)	10,494 (91.2)	16,150 (94.5)	38,631 (94.9)	37,499 (91.2)	15,731 (43.0)	397 (13.4)	$V = 0.452$	$X^2(10) = 57{,}000.00$	< 0.001
Unemployed	4,009 (2.7)	356 (3.1)	535 (3.1)	985 (2.4)	1,217 (3.0)	916 (2.5)	0 (0.0)			
Non-employed	27,037 (18.0)	653 (5.7)	400 (2.3)	1,105 (2.7)	2,408 (5.9)	19,915 (54.5)	2,556 (86.6)			
Marital status, *n* (%)										
Married, with partner[c]	89,935 (60.0)	1,511 (13.1)	7,802 (45.7)	25,165 (61.8)	27,293 (66.4)	26,066 (71.3)	2,098 (71.1)	$V = 0.315$	$X^2(10) = 14{,}832.57$	< 0.001
Migration status, *n* (%)										
Yes	21,419 (14.3)	1,625 (14.1)	3,077 (18.0)	6,964 (17.1)	5,082 (12.4)	4,122 (11.3)	549 (18.6)	$V = 0.077$	$X^2(5) = 897.93$	< 0.001
German language proficiency, *n* (%)										
Native speaker	136,281 (90.9)	10,354 (90.0)	14,737 (86.3)	35,797 (87.9)	38,121 (92.7)	34,465 (94.3)	2,807 (95.1)	$V = 0.059$	$X^2(20) = 2{,}103.00$	< 0.001
Bilingual	4,114 (2.7)	567 (4.9)	740 (4.3)	1,360 (3.3)	793 (1.9)	610 (1.7)	44 (1.5)			
Very good	4,490 (3.0)	366 (3.2)	911 (5.3)	1,720 (4.2)	886 (2.2)	567 (1.6)	40 (1.4)			
Good	3,544 (2.4)	164 (1.4)	521 (3.1)	1,320 (3.2)	897 (2.2)	607 (1.7)	35 (1.2)			
Fair, poor, very poor	1,519 (1.0)	52 (0.5)	176 (1.0)	524 (1.2)	427 (1.0)	313 (0.8)	27 (0.9)			
Number of people living in the household, *M* (SD)	2.42 (1.09)	2.17 (1.00)	2.67 (1.18)	2.97 (1.22)	2.34 (1.01)	1.92 (0.65)	1.83 (0.55)	$\eta^2 = 0.158$	$F(6) = 4730.37$	< 0.001

Abbreviations: LIBRA, Lifestyle for Brain Health; SD, standard deviation.

[a]LIBRA score observed range = −1.0; +12.7.

[b]International Socio-Economic Index of Occupational Status (ISEI-08).

[c]Versus single/separated/divorced/widowed.

TABLE 3 Proportion of LIBRA risk and protective factors for the total sample and according to age group ($n = 149,948$).

		Age group						Trend		
LIBRA factors	Total	20–29	30–39	40–49	50–59	60–69	70–75	Chi-squared (χ^2)	*p*-value	Effect size (slope)
Number of observations	149,948	11,503	17,085	40,721	41,124	36,562	2,953			
Risk factor, %										
Coronary heart disease	12.3	3.5	4.8	7.8	12.5	21.6	30.6	$X^2(5) = 486.73$	<0.001	0.53
Diabetes	5.5	0.8	2.1	3.0	5.1	11.1	13.9	$X^2(5) = 249.08$	<0.001	0.56
Hypercholesterolemia	23.6	3.3	7.0	16.7	27.9	38.8	43.8	$X^2(5) = 786.89$	<0.001	0.57
Hypertension	42.8	13.5	18.1	31.1	48.8	67.3	74.4	$X^2(5) = 1,327.56$	<0.001	0.64
Depression	7.4	8.7	7.6	7.5	8.6	5.6	4.0	$X^2(5) = 26.14$	<0.001	−0.13
Obesity	20.9	10.3	13.8	18.5	22.5	28.0	26.7	$X^2(5) = 156.39$	<0.001	0.24
Smoking	20.1	25.0	24.9	21.5	21.6	14.1	8.4	$X^2(5) = 141.41$	<0.001	−0.22
Physical inactivity	11.8	9.6	13.4	14.5	12.2	8.9	6.8	$X^2(5) = 44.69$	<0.001	−0.09
Chronic kidney disease	2.1	0.8	1.0	1.6	2.1	3.2	4.3	$X^2(5) = 43.28$	<0.001	0.36
Protective factor, %										
Low-to-moderate alcohol intake	79.2	86.2	84.3	80.9	77.4	75.2	76.7	$X^2(5) = 61.74$	<0.001	−0.14

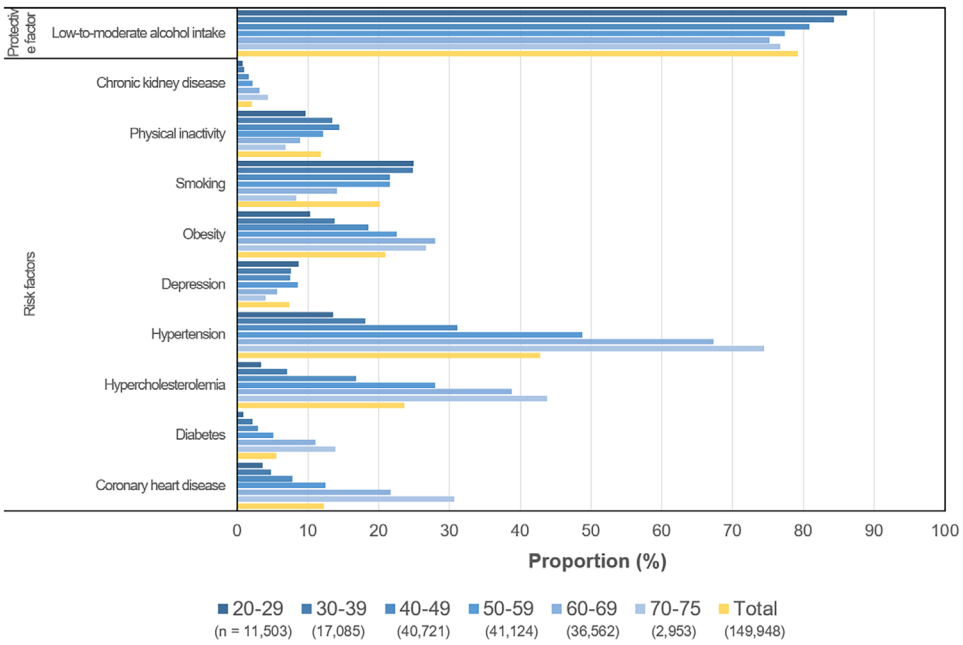

FIGURE 1 Proportion of Lifestyle for Brain Health index risk and protective factors according to age group and total sample in the German National Cohort (NAKO) study.

ple, mean LIBRA scores were higher with higher age in all SES groups. Among men, those with low SES showed higher LIBRA scores in all age groups, while a mean score of 2.67 (SD = 1.90) was observed in the 70 to 75 age group compared to 2.13 (1.81) in men with high SES. Similarly, for women, the LIBRA score in the low SES group peaked at 2.45 (1.94) in the 70 to 75 age group, compared to 1.86 (1.79) for women in the high SES group. Descriptive analyses suggested that the SES gradient was more pronounced in younger age groups. For example, in the 20 to 29 age group, men with low SES had a mean LIBRA score of 0.64 (1.57) compared to 0.00 (1.30) for those with high SES. Among women, the difference in this age group was 0.62 points (0.49 [1.57] for low SES versus −0.13 [1.21] for high SES). The sex-specific analyses further highlighted that men generally had higher LIBRA scores than women in the same SES group, with the largest differences observed in the low SES categories. For instance, in the 40 to 49 age group, women with low SES had a mean LIBRA score of 1.19 (1.63) compared to 1.50 (1.91)

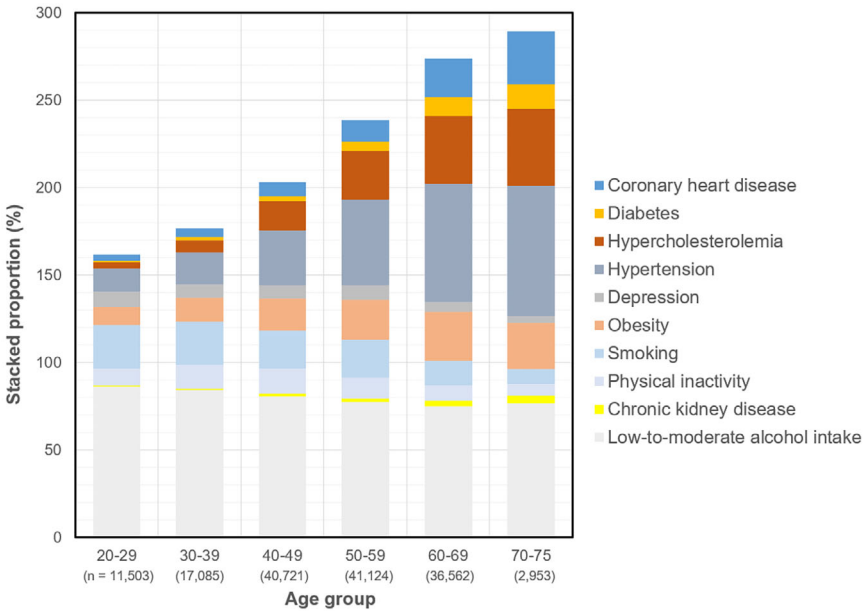

FIGURE 2 Stacked proportion of Lifestyle for Brain Health risk and protective factors, illustrating their cumulative contribution across age groups in the German National Cohort (NAKO) study.

TABLE 4 Association of the LIBRA score with cognitive functioning for the total sample and stratified by age group.

Number of observations	Total[1] 149,946	20–29 11,503	30–39 17,085	40–49 40,721	50–59 41,124	60–69 36,562	70–75 2,953
Model 1							
Coefficient	−0.129	−0.076	−0.075	−0.069	−0.068	−0.056	−0.042
95%CI	−0.133; −0.125	−0.092; −0.061	−0.086; −0.064	−0.075; −0.062	−0.073; −0.063	−0.061; −0.051	−0.060; −0.025
p-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
*R*2	0.0677	0.0176	0.0183	0.0196	0.0250	0.0168	0.0090
BIC	405,046.70	28,430.46	43,347.99	104,296.00	104,030.10	91,227.61	7,216.66
Model 2							
Coefficient	−0.027	−0.034	−0.027	−0.020	−0.028	−0.027	−0.026
95%CI	−0.031; −0.024	−0.049; −0.020	−0.033; −0.020	−0.026; −0.015	−0.033; −0.023	−0.031; −0.023	−0.043; −0.008
p-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.006**
*R*2	0.3493	0.1297	0. 1805	0.2078	0.1961	0.1778	0.1350
BIC	351,246.4	27,130.17	40,360.37	95,726.28	96,192.38	84,795.03	6,895.224

Note: Hierarchical approach - Model 1 is unadjusted; Model 2 was adjusted for age[2], sex, education, SES (continuous), employment status, marital status, household size, migration status, and German language proficiency. [1]The total sample was additionally adjusted for age in years in Model 2.

for men with low SES. Results are detailed in Table 5 and illustrated in Figure 3.

3.6 | Association of LIBRA and cognitive functioning by age group, sex, and level of SES

Associations between LIBRA scores and cognitive functioning differed in their statistical significance across subgroups defined by age, sex, and SES (Table S2 in supporting information). Significant negative associations were more frequently observed among women than men, particularly in the low and moderate SES groups. These associations were evident mainly in younger and midlife adults, whereas for both sexes most associations in the oldest age group (70–75 years) did not reach significance. An SES gradient was apparent, especially among women, with individuals in low and moderate SES groups more often showing significant negative associations compared to those in high SES groups.

TABLE 5 Mean (SD) LIBRA scores stratified by age group, sex and socio-economic status, colored from low (light) to high (dark) scores within sex groups.

	SES									
	Men				Group	Women				Group
Age group	Low	Moderate	High	Total	difference[a]	Low	Moderate	High	Total	difference[a]
20–29	0.64 (1.57)	0.26 (1.40)	0.00 (1.30)	0.32 (1.46)	$V = 0.196$; $p < 0.001$	0.49 (1.57)	0.31 (1.45)	−0.13 (1.21)	0.25 (1.45)	$V = 0.176$; $p < 0.001$
30–39	1.00 (1.73)	0.62 (1.58)	0.33 (1.47)	0.61 (1.61)	$V = 0.184$; $p < 0.001$	0.80 (1.61)	0.51 (1.60)	0.13 (1.31)	0.45 (1.52)	$V = 0.180$; $p < 0.001$
40–49	1.50 (1.91)	1.21 (1.86)	0.78 (1.66)	1.14 (1.82)	$V = 0.166$; $p < 0.001$	1.19 (1.93)	0.85 (1.73)	0.48 (1.51)	0.85 (1.76)	$V = 0.152$; $p < 0.001$
50–59	2.15 (2.11)	1.77 (2.02)	1.33 (1.84)	1.76 (2.02)	$V = 0.166$; $p < 0.001$	1.75 (2.07)	1.47 (1.96)	1.02 (1.79)	1.47 (1.98)	$V = 0.145$; $p < 0.001$
60–69	2.60 (2.02)	2.32 (1.95)	1.96 (1.88)	2.28 (1.96)	$V = 0.142$; $p < 0.001$	2.26 (2.02)	1.98 (1.91)	1.62 (1.81)	2.00 (1.95)	$V = 0.144$; $p < 0.001$
70–75	2.67 (1.90)	2.23 (1.73)	2.13 (1.81)	2.31 (1.82)	$V = 0.276$; $p < 0.001$	2.45 (1.94)	2.27 (1.82)	1.86 (1.79)	2.25 (1.88)	$V = 0.260$; $p < 0.001$
Total	1.86 (2.01)	1.53 (1.98)	1.13 (1.83)		Total	1.57 (2.03)	1.25 (1.90)	0.77 (1.71)		Total
Group difference[b]	$V = 0.210$; $p < 0.001$	$V = 0.221$; $p < 0.001$	$V = 0.213$; $p < 0.001$		Group difference[b]	$V = 0.207$; $p < 0.001$	$V = 0.210$; $p < 0.001$	$V = 0.210$; $p < 0.001$		Group difference[b]

[a]Effect size (Cramér *V*) and *p* value for group differences for levels of SES in each age group separately for men and women.
[b]Effect size (Cramér *V*) and *p* value for age groups in each level of SES separately for men and women.

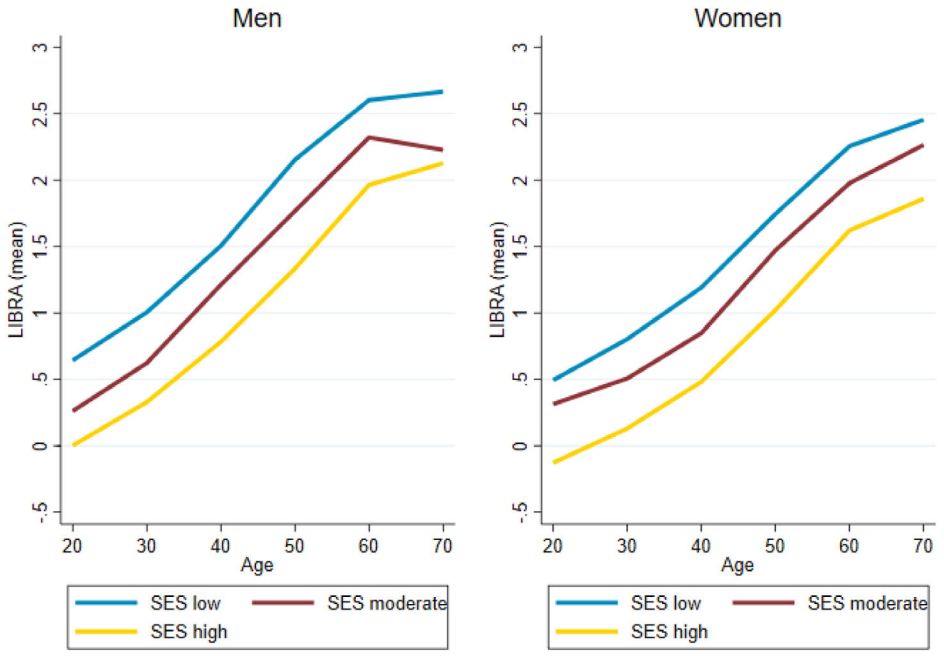

FIGURE 3 Mean Lifestyle for Brain Health score according to age groups and socioeconomic status (SES) stratified by sex.

3.7 | Results of supplementary analyses

3.7.1 | Associations of individual LIBRA factors and cognitive functioning

In the total sample, all LIBRA factors, except for physical inactivity, were associated with cognitive functioning after adjustment for age, age^2, sex, education, SES (continuous), employment status, marital status, household size, migration status, and German language proficiency, indicating that the presence of a respective risk factor was linked to lower cognitive functioning.

The age-stratified analyses highlighted differential associations. Notably, diabetes showed associations with cognitive functioning from midlife (40+). Coronary heart disease was also only associated with

cognitive functioning in an older age group (60–69), similarly to hypercholesterolemia (50–59, 60–59). Hypertension, depression, obesity, and smoking showed the most consistent associative pattern across all age groups, significantly linked with lower cognitive functioning with most age groups from younger to older. Low-to-moderate alcohol intake showed a negative association from midlife on (40+). Physical inactivity and chronic kidney disease did not reveal associations with cognitive functioning in any of the age groups. Results are detailed in Table S3 in supporting information.

As expected, associations for individual LIBRA components were attenuated in mutually adjusted models compared to single-factor analyses, but key behavioral, psychosocial, and cardiometabolic factors remained independently associated with cognitive functioning, indicating that observed associations were not driven solely by confounding between risk factors (Tables S3a, S3b).

3.7.2 | Results of the LIBRA2 factors and overall score

Comparisons of included and excluded participants in the LIBRA2 (observed score range = −1.9; +22.3) analytical sample are shown in Table S4 in supporting information. Characteristics of this sample are presented in Table S5 in supporting information.

Regarding the frequencies of added factors, approximately half of the total sample (50.7%) showed low social participation. This was highest in the age group 30 to 39 (55.3%) and lowest in the age group 70 to 75 (46.4%). Sleep disturbances were found in ≈ 28% of the total sample, with higher occurrence in the age groups from 30 to 39 to 50 to 59 (28.2%–30.5%) and lower proportions in the youngest age group 20 to 29 (26.2%) and those 70 to 75 years old (25.8%; Table S6 in supporting information). This is further illustrated in Figures S1 and S2 in supporting information.

The associations between the LIBRA2 scores and cognitive functioning revealed very similar findings as for the original LIBRA scores (Table S7 in supporting information), evident in the explained variance and BIC when re-running the adjusted analysis using LIBRA with the LIBRA2 sample.

Stratifying the sample according to age group, sex, and SES, we found that the mean LIBRA2 score increased with age and level of SES with significant group differences (Table S8 in supporting information). Notably, in contrast to LIBRA, the mean LIBRA2 score for men with moderate SES was lower in the highest age group 70 to 75 compared to 60 to 69. Otherwise, results showed very similar patterns to the original LIBRA score (Figure S3 in supporting information).

Associations of the stratified analyses of LIBRA2 and cognitive functioning can be found in Table S9 in supporting information. Among men, significant associations between the LIBRA2 and cognitive functioning were observed for those aged 50 to 59 years across all levels of SES as well as for those aged 60 to 69 years with low and moderate SES. In contrast to LIBRA results, no associations were observed for the age group 20 to 29 with moderate SES and the age group 40 to 49 with high SES. Among women, the stratified analyses showed minimal differences between the LIBRA versions, except for the age group 40 to 49 with high SES, for which an association between the LIBRA2 and cognitive functioning was found, which was not observed for LIBRA. R^2 was slightly lower for models using the LIBRA2, although all models showed improved fit as indicated by lower BIC values.

4 | DISCUSSION

The study contributes novel findings for younger adults (20–39 years) by showing distinct age-related patterns in the occurrence of LIBRA factors. Behavioral and psychosocial risk factors, such as smoking, physical inactivity, and depression, were more frequent in younger age compared to older age. Cardiovascular risk factors, such as hypertension, hypercholesterolemia, and coronary heart disease, increased sharply with age, being most frequent among the 70 to 75 age group.

Higher (worse) LIBRA scores were associated with lower cognitive functioning across all age groups. However, effect sizes and incremental variance explained were small. This is in line with prior studies showing that lifestyle indices typically explain less cross-sectional variance in cognition than demographic characteristics.[7,46] Nevertheless, given that LIBRA factors are modifiable and exert cumulative influence over time, their relevance is especially pronounced when addressed early. Despite the overall lower mean LIBRA scores in younger adults compared to older adults, the relatively higher occurrence of behavioral and psychosocial LIBRA risks warrants attention as these factors are established pathways to the increasing vascular risk from midlife.[47–50] Notably, while the overall prevalence of smoking decreased in Germany over the past two decades due to the implementation of numerous smoking prevention measures,[51,52] still one in four younger adults (20–39 years) reported to smoke (tobacco products, not vaping) at least occasionally in NAKO (assessed 2014–2019). The decreasing prevalence with increasing age is largely attributed to smoking cessation, selective survival, and cohort differences with regard to smoking uptake.[51] Higher prevalence of depression and depressive symptoms in younger adults compared to older adults has been consistently reported in recent large-scale German studies.[53,54] While some argue the age-related decrease in depression is due to a shift from mood-related to somatic symptoms in older age and thus a lower prevalence may be the result of underreporting, mis-, and underdiagnoses,[55] others suggest a true decline due to improved coping strategies and greater resilience.[56] A study investigating the prevention potential of Alzheimer's disease (AD) in Germany found that smoking and physical inactivity had the highest estimated impact on AD prevalence,[57] and another study estimated that most cases of dementia in Germany were associated with the risk factors hearing loss, hypertension, depression, obesity, and smoking in the population aged ≥ 40 years.[21] Our findings emphasize that five impactful modifiable dementia risk factors—hypertension, smoking, obesity, depression, and physical inactivity—were already frequent among younger adults (20–39 years). Furthermore, all of them (excluding physical inactivity) were individually associated with lower cognitive functioning. Albeit more risk factor research in younger adults is needed, it might

be useful to extend dementia prevention approaches to younger adults with an emphasis on promoting brain health. Notably, LIBRA in younger adults should be interpreted as a descriptive composite of modifiable dementia risk factors and their associations with cognitive functioning, rather than as a measure of future dementia risk.

In addition, our findings contribute to the growing evidence of LIBRA's utility as a composite index characterizing profiles of modifiable dementia risk across diverse populations and settings. Previous studies, including a validation across 21 international cohort studies of aging,[14] have consistently shown that higher LIBRA scores are associated with lower cognitive functioning, a higher likelihood of cognitive impairment, and markers of adverse brain health in midlife and older adulthood.[12, 13, 24, 58] Our study particularly adds that this utility may extend to younger adults, but further research is needed to confirm this.

Using the LIBRA2 index (which included two of the three added factors: sleep disturbances and low social participation but not hearing impairment) largely reflected the results of the original LIBRA index. Regarding the two additional factors, we observed low variation in the occurrence of sleep disturbances and low social participation across age groups. Low social participation was highest among the 30- to 39-year-olds and decreased from this age group onward, consistent with studies from other contexts.[59, 60] The frequency of sleep disturbances was distributed relatively similarly across age groups, however, with a trend toward lesser sleep disturbances in older age. While sleep disturbances were significantly associated with cognitive functioning in the total sample, this did not hold true for individual age groups. The results align with previous mixed evidence on the relationship between sleep markers and cognitive functioning or dementia, possibly partially due to heterogeneous sleep measures.[1, 61, 62] LIBRA2 did not differ substantially from LIBRA in explaining variance in cognitive functioning, but the addition of new factors and revised weights may better reflect the complexity of modifiable dementia risk, whereas LIBRA offers greater parsimony with less data loss. The largely consistent findings across LIBRA and LIBRA2 suggest that the reported population patterns are not driven by a score specification but rather reflect stable gradients in modifiable dementia risk and its associations with cognitive functioning.

Our findings suggest a persistent social gradient in modifiable dementia risk factors, with individuals with lower SES showing higher LIBRA scores from early adulthood onward, consistent across age groups and sexes. There is well-established evidence that lifestyle choices are shaped by social determinants and constrained by social hierarchy.[63, 64] Disadvantageous social determinants, particularly socioeconomic factors, were associated with higher LIBRA scores in the German Leipzig Research Centre for Civilization Diseases (LIFE) adult study, and LIBRA explained socioeconomic disparities in cognitive functioning, but only to a small extent.[6, 7] In addition, our findings point out significant associations of higher LIBRA and lower cognitive functioning in young women (20–39 years) with low and moderate SES, whereas almost no associations were significant for men, indicating minimal SES variation. These findings highlight the critical role of SES and sex/gender in lifestyle–cognition links and their importance for prevention strategies across the life course. Such social determinants have been suggested to influence cognitive functioning through multiple, interrelated pathways. For example, socioeconomic disadvantage can constrain access to education opportunities, cognitively stimulating environments, and health-promoting resources, while increasing exposure to chronic stressors, job insecurity, and financial strain.[65] These conditions are associated with higher prevalence of behavioral and psychosocial risk factors, observed in younger adults in this study, including smoking, physical inactivity, and depressive symptoms,[66] which are themselves linked to cognitive performance.[24] In addition, prolonged stress exposure and mental health burden may directly affect cognitive processes via neuroendocrine and inflammatory pathways, potentially shaping cognitive trajectories well before midlife.[67]

Overall, our results underscore that it is never too early and never too late to target modifiable lifestyle factors to promote brain health and reduce cognitive disparities. Interventions tailored for younger adults, particularly socioeconomically disadvantaged women, could focus on behavioral and psychosocial factors such as smoking prevention, increasing physical activity, and addressing depression. Additionally, addressing social determinants of health is profound as they shape lifestyle opportunities.

4.1 | Limitations

Our analyses relied on cross-sectional data, and while we primarily interpret from the perspective of cognitive functioning being influenced by modifiable lifestyle factors, consistent with the dementia risk reduction framework, it is equally plausible that cognitive ability, particularly from earlier life stages, shapes lifestyle trajectories.[68] Our results may also be associated with generational differences rather than aging.[69] Second, the constrained observed range of the LIBRA scores due to non-available factors specifically reflects limited availability of protective components (cognitive activity, healthy diet) rather than poorer population health. However, this does not affect the interpretation of relative differences across sociodemographic groups. Third, despite the large, population-based sample, generalizability is restricted to the German context, and participation bias may have favored healthier individuals. Fourth, treated individuals with controlled cardiometabolic risk factors could be misclassified, and thus, associations may be slightly biased; however, this limitation reflects common challenges in risk-factor operationalization and is not specific to LIBRA. Fifth, most LIBRA factors relied on self-report and may therefore be subject to recall bias. Given the generally high functional status of participants able to complete the baseline assessment, substantial misclassification due to cognitive impairment is unlikely. In addition, as is common in center-based population studies, individuals with moderate to severe cognitive impairment are underrepresented, which may have led to an underestimation of the associations between LIBRA and cognitive functioning, particularly in older age groups. Finally, although associations were statistically significant in some subgroups, effect sizes were small and incremental variance explained was modest.

5 | CONCLUSIONS

The study underscores the usefulness of the LIBRA index in evaluating modifiable dementia risk factors and their associations with cognitive functioning. Adding to the literature, our findings suggest that LIBRA may also be a valuable tool to assess dementia risk factors in younger adults, a demographic group often overlooked in dementia research. The findings highlight distinct patterns in the occurrence of LIBRA factors, with behavioral and psychosocial risks more common among younger adults and vascular risks more common among older adults. Overall, higher LIBRA scores were consistently linked to lower cognitive functioning across adulthood, and sex/gender and SES disparities highlight the need for tailored, life-course risk reduction strategies, especially for younger adults in disadvantaged groups. Interventions addressing modifiable behavioral and psychosocial factors early could help mitigate long-term cognitive risks. Taken together, our findings reinforce the usefulness of the LIBRA approach, while underscoring the need for further research in younger adults and validation of LIBRA2.

AUTHOR CONTRIBUTIONS

S.R., F.W.: conceptualization, methodology, formal analysis, visualization, writing—original draft. A.P.: methodology, validation, writing—review and editing. P.Be., P.Bo., H.B., A.F., J.K.H., A.K., T.K., M.Le., W.L., C.M.F., R.M., U.M., K.N., C.Oe., A.P., T.P., T.S., M.B.S., O.T., S.N.W., M.W., K.B., S.G.R.H.: data curation, funding acquisition, investigation, project administration, resources, writing—review and editing. M.Lu., S.K., K.D., C.R.: writing—review and editing. All authors have reviewed and agreed with the final version of the manuscript.

AFFILIATIONS

[1]Centre for Healthy Brain Ageing (CHeBA), Discipline of Psychiatry and Mental Health, School of Clinical Medicine, Faculty of Medicine and Health, UNSW Sydney, Sydney, New South Wales, Australia

[2]Institute of Social Medicine, Occupational Health and Public Health (ISAP), Medical Faculty, University of Leipzig, Leipzig, Germany

[3]Global Brain Health Institute (GBHI), Trinity College Dublin, Dublin, UK

[4]Alzheimer Centrum Limburg, Department of Psychiatry and Neuropsychology, Mental Health and Neuroscience Research Institute (MHeNs), Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, the Netherlands

[5]Department of Epidemiology, Helmholtz-Centre for Infection Research (HZI), Braunschweig, Germany

[6]Department of Epidemiology and Preventive Medicine, University of Regensburg, Regensburg, Germany

[7]Department of Neurology, medbo District Hospital and University Hospital of Regensburg, Regensburg, Germany

[8]German Cancer Research Center (DKFZ), Heidelberg, Germany

[9]University Medicine Greifswald, Greifswald, Germany

[10]German Center for Neurodegenerative Diseases (DZNE), Rostock/Greifswald, Germany

[11]Institute of Epidemiology and Social Medicine, University of Münster, Münster, Germany

[12]Institute of Social Medicine, Epidemiology and Health Economics, Charité - Universitätsmedizin Berlin, Berlin, Germany

[13]Institute of Clinical Epidemiology and Biometry, University of Würzburg, Würzburg, Germany

[14]State Institute of Health I, Bavarian Health and Food Safety Authority, Erlangen, Germany

[15]Institute of Epidemiology, Kiel University, Kiel, Germany

[16]Institute for Medical Epidemiology, Biometrics, and Informatics, Interdisciplinary Center for Health Sciences, Medical Faculty of the Martin Luther University Halle-Wittenberg, Halle (Saale), Germany

[17]German Center for Mental Health, Site Halle-Jena-Magdeburg, Halle (Saale), Germany

[18]Division of Primary Cancer Prevention, German Cancer Research Center (DKFZ), Heidelberg, Germany

[19]Molecular Epidemiology Research Group, Max Delbrück Center for Molecular Medicine (MDC), Berlin, Germany

[20]Institute of Epidemiology, Helmholtz Zentrum München - German Research Center for Environmental Health, Munich, Germany

[21]IUF - Leibniz Research Institute for Environmental Medicine, Düsseldorf, Germany

[22]School of Public Health, University of Bielefeld, Bielefeld, Germany

[23]Department of Molecular Epidemiology, German Institute of Human Nutrition (DIfE), Nuthetal, Germany

[24]Institute of Nutritional Science, University of Potsdam, Nuthetal, Germany

[25]Department of Psychiatry, Psychotherapy and Psychosomatics, University Hospital Halle (Saale), Halle (Saale), Germany

[26]Department of Old Age Psychiatry and Cognitive Disorders, University of Bonn Medical Center, Bonn, Germany

[27]German Center for Neurodegenerative Diseases (DZNE), Bonn, Germany

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DATA AVAILABILITY STATEMENT

The datasets analyzed during the current study are not publicly available due to privacy concerns but can be requested via the NAKO transfer hub (https://transfer.nako.de/transfer/index)

CONSENT STATEMENT

We confirm that informed consent was obtained from all human subjects.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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