Diet Quality Index for older adults (DQI-65): development and use in predicting adherence to dietary recommendations and health markers in the UK National Diet and Nutrition Survey

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Abbreviations**:** 25(OH)D, 25-hydroxyvitamin D; AHEI-2010, Alternative Healthy Eating Index-2010; BP, blood pressure; CHD, coronary heart disease; CRP, C-reactive protein;

CVD, cardiovascular disease; DBP, diastolic blood pressure; DQI, diet quality index; DQI-65, Diet Quality Index for Older Adults; FDQI-65+PA, Food-based Diet Quality Index for Older Adults with Physical Activity; HDL-C, high density lipoprotein cholesterol; HEI, Healthy Eating Index; HEI-2015, Healthy Eating Index-2015; LDL-C, low density lipoprotein cholesterol; MDS, Mediterranean Diet Scores; NDNS, National Diet and Nutrition Survey; NFDQI-65, Nutrient and Food-based Diet Quality Index for Older Adults; NFDQI-65+PA, Nutrient and Food-based Diet Quality Index for Older Adults with Physical Activity; SACN, Scientific Advisory Committee on Nutrition; SBP, systolic blood pressure; T2D, type 2 diabetes; TC, total cholesterol; WC, waist circumference.

Abstract

Diet quality indexes (DQIs) are useful tools for assessing diet quality in relation to health and guiding delivery of personalised nutritional advice, however existing DQIs are limited in their applicability to older adults (aged ≥65 years). Therefore, this research aimed to develop a novel evidence-based DQI specific to older adults (DQI-65). Three DQI-65 variations were developed to assess the impacts of different component quantitation methods and inclusion of physical activity. The variations were: Nutrient and Food-based DQI-65 (NFDQI-65), NFDQI-65 with Physical Activity (NFDQI-65+PA) and Food-based DQI-65 with Physical Activity (FDQI-65+PA). To assess their individual efficacy, the NFDQI-65, NFDQI-65+PA and FDQI-65+PA were explored alongside the validated Healthy Eating Index-2015 (HEI-2015) and Alternative Healthy Eating Index-2010 (AHEI-2010) using data from the cross-sectional UK National Diet and Nutrition Survey (NDNS) rolling programme. Scores for DQI-65 variations, the HEI-2015 and AHEI-2010 were calculated for adults ≥65 years from years 2-6 of the NDNS (n=871). Associations with nutrient intake, nutrient status and health markers were analysed using linear and logistic regression. Higher DQI-65s and HEI-2015 scores were associated with increased odds of meeting almost all of our previously proposed age-specific nutritional recommendations, and with health markers of importance for older adults, including lower body mass index, lower medication use and lower C-reactive protein ($P<0.01$). Few associations were observed for the AHEI-2010. This analysis suggests value of all three DQI-65s as measures of dietary quality in UK older adults. However, methodological limitations mean further investigations are required to assess validity and reliability of the DQI-65s.

Introduction

The ageing global population[1] poses challenges to all aspects of society[2], most notably health and social care. To lessen this burden and support individuals to maintain their physical, social and mental wellbeing later in life, exploring ways to promote healthy ageing is of high priority. In particular, appropriate nutrition is considered an important factor in reducing risk of cardiometabolic disease, slowing loss of bone and muscle mass, preserving cognitive function, and helping to maintain physical and mental fitness in older age[3].

Diet quality indexes (DQIs) are useful nutritional assessment tools, accounting for the complexity of dietary exposure and the principle that people eat foods and not nutrients[4], that can be easily translated into food-based, dietary advice[5]. Their use is increasingly prevalent, with several DQIs being investigated within older adults[6-18]. For example, Mediterranean Diet Scores (MDS) have been inversely associated with risk of incident disability[15] and with overall, coronary heart disease (CHD) and cancer mortality[8,13,16] in longitudinal studies. Moreover, US Healthy Eating Index (HEI) scores have been positively associated with components of the Fried et al. frailty phenotype[19] and indicators of functional decline such as gait speed and knee extensor power cross-sectionally[17].

Nonetheless, component choice and scoring method mean current, widely used, DQIs could be deemed unsuitable for older adults (aged ≥65 years) whereby a range of key health outcomes related to mortality risk and quality of life, and impacts of physical and cognitive decline, should be considered. Specifically, MDS discourage high dairy intake, a food group beneficial for musculoskeletal health[20] and associated with lower risk of type 2 diabetes[21] and cardiovascular disease (CVD)[22], whereas the HEI disregards the importance of oily fish consumption, particularly long chain (LC) n-3 PUFA content, which has been associated with reduced cognitive impairment[23], inflammation[24] and risk of CHD[25]. Moreover, the

Alternative Healthy Eating Index-2010 (AHEI-2010) includes three fatty acid components, resulting in strong associations with CVD risk[(26)], however overall dietary quality may not be reflected in scores and associations with other health outcomes may be limited.

To our knowledge, only one DQI specifically tailored to older populations exists, the US Elderly Dietary Index, for which scores have been cross-sectionally inversely associated with CVD risk[(9)]. However, it has not been widely explored nor validated and may be limited in its associations with physical function and sarcopenia by favouring only moderate protein intake (highest scores awarded for only 1-2 servings/week each of meat, fish or seafood and legumes) and excluding physical activity as high protein intake (1.0-1.2g/kg/day; equivalent to ≥ 3 servings/day of meat, fish or seafood and legumes) has been associated with improved or reduced loss of muscle mass and strength[(27)], and physical activity acts synergistically with protein to enhance its effect[(28)]. Moreover, current established and validated scores such as the HEI and MDS were developed for use in US and Mediterranean populations respectively, questioning the suitability within a UK population.

Therefore, this study aimed to develop three variations of an evidence-based DQI suitable for UK older adults (aged ≥65 years) (DQI-65) that characterised an optimum dietary pattern, and assess i) their ability to predict adherence to our previously proposed age-specific nutritional recommendations for this population group[(27)] and ii) associations with health markers of importance to older adults, using cross-sectional data. The novel DQI were explored alongside the validated HEI-2015 and AHEI-2010 to identify whether the new DQI-65s were better predictors of adherence to nutritional recommendations and health status.

Methods

Development of the diet quality index for UK older adults

Index structure and variations

DQI-65 development was based on the steps documented by Waijers, Feskens and Ocke[29] with all decisions being made by an experienced registered nutritionist (JAL) and registered dietitian (RF), and a nutrition student (ND). Following a thorough evaluation of existing indexes identified in the current literature, it was decided that the primary DQI-65 would be comprised of the more frequently used combination of foods and nutrients, with physical activity added due to the range of health benefits in older adults[30]. However, it was deemed appropriate to develop two further variations in order to test the effect of including physical activity and the effect of exchanging nutrient components with food groups on the predictive value of the index. The three DQI-65s were: Nutrient and Food-based DQI-65 (NFDQI-65), which contained food groups and nutrients, NFDQI-65 with Physical Activity (NFDQI-65+PA), which contained food groups, nutrients and physical activity, and Food-based DQI-65 with Physical Activity (FDQI-65+PA), which contained solely food group components with physical activity.

Choice of index components

All decisions regarding choice of components and scoring criteria were guided by the nutritional recommendations for UK older adults (≥65 years) proposed in our previous critical review, along with the practical food-based advice we devised[27]. Nutrients from our proposed age-specific nutritional recommendations were selected to be represented in the index if new recommendations had been set (i.e. protein, calcium, vitamin B12, folate and fluid) or if strong evidence supported their physiological role among older adults (i.e. dietary fibre, free sugars, MUFA, PUFA and SFA, LC n-3 PUFA, sodium, vitamin D and alcohol). Guidance from the UK *Eatwell Guide*[31] was considered alongside these recommendations as consistency between dietary guidelines, where appropriate based on the identified age-specific evidence, would likely enhance adherence.

Twelve main components were devised, eleven of which were dietary components (a mixture of food groups and nutrients) and the twelfth represented physical activity (except for NFDQI-65 in which this was excluded).

Components 1-3 and 5-6 (fruit, vegetables, protein, low-fat dairy and wholegrain carbohydrates) represent nutrients identified as important to older adults and, in the case of protein, calcium, folate and vitamin B12, for which we proposed new, higher, recommendations[(27)]. Specifically, sufficient protein intake is important to support maintenance of muscle mass and strength among older adults, which diminishes with age[(32)], and we found that evidence suggests older adults have higher protein requirements due to impaired absorption and utilisation[(27)]. Furthermore, dairy provides bioavailable calcium, an essential mineral required to minimise age-associated loss of bone mineral density[(33)], and, along with animal proteins, is a good source of vitamin B12. Finally, fruit, vegetables and wholegrain carbohydrates provide dietary fibre and a wide range of vitamins and minerals (e.g., vitamins A, C, E and folate), supporting various physiological functions, and have been associated with lower risk of CVD[(34,35)].

Component 4 (oily fish) was selected due to oily fish containing LC n-3 PUFAs and vitamin D, and being associated with lower risk of CHD[(25)].

Components 7-8 and 11 (free sugars, sodium, and alcohol) reflect nutrients in our previously proposed nutritional recommendations that are considered detrimental to health of older adults[(27)]. Specifically, high intake of free sugar containing foods may displace protein and micronutrient intake and increase risk of overweight or obesity[(27)] and sodium intake is a major risk factor for hypertension[(36)] and has been positively associated with systolic blood pressure (SBP) and diastolic blood pressure (DBP) in an elderly population[37]. Moreover, sensitivity to the toxicity of alcohol increases with age[38] and methodological limitations exist within age-specific evidence supporting benefits of light-to-moderate intake on health (as is appraised in the AHEI-2010), therefore discouraging alcohol consumption seems prudent in this age group[27].

Component 9 (fat and fatty acids) reflects recommendations for dietary fat and fatty acids in our previous review and accounts for the variable relationships between different fatty acids and risk of chronic disease such as type 2 diabetes and CVD[27]. Specifically, SFA intake is discouraged and substitution with PUFA and MUFA is encouraged.

Component 10 (fluid) was selected as fluid intake is essential to prevent dehydration, which is associated with impaired cognitive and physical function, and to lower risk of constipation[39], which can impair appetite. Fluid intake is commonly low within this demographic due to impaired thirst sensation, poor renal function and fear of incontinence[40], meaning it should not be overlooked within dietary assessments among older adults.

Finally, component 12 (physical activity) was included in the FDQI-65+PA and NFDQI-65+PA due to physical activity acting synergistically with protein to enhance muscle maintenance or synthesis in response to amino acids[28], and its additional role in supporting weight maintenance, cardiovascular health and preventing loss of bone strength[30].

No dietary variety component was included, but instead limitations were imposed regarding number of portions of certain foods, notably for vegetables, fruit and protein, preventing the maximum score being achieved without a varied diet. For example, for protein only ≤1 portion each of legumes or nuts, dairy, and red meat were allowed per day, and for vegetables only ≤1 portion each of legumes and tomato puree were allowed. These limitations were based on a consensus decision by the nutrition experts, taking into account the health benefits or detriments of each. Justification of these decisions are in **Supplementary Table 1**.

Component measurement methods and recommendations

Measurement methods chosen were either based on portions of representative foods or nutrient intakes. The NFDQI-65/NFDQI-65+PA and FDQI-65+PA measured fruit, vegetables, protein, low-fat dairy, wholegrain carbohydrates and fluid as portions of representative foods, and the NFDQI-65/NFDQI-65+PA measured free sugars, sodium, fat and fatty acid, and alcohol as nutrient intakes. In comparison, the FDQI-65+PA measured the free sugars, sodium, fat and fatty acid, and alcohol components as portions of representative foods which were selected based on main contributors to nutrient intakes in the NDNS and the panel's consensus decision.

Guidelines for food-group components were based on number of portions eaten, with a portion being a quantity considered as standard for UK adults (such as 80g for fruits and vegetables)[31,41,42] to ensure applicability of the index to general UK portion sizes, or a quantity specified in SACN advice[25,43]. No age or sex-specific portion size guidance was identified and therefore portion sizes were generalised to older adults and both men and women. All portion weights were given as cooked or eaten. For nutrient components, quantitation was as mg, g or percentage of total energy intake (as relevant) and was guided by our previously proposed nutritional recommendations[27]. For the NFDQI-65 and NFDQI-65+PA, nutrient intake data for sodium and alcohol was used as mg and g, respectively, and free sugars, MUFA, PUFA and SFA were as percentage of total energy intake. Physical activity was assessed as minutes/day of moderate intensity activity which was calculated within the NDNS dataset from data collected using an NDNS specific self-reported questionnaire (Year 1) or the self-reported Recent Physical Activity Questionnaire (Years 2 onwards). Full details of physical activity assessment methods are detailed elsewhere[44].

Required numbers of portions for each food-based component were set by analysing nutritional composition of specified foods and considering the evidence-base, as well as the quantity required to meet specific nutritional recommendations. For example, for protein the index recommendation is ≥3 portions/day to promote protein consumption at each meal due to evidence of benefits of even protein distribution[45], and as it was determined that 3 portions of protein, combined with specified quantities of other protein-rich foods in the index including low-fat dairy, oily fish and wholegrain carbohydrates, would help support an individual to meet the nutritional recommendation we proposed of 1.2g/kg/day[27]. Similarly, for low-fat dairy, the recommendation of ≥3 portions/day of the specified quantities was calculated as each portion provides 200-250mg calcium therefore providing up to 75% of our proposed daily calcium requirements of 1000mg which, in conjunction with other dietary sources of calcium, should allow this to be met. Recommendations for oily fish were based on the most recent UK Scientific Advisory Committee on Nutrition (SACN) advice[25], with 1 portion/week meeting advised LC n-3 PUFA intake, and for physical activity were taken from the UK *Physical activity guidelines for older adults*[30]. For the remainder of the components, decisions were made from panel discussions, taking into account UK *Eatwell guide* recommendations in the case of fruit, vegetables and wholegrain carbohydrates due to their evidence-based nature and to promote consistency between guidelines where any reason to differ did not exist. Full explanations for all components are in Supplementary Table 1.

Index scoring

The components were scored in a manner that accounted for their evidence-based associations with health outcomes, negatively scoring those considered detrimental to health (i.e., lower intake receives higher score) and positively scoring those considered beneficial to health (i.e., higher intake receives higher score). Specifically, the fruit, vegetables, protein, oily fish, low-fat dairy, wholegrain carbohydrates, fat and fatty acids, fluid and physical activity components were positively appraised due to their proposed health benefits and the free sugar, sodium and alcohol components negatively appraised due to their proposed detrimental effects and the conclusions from our previous review[27].

In the absence of qualitative evidence to suggest otherwise, components were equally weighted, with scores for each ranging between 0-10 points. This is in line with other widely-used DQIs, such as the HEI-2015 whose authors stated that dietary guidelines are to be considered as a whole and “all concepts are equally important”[46]. A score of 10 was awarded for full adherence to each component recommendation, except for the fat and fatty acids component of the NFDQI-65 and NFDQI-65+PA, which were subdivided into two sub-components (MUFA+PUFA:SFA ratio and SFA intake) each worth up to 5 points. A proportionate score was allocated for intakes between the minimum and maximum criteria using a linear slope, for example if an individual consumed 1 portion of fruit/day (for which the recommendation is ≥2 portions/day) they would score 5 out of 10 points, whereas 1.5 portions of fruit/day would score 7.5. The maximum total score was 120 points for FDQI-65+PA and NFDQI-65+PA and 110 points for NFDQI-65. Higher scores reflect greater adherence to the recommendations.

Full details of the components and scoring methods of the DQI-65 variations are in **Table 1**.

Ability of diet quality indicies to predict adherence to dietary recommendations and health markers

The three DQI-65s were assessed alongside two widely used and validated scores: the Healthy Eating Index-2015 (HEI-2015), which assesses adherence to the 2015-2020 US Dietary Guidelines for Americans[46], and the US-based AHEI-2010, which assesses intake of foods and nutrients associated with chronic disease risk[26].

Study design and population

Data was used for participants aged ≥65 years (*n*=1076) from years 2-6 of the UK NDNS rolling programme (2009/2010-2013/2014)[47] (the most recent available NDNS data when the DQI-65 was developed). The NDNS is a UK cross-sectional survey of randomly selected individuals aged ≥1.5 years designed to assess dietary intake and nutritional status of a representative UK population. The methodology of the NDNS has been fully described elsewhere[48] and is summarised in the **Supplemental Methods**. Of importance, dietary assessment is based on 4-day diet diaries and physical activity measured via self-reported questionnaires on recent physical activity.

Individuals from year 1 were excluded due to the absence of physical activity data (*n*=174), as were participants in years 2-6 where this data was not reported (*n*=29), and those with energy intake <600kcal/day (600-4500kcal reflected reasonable intake[49]) (*n*=2), leaving a total of 871 participants in the final analysis.

Variables and measurement method

In the present analysis, data for food and nutrient intake (excluding nutrients from vitamin, mineral or other dietary supplements) from the NDNS were used to calculate DQI-65 scores for each participant as per the index criteria (Table 1). Disaggregated foods were selected from the NDNS dataset where available (fruit, vegetables, legumes, meat, fish, nuts, and cheese), or data for individual food items was collated, using conversion factors and standard recipes from *McCance and Widdowson's The Composition of Foods, 6th & 7th Summary Editions*[50,51] for obtaining cooked weights for wholegrain foods or disaggregating additional dishes where necessary to contribute to the DQI-65 calculations.

HEI-2015 and AHEI-2010 scores were also calculated for all subjects based on their original methodology[26,46] in a similar manner to the DQI-65s. Insufficient guidance was available for calculating the Elderly Dietary Index in our population[9], so a comparison was not possible. Details of components in the HEI-2015 and AHEI-2010 are in **Supplemental Table 2**.

Ethical considerations

The NDNS was conducted according to the guidelines laid down in the Declaration of Helsinki, and ethical approval for all procedures was granted by Local Research Ethics Committees covering all areas covered in the survey. All participants gave informed consent.

Statistical analysis

Mean component and total scores, and percentages of subjects achieving maximum component scores, were calculated for the DQI-65s, HEI-2015 and AHEI-2010 to assess adherence to index recommendations. Data are expressed as mean (SD) or percentages.

Where mean (SD) is used, data is also represented as percentages to facilitate comparison between scores.

Statistical tests were performed in SPSS Version 25.0 (SPSS Inc., Chicago, IL, USA), where P-values <0.01 were considered statistically significant on account of multiple testing. Data was visually inspected for normality. Variables identified as not normally distributed were log-transformed prior to analysis (see table footnotes). Sample weights were generated by the NDNS to adjust for differences in probability of selection and for non-response. The three types of weights used were: 1) interviewer weights, which were applied to demographic and dietary data to adust for non-response to the individual interview and food diaries, 2) nurse weights, which were applied to health outcome measures taken in the nurse visit (e.g. weight, blood pressure (BP)) to adjust for differences in participants and non-participants with these, and 3) blood sample weights, which were applied to all biomarkers of nutritional status and health outcomes based on biochemical measures to adjust for non-response to blood samples. Full details of how sample weights were calculated have been previously published[(52)].

To investigate the predictive ability of the DQI-65s in relation to the proposed nutritional recommendations for adults aged ≥65 years from our previous review[(27)], through which our decisions around components, portion or nutrient recommendations and scoring method could be explored, participants were classified by whether they met proposed nutritional recommendations[(27)] based on daily nutrient intake from NDNS data. Associations between DQI-65s, HEI-2015 and AHEI-2010 scores and odds of meeting these nutritional recommendations for these categorical variables were assessed using binomial logistic regression analysis.

To investigate health markers, associations between DQI-65s, HEI-2015 and AHEI-2010 total scores and 1) biochemical markers of nutritional status (plasma 25-hydroxyvitamin D [25(OH)D], serum vitamin B12, plasma total homocysteine, haemoglobin concentration, plasma α-tocopherol, plasma β-carotene), 2) anthropometric measures (BMI, obesity, waist circumference [WC], visceral obesity), 3) selected health indicators (medication use, longstanding illness, self-assessed health, activity limitation due to illness), 4) cardiometabolic risk factors (SBP, DBP, hypertension, total cholesterol [TC], fasting TG, low-density lipoprotein cholesterol [LDL-C], high-density lipoprotein cholesterol [HDL-C], TC:HDL-C, C-reactive protein [CRP], fasting glucose, glycated haemoglobin, classification of metabolic syndrome[(53)]) were assessed using linear regression analysis for continuous variables and logistic regression analysis for categorical variables. Missing data in the NDNS dataset meant different numbers of subjects were included in the health marker analyses. Since the maximum score available differed between scores, they were adjusted by proportional scaling for direct comparison between DQIs and to allow for a greater magnitude of change to be assessed than when considering a 1-point change. Therefore, a change in unadjusted B coefficient or odds ratio represents a 5% change in DQI-65, AHEI-2010 and HEI-2015 scores (equivalent to a standard unit increase of 6 points for FDQI-65+PA and NFDQI-65+PA, 5.5 points for NFDQI-65 and AHEI-2010 and 5 points for HEI-2015 scores).

Analyses of associations between DQI-65s, HEI-2015 and AHEI-2010 scores and odds of meeting nutritional recommendations were performed unadjusted. However, for health outcomes and biochemical markers of nutritional status, a step-wise approach for confounder adjustment was implemented to assess whether the DQIs predicted risk above and beyond other potential modifying factors. Confounders adjusted for were: age and sex (model 1), model 1 confounders plus BMI, WC, supplement use (nutrient biomarker analyses only), BP and/or lipid lowering medication (where applicable) and smoking status (model 2), and model 2 confounders plus income, marital status and education level (model 3). Unless specified, the results discussed are from the most adjusted model.

Results

Characteristics of study population, and DQI total and component scores

The mean age of the 871 subjects included in the analysis was 74 (7) years, and 44.2% were men. Study population characteristics are detailed in **Table 2.**

Mean total DQI-65 scores were 71.8 (15.1) out of 120 for the FDQI-65+PA (59.8%), 68.1 (14.4) out of 120 for the NFDQI-65+PA (56.8%) and 61.6 (12.8) out of 110 for the NFDQI-65 (56.0%). Mean component scores in all DQI-65s were ≥7 out of 10 for vegetables, fruit, protein, fluid and sodium, reflecting greater adherence to these recommendations, whereas they were ≤3 out of 10 for low-fat dairy and NFDQI-65/NFDQI-65+PA free sugars (**Figure 1**). Correspondingly, ≥50% of subjects scored maximum points for the sodium component in all DQI-65s, alcohol in the FDQI-65+PA and physical activity in the FDQI-65+PA/NFDQI-65+PA. Conversely, a ≤10% of subjects scored maximum points for protein, low-fat dairy, wholegrain carbohydrates and NFDQI-65/NFDQI-65+PA fat and fatty acids, suggesting low adherence to these recommendations in UK adults aged ≥65 years.

The mean HEI-2015 score was 59.9 (11.3) out of 100 (59.9%), with component scores of ≥3.5 out of 5 or ≥7 out of 10 for total protein, refined grains, sodium and added sugars, and ≤1.5 out of 5 or ≤3 out of 10 for wholegrains, fatty acids and SFA (**Figure 2**). For whole fruit, total protein and refined grains, ≥50% of subjects scored maximum points, yet for wholegrains, fatty acids and SFA only ≤10% of subjects scored maximum points.

Mean AHEI-2010 score was 50.1 (11.4) out of 110 (45.5%), with scores of ≥7 out of 10 for trans fatty acids, and of ≤3 out of 10 for the wholegrains and nuts and legumes components (**Figure 3**). Proportions of subjects scoring maximum points was ≤10% for vegetables, fruit, wholegrains, nuts and legumes, red and processed meat and PUFA.

Full details of mean component scores and proportions meeting recommendations for each component are in Supplemental Table 2.

Associations between DQI-65s, HEI-2015 and AHEI-2010 scores and nutrient intake

As per **Table 3**, higher FDQI-65+PA, NFDQI-65 and NFDQI-65+PA scores were significantly associated with increased odds of meeting recommendations for almost all nutrients, except carbohydrates, MUFA, PUFA, sodium and alcohol for the FDQI-65+PA and MUFA and PUFA for the NFDQI-65+PA. In contrast, HEI-2015 and AHEI-2010 scores were not associated with increased odds of meeting our previously proposed nutritional recommendations[27] for several nutrients of age-specific importance including calcium, vitamin D, vitamin B12 and alcohol (for the HEI-2015), and calcium, zinc, vitamin D, folate, vitamin B12, vitamin B6 and alcohol (for the AHEI-2010).

Associations between DQI scores and biomarkers of nutrient intake

DQI-65s, HEI-2015 and AHEI-2010 scores were significantly positively associated with nutritional intake biomarkers of relevance among older adults, particularly serum vitamin B12 and plasma 25(OH)D, when adjusted for age and sex only, but not with haemoglobin concentration (**Supplemental Table 3**). After adjustment for all covariates, including supplement use and socioeconomic factors (model 3), the associations between DQI-65s and serum vitamin B12 became non-significant (**Table 4**) and AHEI-2010 scores became significantly inversely associated with haemoglobin concentration. Results for all models are in Supplemental Table 4.

Associations between DQI scores and health markers

When adjusting for age and sex only, DQI-65s, HEI-2015 and AHEI-2010 scores were all significantly inversely associated with anthropometric measures (BMI and WC), medication use, fasting TG, CRP, and odds of being classified with metabolic syndrome (except for NFDQI-65 and NFDQI-65+PA). They were also significantly positively associated with odds of good self-assessed health (**Supplemental Table 4**). Differential associations existed with other cardiometabolic risk factors (i.e., cholesterol markers and BP), with higher FDQI-65+PA scores being significantly associated with higher TC and HDL-C, and higher NFDQI-65 and NFDQI-65+PA scores being significantly associated with lower DBP.

After adjustment for age, sex, BMI and WC (where appropriate), smoking, and relevant medications (model 2), associations between FDQI-65+PA scores and TC were attenuated to become non-significant, as were associations between NFDQI-65, NFDQI-65+PA and AHEI-2010 and both TG and metabolic syndrome classification, and NFDQI-65 and odds of good self-assessed health. All other previously observed associations remained significant in model 2.

After full adjustment, several of the associations were further attenuated to become non-significant. However, significant inverse associations remained between all DQIs and BMI, WC (except AHEI-2010 and FDQI-65+), medication use and CRP (**Table 5**). Moreover, higher FDQI-65 scores remained significantly associated with lower odds of being classified with metabolic syndrome and higher odds of good self-assessed health, and higher

NFDQI-65+PA and NFDQI-65 scores remained associated with lower DBP. Finally, higher HEI-2015 scores remained significantly associated with higher odds of good self-assessed health. AHEI-2010 scores did not remain associated with any other outcomes.

Discussion

This study developed three variations of the DQI-65, which were tailored to nutritional and, in the case of FDQI-65+PA and NFDQI-65+PA, physical activity recommendations for UK older adults aged ≥65 years. Unique aspects of the DQI-65s were the positive appraisal of protein, inclusion of physical activity (FBDQI-65+PA/NFBDQI-65+PA) and fluid, and the negative appraisal of alcohol. The DQI-65 variations differed in component assessment method, with the FBDQI-65+PA using a food-based approach, such as portions/day of sugary foods, number of alcoholic drinks and ratio of unsaturated fat rich oils and spreads to those containing primarily SFA. In contrast, the NFBDQI-65+PA and NFBDQI-65 assessed these components using a nutrient-based approach, such as mg/day, alcohol units and % of total energy intake. These variations were created to assess the optimum composition of a DQI for this age group through evaluating the impact of selecting food groups (such as portions/day of sugary foods, number of alcoholic drinks), which would more easily translate into dietary and lifestyle advice) vs food groups and nutrients (such as sugar as % of total energy, alcohol units), and of the inclusion of physical activity on associations with the index.

All three of the DQI-65 scores were associated with increased odds of meeting almost all of our previously proposed nutritional recommendations[27] when using UK population nutritional intake data for those aged ≥65 years. This demonstrates the DQI-65s, as composite indexes, effectively represent individual age-specific nutritional recommendations upon which they were developed. This was particularly the case for certain nutrients of importance among older adults such as protein, calcium, vitamin D and zinc, for which the DQI-65s demonstrated greater association with adherence to recommendations of these nutrients (based on larger magnitude of effect) relative to the HEI-2015 and AHEI-2010. Since the nutritional recommendations assessed against were also used to develop the DQS-65s, these findings may be considered biased. However, it seems prudent that any DQI to be used within this age group (whether this be the novel DQI-65s or existing HEI-2015/AHEI-2010) should predict adherence to these evidence-based recommendations.

In contrast to the NFDQI-65 and NFDQI-65+PA, higher FBDQI-65+PA scores were associated with a lower likelihood of meeting recommendations for alcohol intake. This was surprising as all scores assessed units of alcohol, whether directly or via numbers of drinks. It may be that those with higher alcohol intakes also had greater diet quality when considering other components (e.g. lower intakes of salty or sugary foods, higher intakes of vegetables) resulting in this unexpected association. Furthermore, there was a lack of association between FBDQI-65+PA scores and sodium intake. This may be due to the assessment of portions/day of salty foods rather than absolute sodium intakes (as per the NFDQI-65/NFDQI-65+PA). It is likely that sodium intake was underestimated in the FBDQI-65+PA as only key sources of sodium were included in the 'salty foods' classification. Therefore, component choices (food vs. nutrition based) and scoring methods are important in DQI design, with current findings suggesting the NFDQI-65 and NFDQI-65+PA may be superior to the FBDQI-65+PA when assessing nutritional intake in relation to evidence-based requirements.

Similarly, results suggest that the NFDQI-65 and NFDQI-65+PA may be more suited to assessing the dietary quality of UK older adults in relation to adequacy of nutritional intake than the HEI-2015 and AHEI-2010. For example, the HEI-2015 showed weaker associations with calcium and vitamin A intake than the DQI-65s, which could be attributed to the quantification method for dairy, a rich source of these nutrients, where the HEI-2015 sums total dairy irrespective of type (including fortified soy products), yet the DQI-65s account for typical portion sizes of milk, yoghurt and cheese, which vary in their nutritional profiles. As calcium intake is key in preserving bone health[27], this approach may enhance predictive ability for musculoskeletal outcomes, although this would need confirmation using markers of bone health. Moreover, neither the HEI-2015 nor AHEI-2010 were associated with odds of meeting vitamin B12 recommendations, deficiency in which is prevalent among older adults due to impaired absorption with aging and poor intake of vitamin B12-rich foods [55]. Dairy and other animal products are also good sources of vitamin B12, therefore the higher weighting towards animal products in the DQI-65s may have contributed to the positive association with odds of meeting vitamin B12 recommendations, supporting its use to assess nutritional quality in an older population. Due to the HEI-2015 and AHEI-2010 being developed for a US rather than UK population, and based on the DQI-65 closely reflecting the proposed nutritional recommendations against which they were tested, greater suitability of the DQI-65s may be unsurprising. Further investigation is required to confirm this conclusion.

The DQI-65s, HEI-2015 and AHEI-2010 were all associated with various markers of cardiometabolic risk. For example, NFDQI-65 and NFDQI-65+PA (but not FDQI-65+PA, HEI-2015 and AHEI-2010) scores were inversely associated with DBP, and high BP is considered the leading risk factor for morbidity and mortality globally[56], particularly relating to CVD[57]. Sodium intake has been positively associated with DBP in older adults[58], therefore lack of association between DBP and the FDQI-65+PA may result from differential assessment of sodium intake as previously discussed.

Higher DQI-65 scores were associated with lower medication use, and the FDQI-65+PA with better self-assessed health, like the HEI-2015. This suggests potential value of these indexes in predicting quality of life measures in an older population. The NFDQI-65+PA, NFDQI-65 and HEI-2015 were also associated with lower WC, yet the FDQI-65 was not. Higher WC is considered an independent risk factor for mortality[59], a key indicator of insulin resistance and overall cardiometabolic health[60], and has been inversely associated with grip strength[61], which is a component of Fried's frailty phenotype[19]. Finally, significant negative associations were also observed between CRP and all five DQIs. Like WC, higher CRP is associated with lower grip strength[62] and increased disability risk[63].

When comparing the nutrient and food based DQI-65s with and without physical activity, the magnitude of effect for associations between the NFDQI-65+PA and both CRP and number of medications were higher than for the NFDQI-65, whereas this was lower for associations with DBP. Few other differences existed in the present analysis with overall associations between the two nutrient and food-based DQI-65s (with/without physical activity) and nutrient, biochemical and health variables similar in both significance and magnitude of effect. Therefore, without statistical comparison between indexes it cannot be concluded whether including a physical activity component in the DQI-65s impacts associations and requires further investigation. In contrast, the nutrient and food-based DQI-65s may potentially be superior to the food-based DQI-65 due to marginally greater associations with adherence to nutritional recommendations and some important health markers (e.g., BMI, WC and DBP). However, associations with health markers are limited by the methodology of the statistical analysis. Specifically, the cross-sectional NDNS data results in potential for reverse causality where dietary change has occurred following chronic disease diagnosis or identification of risk factors (e.g., high BP or TC), or where functional decline affects food accessibiliy, meal preparation and impairs food choice. This affects validity of associations, prevents cause and effect from being established, and limits conclusions regarding both the predictive and comparative value of individual DQIs. In addition, 4-day diet diaries may not reflect habitual diet, especially for components with weekly recommendations (e.g., oily fish and alcohol), and bias may exist in dietary records, therefore it is possible that subject misclassification exists. Consequently, prospective cohort studies using dietary assessment methods that capture longer term habitual diet (such as food frequency questionnaires) would help explore associations with clinical events, morbidity and mortality to determine the value of the novel DQI-65 in assessing dietary quality in relation to health outcomes. This is a future aim to scientifically validate the DQI-65.

This study's strengths include the development of three DQI-65 variations and comparison with validated and widely-used indexes. Moreover, despite high non-response rates in the NDNS for biological risk factors, applying sample weights reduced risk of selection and non-response bias[(52)], and facilitated validation within a representative sample of UK older adults. However, some limitations exist. Development of the DQI-65s required subjectivity and, although decisions were justified by current research, different components and scoring methods may alter associations. For example, assumptions were made in equally weighting components (in line with approaches used by HEI-2015 and AHEI-2010) due to absence of qualitative evidence to support a different approach and the aim of targeting a range of markers of diet quality and health . Also, factor analysis was not performed to ensure that all included components relate to a single underlying dimension. Protein recommendations of 1.2g/kg/day may also be insufficient for those who undertake high levels of physical activity which would not be captured in the index. Moreover, maximum DQI-65 scores were only obtainable if both dairy and oily fish were consumed as some consider the anabolic potential of animal protein in older adults higher than plant protein[(64)], however applicability to vegetarian or vegan groups is limited. Further investigation is required to justify these decisions. Some measures of nutrient status (e.g., haemoglobin) may not directly reflect dietary intake due to physical adaptation to low status increasing bioavailability, affecting interpretation of results. Sodium content of water, which can be significant, was not fully quantified in NDNS data, and may have impacted assessment of sodium intake. Furthermore, less than 10% of individuals met many of our nutritional recommendations and criteria for health marker variables, so the commonly used odds ratio[18,65] may not be the optimal measure, and multiple testing was not formally accounted for as analyses were treated independently. Although a more conservative P-value for statistical significance was used, <0.01, the potential for false positive results still cannot be excluded. Finally, linearity across the DQI score range has been assumed. This is unlikely to be the case in all score categories, however this approach is used widely in DQI analyses[17,26]. Nonetheless, scope for further investigations exist, including scientific assessment of the validity and reliability of the DQI.

In conclusion, three variations of a novel DQI-65 were developed that effectively assess adherence to our previously proposed evidence-based age-specific nutritional recommendations for UK adults aged ≥65 years, potentially to a greater degree than existing indexes tested. In addition, this cross-sectional analysis found the DQI-65s, HEI-2015 and AHEI-2010 to be associated with a range of important health markers related to morbidity and mortality within a UK representative sample of adults aged ≥65 years, although methodological limitations may affect the validity of conclusions. The data from this analysis suggest the DQI-65s may be valuable tools for assessing diet quality in older adults in the UK, particularly when aiming to evaluate nutrient intake, and could support delivery of tailored nutritional advice. It is possible that the nutrient and food-based DQI-65s (NFDQI-65/NFDQI-65+PA) may be superior to the food-based DQI-65 (FDQI-65+PA), however the added benefit of including physical activity within the index is uncertain. Assessment of the DQI-65s predictability in relation to clinical and health outcomes was limited, yet these results indicate that further exploration is warranted. This would require use of longitudinal study data, including clinical outcomes and mortality, with further comparisons against existsing indexes to support DQI-65 validation.

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Author contributions: ND, RF, MW and JAL designed research; ND conducted research; ND analysed data; DH assisted in calculation of diet quality scores; ND drafted the paper. All authors read and approved the final manuscript.

Supplemental Methods, Supplemental Table 1-5 and Supplemental References are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/jn/.

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Table 1. Components and scoring method of DQI-65 variations[1].

Component	Recommendation	Criteria for minimum score (0 points)	Criteria for maximum score	Maximum score
FDQI-65+PA				
Vegetables[2,3]	≥3 portions/day	0 portions/day	≥3 portions/day	10
Fruit[2,4]	≥2 portions/day	0 portions/day	≥2 portions/day	10
Protein[5]	≥3 portions/day	0 portions/day	≥3 portions/day	10
Oily fish[6]	≥1 portion/week	0 portions/day	≥1 portion/week	10
Low fat dairy[7]	≥3 portions/day	0 portions/day	≥3 portions/day	10
Wholegrain carbohydrates[2,8]	≥3 portions/day	0 portions/day	≥3 portions/day	10
Free sugars[9,10]	≤1 portion/day	>2 portions/day	≤1 portion/day	10
Sodium[9,11]	≤1 portion/day	>2 portions/day	≤1 portion/day	10
Fat and fatty acids[9,12]	100% unsaturated	0% unsaturated	100% unsaturated	10
Fluid[9,13]	≥6 portions/day	0 portions/day	≥6 portions/day	10
Alcohol[9,14]	≤14 units/week	>14 units/week	0 units/week	10
Physical activity[15]	≥20 minutes/day moderate activity	0 minutes/day	≥20 minutes/day	10
			Maximum Total Score	**120**
NFDQI-65+PA *(and NFDQI-65)*				
Vegetables[2,3]	≥3 portions/day	0 portions/day	≥3 portions/day	10
Fruit[2,4]	≥2 portions/day	0 portions/day	≥2 portions/day	10
Protein[5]	≥3 portions/day	0 portions/day	≥3 portions/day	10
Oily fish[6]	≥1 portion/week	0 portions/day	≥1 portion/week	10
Low fat dairy[7]	≥3 portions/day	0 portions/day	≥3 portions/day	10
Wholegrain carbohydrates[2,8]	≥3 portions/day	0 portions/day	≥3 portions/day	10

Free sugars[9,16]	≤5% energy intake	>10% energy intake	≤5% energy intake	10
Sodium[9,17]	≤2400 mg/day	>3200 mg/day	≤2400 mg/day	10
Fat and fatty acids[18]				
Ratio of PUFA+MUFA to SFA[9,19]	(PUFA+MUFA)/SFA ≥2	(PUFA+MUFA)/SFA <1	(PUFA+MUFA)/SFA ≥2	5
SFA[9]	≤10% energy intake	>20% energy intake	≤10% energy intake	5
Fluid[9,13]	≥6 portions/day	0 portions/day	≥6 portions/day	10
Alcohol[9,20]	≤14 units/week	>14 units/week	0 units/week	10
Physical activity[15,21]	*≥20 minutes/day moderate activity*	*0 minutes/day*	*≥20 minutes/day*	*10*
			Maximum Total Score[21]	**120 *(110)***

[1] % energy intake refers to total energy; BMI, body mass index; DQI-65, diet quality index for older adults; FDQI-65+PA, Food-based Diet Quality Index for older adults with physical activity; MUFA, monounsaturated fatty acids; NDNS, National Diet and Nutrition Survey; NFDQI-65, Nutrient and Food-based Diet Quality Index for older adults; NFDQI-65+PA, Nutrient and Food-based Diet Quality Index for older adults with physical activity; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; SACN, Scientific Advisory Committee for Nutrition.
[2] Quantification based on the UK *Eatwell Guide* recommendations[(31)].
[3] Portion sizes based on standard portions[(31)]: 80 g vegetables or legumes, 15 g tomato puree; only up to 1 portion of legumes and 1 portion of tomato puree allowed.
[4] Portion sizes based on standard portions[(31)]: 80 g fruit, 150 mL fruit juice, 30 g dried fruit; only up to 1 portion of dried fruit or fruit juice allowed.
[5] Represents food group from the UK *Eatwell Guide*[(31)]; based on portions required to meet our previously proposed protein recommendations[(27)]; standard portion sizes used[(41)]: 70 g red meat, 100 g poultry, 140 g fish or shellfish, approximately 120 g or 2 eggs, 150 g legumes, 30 g nuts, 250 mL milk, 30 g cheese, 125 g yoghurt, 100 g meat alternatives; only up to 1 portion of red meat (not processed meat), 1 portion of legumes or nuts and 1 portion of dairy or alternatives allowed per day.
[6] Quantification and portion size based on SACN advice[(25)]; portion size 140 g cooked fish.
[7] Represents food group from the UK *Eatwell Guide*[(31)]; quantification based on portions required to meet proposed calcium recommendations; low fat milk, low fat yoghurt, reduced fat or low fat cheese only, no other dairy included nor dairy alternatives; high fat dairy if BMI <18.5 kg/m^2; portion sizes based on standard portions[(41)]: 250 mL milk, 30 g cheese, 125 g yoghurt; 1 portion of cheese allowed per day.
[8] Portion sizes based on standard portions[(41)]: 190 g cooked pasta, rice or grains, 80 g bread or crackerbreads, 30 g breakfast cereals or flour.
[9] Quantification based on our previously proposed nutritional recommendations[(27)].
[10] Foods chosen are main contributors to free sugar intake in NDNS; portion sizes based on average available portions: 40 g cakes, biscuits or cereal bars, 100 g buns, pastries, pancakes, dairy desserts and sponge puddings, 20 g confectionery or sweet preserves, 330 mL sugar sweetened beverages, 15 g sugar.
[11] Foods chosen are main contributors to sodium intake in NDNS; portion sizes based on average available portions or standard portion sizes[(43)]: 25 g salty savoury snacks, crisps or salted nuts, 70 g processed meat.
[12] Based on cooking oils and spreads; percentage of spreads and oils predominantly comprised of unsaturated fatty acids; unsaturated oils and spreads defined as having fat composition of (MUFA+PUFA)/SFA≥2; percentage calculated as proportion of MUFA/PUFA oils and spreads out of total oils and spreads; score of 5 assigned if no cooking oils or spreads used.
[13] Portion sizes based on the UK *Eatwell Guide* recommendations[(31)]: 250 mL; only up to 150 mL portion of fruit or vegetable juice allowed according to the UK *Eatwell Guide*[(31)]; not including alcohol or sugar sweetened beverages.
[14] 1 portion equals 1 alcohol unit[(42)]: 75 mL wine, 220 mL beer, lager, cider or alcoholic soft drinks, 25 mL spirits, liqueurs or fortified wine; not including low or no alcohol versions.
[15] Quantification based on *UK physical activity guidelines*[(30)]; includes walking, cycling, swimming, dancing, gardening, and other active leisure pursuits.
[16] Represented as % total energy intake; based on non-milk extrinsic sugars where free sugars not available.
[17] No lower limit set as recommendation to increase sodium intake only justified based on diagnosis of low blood electrolytes; represented as mg/day; adjusted to account for underreporting in analysis based on average underreporting in NDNS sample compared to urinary sodium; adjusted score based on 10 points for ≤2000 mg/day and 0 points for ≤2800 mg/day.
[18] Component split into two parts
[19] Ratio determined by recommended relative % contribution to energy intake for MUFA, PUFA and SFA.
[20] Represented as g/day; 1 unit is 8 g alcohol.
[21] Component not included in NFDQI-65.
[22] Total score for NFDQI-65 110 points.

Table 2. Characteristics of study population from UK NDNS[1].

Characteristic	Total (*n* = 871)
Male (%)	44.2
Age (year)	73.6±6.6
Age group (%)	
65-79 years	80.1
≥80 years	19.9
BMI category (%)	
Underweight <18.5kg/m^2	0.9
Healthy 18.5-24.99kg/m^2	24.0
Overweight 25-29.9kg/m^2	37.6
Obese ≥30kg/m^2	24.9
Not available	12.6
Ethnicity (%)	
White	96.8
Mixed ethnic group	0.8
Black or Black British	0.7
Asian or Asian British	0.9
Any other group	0.9
Smoking (%)	
Current smoker	9.8
Ex-regular smoker	39.2
Never regular smoker	51.0
Education (%)	
Degree or equivalent	11.6
Higher education, below degree level	6.1
GCE, A level, or equivalent	6.8
GCSE A*-C or equivalent	15.8
GCSE grades D-G, commercial qualifications or apprenticeship	3.3
Foreign or other qualifications	11.3
No qualifications	44.0
Refused	1.2
Income (%)	
≤£10,000	4.4
>£10,000-£20,000	33.2
>£20,000-£40,000	29.8
>£40,000	10.8
Not available	21.9
Marital status (%)	
Married	58.7
Widowed	21.0
Divorced	3.1
Separated	12.9
Never married	4.3
Vegetarian (%)	
Vegetarian	1.0
Vegan	0.3
Neither	98.7
Supplement use (%)	40.5

[1] Values for continuous variables are $\bar{x} \pm SD$ and values for categorical variables are percentages of subjects within each category; NDNS interviewer weights applied; BMI, body mass index; NDNS, National Diet and Nutrition Survey.

Table 3. Association between DQI-65 s, HEI-2015 and AHEI-2010 scores and odds of meeting nutritional recommendations for subjects aged ≥65y from UK NDNS years 2-6 (*n*=871)[1]

Nutrient	Recommendation[2]	Mean (SD)	Proportion meeting recommend dations (%)	FDQI-65+PA		NFDQI-65+PA		NFDQI-65		HEI-2015		AHEI-2010	
				OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Carbohydrate[3]	50% total energy	45.8 (6.8)	79.9	1.00 (0.95,1.06)	0.969	1.13 (1.07,1.20)	<0.001	1.16 (1.10,1.23)	<0.001	1.10 (1.04,1.17)	0.002	1.05 (0.98,1.14)	0.193
Free sugars[4]	≤5% total energy	11.0 (5.6)	13.8	1.11 (1.04,1.19)	0.001	1.26 (1.18,1.36)	<0.001	1.29 (1.19,1.38)	<0.001	1.11 (1.03,1.19)	0.006	1.16 (1.10,1.22)	<0.001
Protein[5]	≥1.2 g/kg body weight/day	1.0 (0.3)	18.8	1.23 (1.16,1.31)	<0.001	1.30 (1.22,1.40)	<0.001	1.31 (1.22,1.40)	<0.001	1.18 (1.11,1.26)	<0.001	1.10 (1.03,1.18)	0.007
Fat	≤33% total energy	33.8 (5.9)	44.8	1.15 (1.10,1.20)	<0.001	1.23 (1.17,1.29)	<0.001	1.23 (1.17,1.29)	<0.001	1.47 (1.39,1.56)	<0.001	1.31 (1.22,1.41)	<0.001
SFA	≤10% total energy	13.2 (3.4)	17.8	1.18 (1.11,1.25)	<0.001	1.30 (1.22,1.39)	<0.001	1.31 (1.22,1.40)	<0.001	1.97 (1.79,2.17)	<0.001	0.85 (0.80,0.90)	<0.001
Trans fatty acids[6]	≤2% total energy	0.6 (0.3)	100	-	-	-	-	-	-	-	-	-	-
MUFA[3]	12% total energy	11.8 (2.4)	66.3	0.91 (0.87,0.95)	<0.001	0.91 (0.87,0.96)	<0.001	0.90 (0.86,0.95)	<0.001	0.85 (0.81,0.90)	<0.001	0.85 (0.80,0.90)	<0.001
PUFA[3]	6% total energy	9.2 (2.8)	66.9	0.90 (0.86,0.95)	<0.001	0.87 (0.83,0.92)	<0.001	0.87 (0.83,0.92)	<0.001	0.84 (0.80,0.89)	<0.001	0.80 (0.75,0.85)	<0.001
AOAC fibre[7]	≥30 g/day	18.5 (6.5)	5.9	1.51 (1.35,1.70)	<0.001	1.32 (1.18,1.46)	<0.001	1.29 (1.16,1.44)	<0.001	1.34 (1.20,1.49)	<0.001	1.28 (1.15,1.44)	<0.001
Calcium	≥1000 mg/day	835 (300)	21.0	1.28 (1.21,1.36)	<0.001	1.22 (1.15,1.29)	<0.001	1.19 (1.12,1.26)	<0.001	1.05 (0.99,1.11)	0.135	1.07 (1.00,1.14)	0.038
Sodium[8]	≥1600 mg/day ≤2400 mg/day	1980 (685)	47.3	1.00 (0.96,1.05)	0.865	1.15 (1.10,1.20)	<0.001	1.20 91.14,1.26)	<0.001	1.16 (1.10,1.22)	<0.001	1.15 (1.09,1.22)	<0.001
Potassium	≥3500 mg/day	2830 (772)	17.7	1.51 (1.40,1.62)	<0.001	1.37 (1.28,1.47)	<0.001	1.32 (1.23,1.42)	<0.001	1.32 (1.23,1.42)	<0.001	1.22 (1.14,1.31)	<0.001
Iron	≥8.7 mg/day	10.1 (3.2)	59.7	1.28 (1.22,1.34)	<0.001	1.25 (1.19,1.32)	<0.001	1.22 (1.16,1.29)	<0.001	1.24 (1.18,1.31)	<0.001	1.13 (1.07,1.19)	<0.001
Zinc	≥9.5 mg/day (men) ≥7 mg/day (women)	8.2 (2.5)	48.3	1.28 (1.22,1.34)	<0.001	1.23 (1.17,1.29)	<0.001	1.22 (1.16,1.28)	<0.001	1.13 (1.08,1.19)	<0.001	1.01 (0.96,1.06)	0.733
Vitamin A	≥700 µg/day (men) ≥600 µg/day (women)	1270 (1510)	49.9	1.10 (1.06,1.15)	<0.001	1.09 (1.05,1.15)	<0.001	1.10 (1.05,1.16)	<0.001	1.05 (1.00,1.10)	0.058	1.07 (1.01,1.13)	0.015
Vitamin C	≥40 mg/day	82.1 (48.5)	80.4	1.70 (1.57,1.83)	<0.001	1.69 (1.57,1.83)	<0.001	1.62 (1.50,1.75)	<0.001	1.67 (1.54,1.81)	<0.001	1.28 (1.19,1.37)	<0.001

Vitamin D	≥10 µg/day	3.4 (2.3)	1.7	1.73 (1.38,2.16)	<0.001	1.46 (1.20,1.79)	<0.001	1.41 (1.16,1.73)	0.001	1.16 (0.96,1.40)	0.135	1.06 (0.86,1.29)	0.605
Vitamin E	≥4 mg/day (men) ≥3 mg/day (women)	8.8 (3.5)	98.0	1.63 (1.36,1.96)	<0.001	1.75 (1.43,2.13)	<0.001	1.75 (1.44,2.13)	<0.001	1.59 (1.30,1.95)	<0.001	1.35 (1.10,1.66)	0.004
Folate	≥400 µg/day	256 (100)	8.5	1.37 (1.26,1.50)	<0.001	1.25 (1.15,1.37)	<0.001	1.23 (1.13,1.35)	<0.001	1.27 (1.16,1.39)	<0.001	1.09 (1.00,1.20)	0.063
Vitamin B12	≥2.4 µg/day	6.5 (5.2)	93.0	1.20 (1.10,1.31)	<0.001	1.14 (1.04,1.25)	0.005	1.15 (1.05,1.26)	0.003	1.05 (0.95,1.15)	0.359	0.98 (0.88,1.09)	0.699
Vitamin B6	≥1.4 mg/day (men) ≥1.2 mg/day (women)	2.0 (0.8)	86.5	1.47 (1.36,1.58)	<0.001	1.40 (1.30,1.50)	<0.001	1.35 (1.25,1.45)	<0.001	1.45 (1.34,1.57)	<0.001	1.08 (1.00,1.17)	0.053
Alcohol	≤14 alcohol units/week	7.9 (12.8)	78.1	0.91 (0.86,0.96)	<0.001	1.15 (1.09,1.22)	<0.001	1.25 (1.18,1.33)	<0.001	0.93 (0.87,0.98)	0.010	0.96 (0.90,1.02)	0.182

[1] Values are OR of meeting recommendations based on a 5% increase in DQI-65, AHEI-2010 or HEI-2015 total score; two models presented; maximum scores available 120 points (NFDQI-65, AHEI-2010 and HEI-2015 scores adjusted to maximum 120 points prior to analysis for comparison); P-values for significance of OR by logistic regression (NDNS interviewer weights applied); % energy intake refers to total energy; AHEI-2010, Alternative Healthy Eating Index-2010; AOAC, Association of Analytical Chemists; CI, confidence intervals; DQI-65, Diet Quality Index for older adults; FDQI-65+PA, Food-based Diet Quality Index for older adults with physical activity; HEI-2015, Healthy Eating Index-2015; MUFA, monounsaturated fatty acids; NDNS, National Diet and Nutrition Survey; NFDQI-65, Nutrient and Food-based Diet Quality Index for older adults; NFDQI-65+PA, Nutrient and Food-based Diet Quality Index for older adults with physical activity; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids.

[2] Recommendations based on nutritional requirements for UK adults ≥65y proposed in our recent review[27].

[3] Nutrient recommendations set as population average; meeting recommendations classified as within ±20% of recommendation: carbohydrates 45-55% total energy, MUFA 10.4-15.6% total energy, PUFA 4.8-7.2% total energy.

[4] Free sugars represented by non-milk extrinsic sugars from NDNS.

[5] Results from 800 subjects due to non-response for body weight measurement.

[6] No association reported as all subjects meeting recommendations for trans fatty acids.

[7] Nutrient intake approximate conversion from non-starch polysaccharide fibre to AOAC; conversion factor 1.33 as used in NDNS[54].

[8] Adjusted for underreporting in analysis based on average underreporting of 25% in NDNS from comparison with urinary sodium; meeting recommendations based on 1200 mg/day-2000 mg/day instead of 1600 mg/day-2400 mg/day.

2.0 ± 0.8

Table 4. Association between DQI-65s, HEI-2015 and AHEI-2010 scores and biomarkers of nutrient intake for subjects aged ≥65y from UK NDNS years 2-6[1]

Biomarkers of nutrient intake	Mean ± SD	FDQI-65+PA		NFDQI-65+PA		NFDQI-65		HEI-2015		AHEI-2010	
		B (95% CI)	P value	B (95% CI)	P value	B (95% CI)	P value	B (95% CI)	P value	B (95% CI)	P value
Serum vitamin B12[2,3] **(pmol/L)**	270 ± 103	0.01 (0.00,0.02)	0.125	0.01 (0.00,0.01)	0.037	-0.01 (-0.04,0.01)	0.310	0.00 (-0.01,0.01)	0.786	0.00 (-0.01,0.01)	0.969
Plasma 25-hydroxy Vitamin D[4] **(nmol/L)**	44.7 ± 20.5	0.33 (-1.05,1.71)	0.637	0.62 (-0.27,1.51)	0.172	-3.60 (-6.79,-0.40)	0.027	0.63 (-0.61,1.88)	0.319	-0.89 (-2.04,0.26)	0.130
Haemoglobin concentration [5] **(g/dL)**	13.7 ± 1.4	0.11 (0.01,0.21)	0.025	0.02 (-0.05,0.08)	0.600	-0.14 (-0.36,0.08)	0.220	0.01 (-0.08,0.10)	0.771	-0.13 (-0.21,-0.05)	0.002
Plasma total homocysteine[2,6] **(µmol/L)**	11.0 ± 4.5	-0.02 (-0.03,-0.01)	<0.001	-0.02 (-0.02,-0.01)	<0.001	-0.01 (-0.02,-0.01)	<0.001	-0.01 (-0.02,-0.01)	0.001	-0.01 (-0.02,0.00)	0.067
Plasma α-tocopherol[7] **(µmol/L)**	28.3 ± 6.9	0.18 (-0.29,0.65)	0.454	0.05 (-0.25,0.35)	0.759	1.42 (0.34,2.50)	0.010	0.37 (-0.06,0.80)	0.089	0.47 (0.08,0.86)	0.018
Plasma β-carotene[2,8] **(µmol/L)**	0.5 ± 0.4	0.03 (0.01,0.04)	<0.001	0.03 (0.02,0.04)	<0.001	0.03 (0.02,0.04)	<0.001	0.03 (0.02,0.04)	<0.001	0.03 (0.01,0.04)	<0.001

[1] Values are unstandardised B coefficients for continuous variables of change in dependent variable intake with a 5% increase in DQI-65, AHEI-2010 or HEI-2015 total score and OR for categorical variables indicating odds of health outcome based on a 5% increase in DQI-65, AHEI-2010 or HEI-2015 total score; maximum score available 120 points (FNDQI-65 no PA, AHEI-2010, HEI-2015 scores adjusted to maximum 120 points for comparison); P-values are test for significance of relationship between DQI-65, AHEI-2010 or HEI-2015 score and nutrient intake by linear regression for continuous variables or significance of OR by logistic regression for categorical variables; NDNS blood weights applied; most adjusted model presented; model 3 adjusted for age, sex, BMI, waist circumference, supplement use (and iron medication), education, marital status and income; AHEI-2010, Alternative Health Eating Index-2010; CI, confidence intervals; DQI-65, Diet Quality Index for older adults; FDQI-65+PA, Food-based Diet Quality Index for older adults with physical activity; HEI-2015, Healthy Eating Index-2015; NDNS, National Diet and Nutrition Survey; NFDQI-65, Nutrient and Food-based Diet Quality Index for older adults; NFDQI-65+PA, Nutrient and Food-based Diet Quality Index for older adults with physical activity; OR, odds ratio.

[2] Dependent variable transformed by $\log_{10}$ to improve normality; unstandardised B coefficient and CI are log-increase in variable by 5% increase in total score.

[3] *n*=382

[4] *n*=374
[5] *n*=326
[6] *n*=306
[7] *n*=378
[8] *n*=377

Table 4. Associations between DQI-65s, HEI-2015 and AHEI-2010 scores and health status measures and metabolic markers for subjects aged ≥65y from UK NDNS years 2-6[1]

Health marker	Mean ± SD	FDQI-65+PA		NFDQI-65+PA		NFDQI-65		HEI-2015		AHEI-2010	
		B (95% CI)	P value	B (95% CI)	P value	B (95% CI)	P value	B (95% CI)	P value	B (95% CI)	P value
BMI[2] (kg/m²)	27.8 ± 5.0	-0.20 (-0.33,-0.07)	0.003	-0.29 (-0.42,-0.15)	<0.001	-0.25 (-0.38,-0.11)	<0.001	-0.26 (-0.40,-0.13)	<0.001	-0.30 (-0.45,-0.16)	<0.001
Waist circumference[3] (cm)	96.3 ± 13.4	-0.20 (-0.39,-0.02)	0.030	-0.90 (-1.24,-0.56)	<0.001	-0.80 (-1.15,-0.44)	<0.001	-0.99 (-1.36,-0.62)	<0.001	-0.98 (-1.38,-0.58)	<0.001
Number of prescribed medicines[4,16]	4.3 ± 2.8	-0.25 (-0.34,-0.17)	<0.001	-0.22 (-0.30,-0.14)	<0.001	-0.10 (-0.20,-0.01)	0.002	-0.19 (-0.28,-0.09)	<0.001	-0.14 (-0.24,-0.04)	0.005
SBP[5] (mmHg)	135 ± 16.8	-0.01 (-0.58,0.56)	0.966	-0.03 (-0.62,0.55)	0.910	-0.19 (-0.79,0.42)	0.549	0.52 (-0.10,1.14)	0.102	0.56 (-0.11,1.23)	0.101
DBP[5] (mmHg)	71.4 ± 9.9	-0.07 (-0.40,0.25)	0.664	-0.58 (-0.91,-0.25)	0.001	-0.77 (-1.11,-0.43)	<0.001	-0.14 (-0.50,0.21)	0.430	-0.27 (-0.65,0.11)	0.168
TC[6] (mmol/L)	5.1 ± 1.2	0.03 (-0.02,0.07)	0.240	0.00 (-0.05,0.04)	0.951	0.00 (-0.05,0.05)	0.934	0.00 (-0.05,0.05)	0.978	0.01 (-0.04,0.06)	0.691
LDL-C[7,15] (mmol/L)	3.1 ± 1.1	0.01 (0.00,0.01)	0.106	0.00 (0.00,0.01)	0.400	0.00 (0.00,0.01)	0.536	0.00 (-0.01,0.01)	0.761	0.00 (-0.01,0.01)	0.628
HDL-C[6,15] (mmol/L)	1.5 ± 0.5	0.01 (0.00,0.01)	0.012	0.00 (0.00,0.01)	0.666	0.00 (-0.01,0.01)	0.909	0.00 (0.00,0.01)	0.279	0.00 (0.00,0.01)	0.230
TC:HDL-C ratio[6,15]	3.5 ± 1.0	0.00 (-0.01,0.00)	0.112	0.00 (-0.01,0.01)	0.739	0.00 (-0.01,0.01)	0.950	0.00 (-0.01,0.00)	0.282	0.00 (-0.01,0.00)	0.420
TG[7,15] (mmol/L)	1.2 ± 0.6	-0.01 (-0.02,0.00)	0.004	-0.01 (-0.02,0.00)	0.055	-0.01 (-0.02,0.00)	0.069	-0.01 (-0.02,0.00)	0.023	-0.01 (-0.02,0.00)	0.059

CRP[8,15,16] (mg/L)	4.7 ± 7.4	-0.04 (-0.06,-0.02)	<0.001	-0.06 (-0.08,-0.05)	<0.001	-0.04 (-0.06,-0.02)	<0.001	-0.06 (-0.07,-0.04)	<0.001	-0.05 (-0.07,-0.03)	<0.001
Fasting glucose[9, 16] (mmol/L)	5.3 ± 0.9	-0.01 (-0.05,0.03)	0.511	0.00 (-0.05,0.04)	0.869	0.01 (-0.04,0.05)	0.831	0.00 (-0.04,0.04)	0.953	0.03 (-0.02,0.07)	0.274
HbA1c[10, 16] (%)	5.8 ± 0.4	0.00 (-0.02,0.02)	0.821	0.01 (-0.01,0.03)	0.451	0.01 (-0.01,0.03)	0.507	0.01 (-0.01,0.03)	0.352	0.01 (-0.01,0.03)	0.420

Health marker	**Proportion meeting criteria (%)**	**FDQI-65+PA**		**NFDQI-65+PA**		**NFDQI-65**		**HEI-2015**		**AHEI-2010**	
		OR (95% CI)	**P value**	**OR (95% CI)**	**P value**	**OR (95% CI)**	**P value**	**OR (95% CI)**	**P value**	**OR (95% CI)**	**P value**
Self-assessed health[12] Good or very good	72.2	1.18 (1.08,1.29)	<0.001	1.12 (1.03,1.22)	0.010	1.03 (0.95,1.13)	0.471	1.14 (1.04,1.24)	0.005	0.98 (0.89,1.09)	0.748
		1.19 (1.08,1.31)	<0.001	1.12 (1.02,1.23)	0.022	1.05 (0.96,1.16)	0.301	1.15 (1.05,1.27)	0.004	1.00 (0.90,1.12)	0.960
Longstanding illness[12]	59.4	0.95 (0.88,1.02)	0.155	0.92 (0.85,0.99)	0.036	0.98 (0.91,1.06)	0.581	0.95 (0.88,1.03)	0.204	1.01 (0.93,1.10)	0.841
Activities limited due to illness[13, 16]	56.1	0.94 (0.85,1.04)	0.244	0.93 (0.84,1.03)	0.150	1.00 (0.90,1.11)	0.958	0.92 (0.83,1.01)	0.086	0.96 (0.86,1.08)	0.530
Hypertension[5] SBP >140 mmHg or DBP >90 mmHg or Taking BP lowering medication	57.2	1.01 (0.92,1.10)	0.888	1.06 (0.97,1.16)	0.199	1.05 (0.96,1.16)	0.271	1.06 (0.96,1.16)	0.239	1.03 (0.93,1.14)	0.612
Metabolic syndrome[14] ≥3 of the following: Waist circumference >102cm (men) and >88cm (women) TG >1.7mmol/L HDL-C <1.03 (men) and <1.29mmol/L (women) BP >130/85mmHg Fasting glucose >6.1mmol/L	11.9	0.73 (0.59,0.90)	0.003	0.84 (0.69,1.02)	0.080	0.87 (0.71,1.06)	0.168	0.82 (0.67,1.01)	0.062	0.79 (0.63,1.00)	0.052

[1] Values are unstandardised B coefficient for continuous variables of change in dependent variable intake with a 5% increase in DQI-65, AHEI-2010 or HEI-2015 total score and OR for categorical variables indicating odds of health outcome based on a 5% increase in DQI-65, AHEI-2010 or HEI-2015 total score; maximum score available 120 points (NFDQI-65 no PA, AHEI-2010, HEI-2015 scores adjusted to maximum 120 points for comparison); P-values are test for significance of relationship between DQI-65 or HEI-2010 score and nutrient intake by linear regression for continuous variables or significance of OR by logistic regression for categorical variables; fully adjusted model(s) presented; AHEI-2010, Alternative Healthy Eating Index-2010; BMI, body mass index; CI, confidence intervals; CRP, C-reactive protein; DBP, diastolic blood pressure; DQI-65, Diet Quality Index for older adults; FDQI-65+PA, Food-based Diet Quality Index for older adults with physical activity; HbA1C, glycated haemoglobin; HDL-

C, high-density lipoprotein cholesterol; HEI-2015, Healthy Eating Index-2015; LDL-C, low-density lipoprotein cholesterol; NDNS, National Diet and Nutrition Survey; NFDQI-65, Nutrient and Food-based Diet Quality Index for older adults; NFDQI-65+PA, Nutrient and Food-based Diet Quality Index for older adults with physical activity; OR, odds ratio; SBP, systolic blood pressure; TG, triacylglycerols; TC, total cholesterol.

[2] *n*=767; NDNS interviewer weights applied; adjusted for age, sex, smoking, education, marital status and income.

[3] *n*=566; NDNS nurse weights applied; adjusted for age, sex, BMI, smoking, education, marital status and income.

[4] *n*=471; NDNS nurse weights applied.

[5] *n*=419; NDNS nurse weights applied; adjusted for age, sex, BMI, waist circumference, blood pressure medication (for SBP and DBP), smoking, education, marital status and income.

[6] *n*=333; NDNS blood weights applied; adjusted for age, sex, BMI, waist circumference, lipid medication, smoking, education, marital status and income.

[7] *n*=330; NDNS blood weights applied; adjusted for age, sex, BMI, waist circumference, lipid medication, smoking, education, marital status and income.

[8] *n*=381; NDNS blood weights applied.

[9] *n*=336; known diabetics excluded; NDNS blood weights applied.

[10] *n*=333; known diabetics excluded; NDNS blood weights applied.

[11] *n*=443; NDNS nurse weights applied.

[12] *n*=451; NDNS interviewer weights applied; adjusted for age, sex, BMI, waist circumference, smoking, education, marital status and income; model 4 (self-assessed health only) adjusted for age, sex, BMI, waist circumference, smoking, education, marital status, income and longstanding illness.

[13] *n*=291; NDNS interviewer weights applied.

[14] *n*=321; subjects included if 5 variables available or ≥3 variables available when ≥3 variables meet criteria for metabolic syndrome; NDNS blood weights applied; adjusted for age, sex, BMI, blood pressure medication, lipid medication, smoking, education, marital status and income.

[15] log10 transformation applied to improve normality; unstandardized B coefficient and CI is log-increase in variable by 5% change in dietary score.

[16] Adjusted for age, sex, BMI, waist circumference, smoking, education, marital status and income.

Figure 1. Mean ± SEM score per component of FDQI-65+PA and NFDQI-65+PA calculated using data for adults aged ≥65y from UK National Diet and Nutrition Survey (NDNS) rolling programme Years 2-6 (n=871). NFDQI-65 component scores identical to NFDQI-65+PA, except for physical activity which is not included in the NFDQI-65. Maximum score of 10 available per component. NDNS interviewer weights applied. FDQI-65+PA, Food-based Diet Quality Index for older adults with physical activity; NFDQI-65, Nutrient and Food-based Diet Quality Index for older adults; NFDQI-65+PA, Nutrient and Food-based Diet Quality Index for older adults with physical activity.

Figure 2. Mean ± SEM score per component of HEI-2015 calculated using data for adults aged ≥65y from UK National Diet and Nutrition Survey (NDNS) rolling programme Years 2-6 (n=871). Maximum score of 5 available for fruit, whole fruit, vegetables, greens and beans, total protein, and seafood and plant protein components. Maximum score of 10 available for wholegrains, dairy, fatty acids, refined grains, sodium, added sugars and SFA components. NDNS interviewer weights applied. HEI-2015, Healthy Eating Index-2015.

Figure 3. Mean ± SEM score per component of AHEI-2010 calculated using data for adults aged ≥65y from UK National Diet and Nutrition Survey (NDNS) rolling programme Years 2-6 (n=871). Maximum score of 10 available per component. NDNS interviewer weights applied. AHEI-2010, Alternative Healthy Eating Index-2010.