Prospective associations of the original Food Standards Agency nutrient profiling system and three variants with weight gain, overweight and obesity risk: results from the French NutriNet-Santé cohort

Manon Egnell, Louise Seconda, Bruce Neal, Cliona Ni Mhurchu, Mike Rayner, Alexandra Jones, Mathilde Touvier, Emmanuelle Kesse-Guyot, Serge Hercberg, Chantal Julia

Author’s Affiliations
- Sorbonne Paris Cité Epidemiology and Statistics Research Center (CRESS), U1153 Inserm, U1125, Inra, Cnam, Paris 13 University, Nutritional Epidemiology Research Team (EREN), Bobigny, France (ME, LS, MT, EKG, SH, CJ)
- The George Institute for Global Health, Faculty of Medicine, UNSW Sydney, Sydney, New South Wales, Australia (BN, CNM, AJ)
- The Charles Perkins Centre, University of Sydney, Sydney, New South Wales, Australia (BN, AJ)
- Division of Epidemiology and Biostatistics, Imperial College London, London, United Kingdom (BN)
- National Institute for Health Innovation, University of Auckland, Auckland 1072, New Zealand (CNM)
- ADEME (Agence de l’Environnement et de la Maîtrise de l’Energie), 20 avenue du Grésillé BP 90406, 49004 Angers, France (LS)
- Public health department, Avicenne Hospital, Assistance Publique des Hôpitaux de Paris (AP-HP), Bobigny, France (SH, CJ)
Names for PubMed indexing

Egnell, Seconda, Neal, Ni Mhurchu, Rayner, Jones, Touvier, Kesse-Guyot, Hercberg, Julia

Corresponding author information

Manon Egnell: Sorbonne Paris Cité Epidemiology and Statistics Research Center (CRESS), U1153 Inserm, U1125, Inra, Cnam, Paris 13 University, Nutritional Epidemiology Research Team (EREN), 93017 Bobigny, France, 01 48 38 89 68, m.egnell@eren.smbh.univ-paris13.fr

Sources of support

The present study was funded by the New Zealand Ministry for Primary Industries. The NutriNet-Santé study is funded by: French Ministry of Health and Social Affairs, Santé Publique France, Institut National de la Santé et de la Recherche Médicale, Institut National de la Recherche Agronomique, Conservatoire National des Arts et Métiers, and Paris 13 University.

Short running head

Associations of nutrient profiling with weight

Abbreviations

BMI: Body Mass Index
CI: Confidence Interval
DI: Dietary Index
FSA: Food Standards Agency
HCSP: Haut Conseil de Santé Publique (High Council of Public Health)
HR: Hazard Ratio
HSR: Health Star Rating

NPS: Nutrient Profiling System

NPSC: Nutrient Profiling System Criterion
ABSTRACT

Background: Nutrient Profiling Systems (NPSs), including the UK Food Standards Agency (FSA) NPS and its variants, are frequently used to classify foods according to their nutritional composition, for reasons related to preventing diseases and promoting health. However, the validity of these NPSs requires further investigation, especially regarding their prospective associations with health.

Objective: The study aimed to investigate the associations of the original FSA-NPS and three variants – the Food Standards Australia New Zealand Nutrient Profiling Scoring Criterion (NPSC), the Health Star Rating system NPS (HSR-NPS) and the French NPS (HCSP-NPS) –, with weight status.

Design: Dietary Indices (DIs) based on each of the four investigated NPSs applied at the food level were computed at the individual level to characterize the dietary quality of 71,178 French individuals from the NutriNet-Santé cohort study. Associations of these four indices (coded as tertiles) with weight gain were assessed using multivariable mixed models for repeated measures, and with overweight and obesity risks using multivariable Cox models.

Results: For the four NPSs, participants with a higher dietary index (reflecting lower diet nutritional quality) were more likely to have an increase in body mass index over time (median follow-up of 3.14 ± 2.76 years, beta coefficients positive, all p≤0.0001), and an increased risk of overweight (HR_{T3vs.T1}=1.27 [1.17-1.37] for the French HCSP-DI, followed by the original FSA-DI with HR_{T3vs.T1}=1.18 [1.09-1.28], the NPSC-DI with HR_{T3vs.T1}=1.14 [1.06-1.24] and the HSR-DI, HR_{T3vs.T1}=1.12 [1.04-1.21]). Whilst differences were small, the
HCSP-DI appeared to show significantly greater association with risk of overweight compared to other NPS.

Conclusions: Less healthy diets defined using the FSA-NPS and related systems were all associated with weight gain and overweight risk. Demonstrating this association with health outcomes is an important indicator of the validity of NPSs and supports their use in public policies for the prevention of diet-related chronic diseases.

Keywords: Nutritional quality, nutrient profiles, weight status, cohort, nutrition policy
Non-Communicable Diseases (NCDs) are now the biggest cause of deaths worldwide, representing an important burden for individuals, governments and societies (1). Overweight and obesity are major risk factors for a number of NCDs, including cardiovascular diseases, diabetes and cancers. In 2016, 39% of adults developed an overweight and 13% an obesity worldwide, a prevalence which has almost tripled since 1975 (2). Nutrition-related behaviours implicated in the onset of overweight or obesity include both individual and environmental determinants that can be targeted through primary prevention interventions (1,3). In this context, public health authorities are implementing policies that promote healthier diets, including for example front-of-pack nutrition labelling, taxes on unhealthy foods, regulation of health and nutrition claims, restrictions on advertising to children, and programs which promote healthier product reformulation (4).

Nutrient profiling, defined as ‘the science of categorising or ranking foods according to their nutritional composition’, allows characterization of different food products as more or less healthy (5). Nutrient profiling relies on two assumptions: (i) the health of individuals is related to healthiness of the diet, and (ii) the healthiness of the diet is in turn affected by the healthiness of the foods included in the diet (6). Nutrient profiling is frequently used to underpin policies to promote healthier diets (7,8). A logic pathway has been proposed by Sacks et al. to summarize the impact of public polices relying on Nutrient Profiling Systems (NPSs) on health outcomes (7). The effect of polices should modify the food environment and the eating behaviour of populations, thus impacting weight and body mass index through a modification of dietary and energy intakes.
In 2004, a NPS was developed in the United Kingdom by the Food Standards Agency (FSA-NPS) for the purpose of regulating advertising to children (9). The NPS assigns a score for the overall nutritional quality of a food, balancing components which should be limited in the diet (i.e. energy, saturated fats, sugars, sodium) with components that are encouraged to be consumed (i.e. proteins, fibres, fruits, vegetables and nuts). The original FSA-NPS has been validated in several studies, demonstrating its ability to discriminate the nutritional quality of food products and its applicability in public health measures (5,6,10–12). Later, adaptations of this system were made for specific applications in other jurisdictions. In 2013, the Nutrient Profiling Scoring Criteria (NPSC) developed by the Food Standards Australia New Zealand was incorporated into legislation in Australia and New Zealand for the purposes of determining whether or not a product is eligible to display a health claim (13). In 2014, it was adapted further in Australia and New Zealand by a multi-stakeholder committee to underpin the government-endorsed voluntary Health Star Rating front-of-pack nutrition labelling system (HSR-NPS). In France, it has also been adapted for use in front-of-pack labelling, by the High Council of Public Health for the Nutri-Score system (HCSP-NPS).

In the validation process of NPSs, and especially in the framework of NCDs prevention, it appears essential to investigate the potential association of these NPSs with health. An individual Dietary Index (DI) directly based on the original FSA-NPS (FSA-DI) applied at the food level has been developed to reflect the overall nutritional quality of the diet at an individual level (14), and then adapted to correspond to the HCSP-NPS. It has been shown that a higher dietary index based on this latter NPS, reflecting a lower overall diet nutritional quality, was associated with an increased risk of various adverse health outcomes in different French and European cohorts (e.g. cancers, cardiovascular diseases, metabolic syndrome, weight gain) (15–21).
No study has simultaneously investigated the associations of the original FSA-NPS and its derivatives with health outcomes and specifically, weight status.

The present study aimed to investigate four nutrient profiling systems (original FSA-NPS, NPSC, HSR-NPS and French HCSP-NPS) and their associations with weight gain, overweight (including obesity) and obesity, in a large cohort of French participants from the general population.

SUBJECTS AND METHODS

Population study

Participants of the present study were recruited from the NutriNet-Santé cohort, launched in France in 2009 to investigate the associations between nutrition and health as well as the determinants of dietary behaviours and nutritional status. The NutriNet-Santé study has been described in detail elsewhere (22). At inclusion and during the follow-up, participants are invited to complete a set of questionnaires on a dedicated website, including data on dietary intakes (repeated 24h dietary records), anthropometric measurements, health events, sociodemographic characteristics and physical activity (IPAQ questionnaire (23)).

Sociodemographic data collected at baseline included sex, age, educational level, level of monthly income, marital status, and smoking status (24). The NutriNet-Santé study is conducted according to the Declaration of Helsinki guidelines. It was approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB Inserm n°0000388FWA00005831) and the "Commission Nationale de l’Informatique et des Libertés" (CNIL n°908450/n°909216). The NutriNet-Santé study is registered in
ClinicalTrials.gov (NCT03335644). Electronic informed consent is obtained from each participant.

**Anthropometric measurements**

At inclusion and each year of the follow-up, participants are invited to self-report information on height and weight. Web-based self-reported anthropometrics have been demonstrated to be valid against a traditional paper- and pencil- anthropometrics questionnaire (25) and face-to-face declarations, using notably Kappa statistics and percent agreement (i.e., concordance) (26). BMI was calculated as the ratio of weight in kilograms to the square of height in meters (kg/m²). Overweight (including obesity) was defined by the World Health Organization as BMI ≥ 25 kg/m², and obesity as BMI ≥ 30 kg/m² (27).

**Dietary data**

At inclusion, participants were invited to complete three non-consecutive web-based dietary 24h-records, randomly assigned over a two-week period (two weekdays and one week-end day), which have been tested and validated against an interview by a trained dietitian and against blood and urinary biomarkers (25,28,29). Participants were asked to declare all foods and beverages consumed during the main meals or any eating occasion on the recording day, and self-estimate portions using validated photographs, usual containers or specific quantity (30). Mean daily intakes were estimated using a published French food composition database (31). Amounts consumed from composite dishes were estimated using French recipes validated by food and nutrition professionals. Dietary underreporting was identified on the basis of the method proposed by Black, using the basal metabolic rate and Goldberg cut-off (with a value of Physical Activity Level PAL=1.55), and energy under-reporters were excluded from the analyses (N=14,170) (32).
Nutrient profiling systems (at the food level)

The four NPSs investigated in the present study and their methods of calculation are described in detail in Supplemental Material 1.

The original Food Standards Agency Nutrient Profiling System (original FSA-NPS)

The original FSA score, developed in 2004-2005 in order to regulate advertising to children in the United Kingdom, relies on a scoring system based on the nutritional composition of a food or beverage per 100g/100ml. At the food level, the algorithm allocates positive points, from 0 to 10, for the amount of unfavourable nutrients (energy (kJ), saturated fat (g), total sugars (g) and sodium (mg)), yielding a score for unfavourable components from 0 to +40. Then, negative points, from 0 to 5, are allocated for the amount of favourable components in the food (fruits, vegetables and nuts (%), fibre (g) and protein (g)), yielding a score for favourable components from 0 to -15. However, when the sum of negative components points is higher than 11, the positive points from the proteins component is not taken into account. The final score, corresponding to the sum between the negative and positive components scores, is a discrete continuous scale from -15 (for the foods with highest nutritional quality) to +40 points (for the foods with lowest nutritional quality) (9). A higher score reflects a lower nutritional quality food or beverage. The nutrient profile is calculated using the same algorithm for all food categories and beverages.

The Food Standards Australia New Zealand Nutrient Profiling Scoring Criterion (NPSC)

The NPSC was developed in 2013 by the Food Standards Australia New Zealand to regulate eligibility of foods to display health claims in Australia and New Zealand. The main difference between the NPSC score and the original FSA-NPS is the addition of an extra category for oils, spreads and cheese and a category for beverages (33). Baseline points for
foods in this extra category for oils, spreads and cheese were extended linearly to 11 points for energy, 30 points for saturated fat, and 30 points for sodium. The scoring scales for baseline nutrients for other foods and beverages remained unchanged, i.e. maximum 10 points. Additional changes to the original FSA-NPS included: enabling starchy vegetables to score fruit, vegetable, nut and legume points (reflecting national dietary guidelines); amending the eligibility cap to score protein points (13 points instead of 11) and increasing the number of points scored by a food that was 100% of fruit, vegetable, nut and legume (8 points instead of 5); and increasing the starting point for total sugar (from 4.5g/100g to 5g/100g) to ensure plain milks were eligible to display health claims.

The Health Star Rating Nutrient Profiling System (HSR-NPS)

The HSR-NPS was adapted from the NPSC by a multi-stakeholder committee with guidance from the Food Standards Australia New Zealand for the purpose of the Health Star Rating system, a government-led voluntary front-of-pack nutrition labelling system implemented in Australia and New Zealand since 2014. In the HSR-NPS, products are assigned to one of six categories (dairy beverages, other beverages, dairy foods, oils and spreads, cheese and processed cheese, all foods that are not included in previous categories). The NPSC scoring scales for oils and spreads, cheese and processed cheeses was maintained, however the scoring scales for baseline nutrients for dairy and non-dairy foods/beverages were extended to 11 points for energy, 30 points for saturated fat, 22 points for total sugars, and 30 points for sodium; the scoring scale for fruit, vegetable, nut and legume was expanded from 5 to 8 points, whilst those for fibre and protein were expanded from 5 to 15 points. The modifications were made to ensure better discrimination of the nutrient profile for foods within the same category.
The French High Council for Public Health NPS (HCSP-NPS)

The original FSA-NPS was adapted in France for the purpose of front-of-pack labelling, namely the Nutri-Score, by the French High Council for Public Health in 2015 (34). The HCSP-NPS considers four specific food categories: beverages, fats and oils, cheese and a generic category for all other foods. The generic food category is the same as the original FSA-NPS. For the other three categories, the modifications were made on the allocation grid for specific components of the scoring system but maintaining its original structure and thus leading to a final score still based on a discrete continuous scale from -15 to +40 (34). For beverages, the thresholds for points’ attribution in energy and total sugars were modified and the maximum number of points for fruit, vegetable and nut was doubled. For the fats category, the calculation of the saturated fat component was modified to take into account the ratio of saturated fat on total fats. For cheeses, the final score takes into account the protein content, whatever the score of negative components. The modifications were made to ensure better discrimination of the nutrient profile for foods within the same category, and align these food categories with national nutritional recommendations.

Dietary indices computation (at the individual level)

For each of the four nutrient profiling systems included in the present study, a dietary index (14) was computed at the individual diet level (accounting for the whole diet) using arithmetic energy-weighted means with the following equation:

\[ DI = \frac{\sum_{i=1}^{n} FS_i E_i}{\sum_{i=1}^{n} E_i} \]

Where \( i \) represents a food or beverage consumed by the participant, \( FS_i \) the food (or beverage) score, \( E_i \) the mean daily energy intake from this food (or beverage) and \( n \) the number of different foods. A higher dietary index reflects a lower nutritional quality of the
individual’s overall diet. Given the similarity of the four scores’ computation at the food level, the same approach was used for the four nutrient profiles.

**Statistical analyses**

Participants from the NutriNet-Santé cohort, except pregnant women (N=2,890), with three dietary 24h-records at baseline were eligible for the present study. Participants with energy underreporting (N=14,170), with no anthropometrics or sociodemographic data (N=14,001), or dieting during the dietary data collection period (N=12,977) were excluded from the analyses, resulting in a population sample of 71,403 participants. We computed the distribution of the four dietary indices (mean, standard deviation, median, minimum and maximum) and the correlation coefficients between the indices using Spearman correlations. We described sociodemographic and lifestyle characteristics of the NutriNet-Santé sample by sex-specific tertile of each of the four dietary indices, and then compared them across tertiles for each index using Chi square or Mantel-Haenszel tests as appropriate. Individual characteristics included age (18-25, 26-45, 46-65, >65 years), sex, educational level (primary, secondary, university), monthly income (<900€/month, 900-2700€/month, >2700€/month), smoking status (non-smoker, former smoker, current smoker), marital status (in couple, single/divorced/widowed), physical activity level (low, moderate, high) and BMI (<18.5, 18.5-24, 25-29, >30kg/m²). We calculated nutrient intakes across sex-specific tertiles of each dietary index using linear regression and applying the residual method to take into account energy intake (35), and we then compared them across tertile for each dietary index using analysis of variance. Multiple testing was taken into account using a False Discovery Rate approach (36).
Weight gain

For each dietary index, we represented graphically the change of BMI over time by sex-specific tertile. We measured the associations between each of the four individual dietary indices (as sex-specific tertiles) and BMI over time using mixed models for repeated measures (PROC MIXED in the statistical software SAS), with dietary indices as fixed effect, and intercept and time as random effects. Given the non-normal distribution of BMI, a logarithmic transformation was used to normalize the dependent variable in the models. The outcome modelled was the relative change in BMI. Models were adjusted for age, sex, educational level, level of monthly income, smoking status, marital status, physical activity level, energy intake, alcohol intake, and season of dietary data collection.

Overweight and obesity

Two sets of analyses were carried out, one for overweight (including obesity) and another for obesity separately. In each analysis, we excluded prevalent cases of overweight (N=18,433) or obesity (N=4,824) at baseline respectively, and participants with no follow-up and missing covariates, leading respectively to 40,096 participants for overweight analyses and 50,569 for obesity analyses. We characterized the association between individual dietary indices (sex-specific tertiles) and overweight or obesity onset (Hazard Ratio (HR) and 95% Confidence Interval (CI)) using multivariable Cox proportional hazard models with age as the primary time variable (37). We verified the assumptions of risk proportionality through examination of the log–log (survival) versus log–time plots and Schoenfeld residuals, and the log-linearity assumption through the Martingale residuals plot. Participants contributed person-time to the Cox model until the date of onset of overweight or obesity for cases (defined as the middle date between the anthropometrics questionnaire in which the participant’s self-reported weight corresponding to overweight or obesity, and the previous one (38)) or the date of last
completed anthropometrics questionnaire for non-cases. Models were adjusted for age (time-scale), sex, educational level, level of monthly income, smoking status, marital status, physical activity, energy intake, alcohol intake, and season of dietary data collection. Significant associations of the four dietary indices with overweight and obesity risk were formally compared two by two by including simultaneously two dietary indices in the model and using a Wald test (39).

All analyses were carried out using the SAS software (version 9.4; SAS Institute, Inc.) and a p-value $\leq 0.05$ was considered statistically significant.

RESULTS

The flow chart of the present study with the different samples depending on the conducted analyses (descriptive, weight gain, overweight, or obesity) is shown in Figure 1.

Descriptive analyses

The distribution of the four dietary indices and the correlation coefficients between them are presented in Supplemental Table 1. Among the participants, the mean dietary index was 6.95 ± 2.50 points with the original FSA-NPS, 7.26 ± 2.91 points with the NPSC, 7.09 ± 3.33 points with the HSR-NPS and 6.66 ± 2.54 points with the HCSP-NPS. The four dietary indices were highly correlated (all Spearman coefficients over 0.90 for continuous variables). The description of sociodemographic and lifestyle characteristics of the study sample (N=71,403) at baseline by sex-specific tertile of each of the four individual dietary indices is presented in Table 1. For the four NPSs, participants with a higher individual dietary index,
reflecting a lower overall nutritional quality of their diet, tended to be younger, with a university educational level, a lower income per household unit, to be smokers and less physically active. Regarding the marital status, participants in the extreme tertiles (tertiles 1 and 3) were more likely to live alone. Nutrient intakes across each dietary index are displayed in Table 2. Participants with a higher individual dietary index (tertile 3) had significantly higher intakes of energy, total fat, cholesterol, saturated fat, alcohol, added sugars and sodium (except for the HCSP-NPS) and lower intakes of carbohydrates, simple sugars, protein, polyunsaturated fat, fibres, vitamins and minerals.

**Prospective analyses**

A total of 71,403 participants were included in the weight gain analyses (measured using the BMI), with a median follow-up of 3.14 ± 2.76 years. BMI change over time by sex-specific tertile of dietary indices is shown in Figure 2. The mean BMI for each year and each tertile of dietary index is presented along with the 95% confidence interval of the mean. Graphically, while an increase of BMI was observed in all tertiles of each individual dietary index, the BMI gain appeared to be higher for participants in tertile 2 and particularly in tertile 3 of all dietary indexes (individuals with a lower overall dietary quality) compared to individuals from tertile 1. Results of the prospective associations between the four dietary indices and BMI change are shown in Table 3. For the four NPSs, participants in tertiles 2 and 3, having lower dietary nutritional quality) had higher BMI at baseline (β coefficients for tertiles 2 and 3 >0) compared to those in the 1st tertile (reference in the model). In the four NPS, participants in the 1st tertile of dietary index had a significant increase in BMI over time (β coefficients for time significantly >0). However, participants in tertile 2 and especially in tertile 3 of each dietary index had a significantly higher increase of BMI over time compared to tertile 1 (β coefficients for interactions terms between time and tertile >0), with a
significantly higher effect magnitude for the HCSP-DI ($\beta_{T3\times time}=0.18(0.16-0.20)$, $p<0.0001$), followed by the original FSA-DI ($\beta_{T3\times time}=0.14(0.11-0.16)$, $p<0.0001$), and then the NPSC-DI ($\beta_{T3\times time}=0.09(0.06-0.11)$, $p<0.0001$) and the HSR-DI ($\beta_{T3\times time}=0.09(0.07-0.11)$, $p<0.0001$).

Results of the associations between the four dietary indices and overweight (N=40,096 participants, 4.96 ± 2.93 years of median follow-up) or obesity (N=50,569 participants, 5.32 ± 2.90 years of median follow-up) risks are presented in Table 4. During the course of the follow-up, 4,488 participants developed overweight and 1,582 obesity. Overall, participants with a higher dietary index reflecting a lower diet quality (tertile 2 and particularly tertile 3) had a significant increased risk of overweight compared to tertile 1: $HR_{T3\ vs\ T1}=1.27[1.17-1.37]$ (p-trend<0.0001) for the HCSP-DI, followed by the original FSA-DI with $HR_{T3\ vs\ T1}=1.18[1.09-1.28]$ (p-trend<0.0001), the NPSC-DI with $HR_{T3\ vs\ T1}=1.14[1.06-1.24]$ (p-trend=0.0008) and then the HSR-DI, $HR_{T3\ vs\ T1}=1.12[1.04-1.21]$ (p-trend=0.003). No association was found between any of the four dietary indexes and the risk of obesity.

Associations between the four NPS with overweight risk were compared (Table 5); no comparison was made for obesity given the non-significant results. When both the HCSP-DI and the original FSA-DI were included in the model, the HCSP-DI was associated with a significant increased risk of overweight while the original FSA-DI was associated with a significantly decreased risk. Similar results were observed when both the HCSP-DI and NPSC-DI, or the HCSP-DI and HSR-DI, were included in the model: the HCSP-DI was associated with a significantly increased risk while the other index was associated to a significantly decreased risk. Conversely, when both the NPSC-DI and the original FSA-DI, or the HSR-DI and the original FSA-DI, were included in the model, the original FSA-DI was associated with a significantly increased risk of overweight while the NPSC-DI or the HSR-DI were associated to a significantly decreased risk. When both NPSC and HSR dietary...
indices were included in the model, neither index was significantly associated with risk of overweight.

DISCUSSION

In the present study, participants with a lower nutritional quality diet, measured by higher
dietary indices based on the four NPSs, had a higher increase in BMI over time and were at higher risk of becoming overweight. The HCSP-DI appeared to be more strongly associated with risk of becoming overweight, followed by the original FSA-DI, and then the NPSC-DI and HSR-DI.

Very few studies to date have investigated the associations between NPSs, either FSA-NPS or its variants, and anthropometric measurements (21,40). One study conducted in another French cohort found that participants with poorer diet measured by a higher HCSP-DI had a higher weight and BMI gain, and an increased risk of overweight, and obesity (among men only) (21). Another study investigated the relationship between the nutritional quality of meals and snacks assessed using the original FSA-NPS with BMI and waist circumference in British adults, and observed a positive association between the FSA-DI of snacks consumption only, and BMI and waist circumference among women (40).

Several assumptions could explain the associations of the NPSs observed in the study with weight gain or overweight. First, the computation of the scores at the food level using the four NPSs tested in the study is based on the composition of the food product in energy, saturated fats, sugars, protein, fibre and fruits, vegetables and nuts. The inclusion of these key
components leads to an association between higher dietary indexes and higher intakes of energy, fats, saturated fats, added sugars and potentially sodium, and lower intakes of carbohydrates, protein and fibre (together with higher/lower levels of nutrients and other components not included in the NPSs), a finding consistent with previous work (14). Given that individuals tend to maintain a constant volume of food intake, diet rich in fats would lead to a passive over-consumption related to their high energy to volume ratio, promoting energy intake (41,42). In contrast, it has been suggested that other macronutrients – proteins and carbohydrates to a lesser extent – have a positive effect on satiety (41,43). Regarding fibres, several physiological effects could explain their effect on energy regulation, including notably a positive impact on satiety or on a decrease in fat and protein absorption (42,43). Thus, weight gain and overweight could be related to these dietary factors, influencing the energy balance of individuals (44). Our findings on the associations between dietary indices and nutrient intakes are consistent with a study where a higher HCSP-DI was associated with a higher consumption of food groups which can affect weight status and thus should be limited, such as sugary snacks, sweetened beverages, cheeses, fats and sauces, or processed meat, and a lower consumption of fruits, vegetables, and legumes for example (14,43). Second, improved adherence to dietary guidelines by participants with a lower dietary index, which reflects a better overall diet nutritional quality, may lead to more favourable outcomes regarding weight status. Indeed, it has been previously demonstrated that the HCSP-DI was correlated with the PNNS-GS (Programme National Nutrition Santé - Guideline Score) reflecting the adherence to the French nutritional recommendations of 2001 (14).

The relative differences observed between the HCSP and the NPSC or HSR indices may be partly explained by: 1. the specific modification of the scoring system for sweetened beverages in the HCSP-NPS which are penalized more and have higher scores at the food level, and 2.
the inclusion of starchy vegetables in the scoring of fruits, vegetables, nuts and legumes
points for the NPSC and HSR-NPS, which may have improved their nutrient profile,
including for processed foods such as potato chips or French fries.

Validation of a nutrient profiling system requires several steps including an assessment of its
content, construct and predictive validity (45). However, although NPSs are developed in the
framework of NCDs prevention and thus their associations with health outcomes (predictive
validity) is of major importance to test, this dimension of NPS validity is rarely verified (8).
More broadly, a recent systematic review has revealed that no information on validity testing
could be found for 58% of NPS models assessed in the review (8). When comparing the
performance of the various indices, by including two indices at a time in the analyses, a
significant relative risk over 1 for the first index while the relative risk of the second index is
below 1 indicate that the first index is more strongly associated to the outcome and shows
higher performance compared to the other index. In these analyses, we observed a higher
performance of the HCSP-NPS compared to other indices, suggesting that the specific
modifications of this NPS are leading to a stronger association with overweight. Conversely,
NPSC and HSR did not appear to be associated with an improved performance compared to
the original FSA. Nevertheless, the differences observed between the four NPS were of small
magnitude. This suggests that the prospective associations mainly relate to the common core
of the profiling system and that adaptations, including modification to the scoring or the use
of food categories, have only a marginal impact on the association with weight gain or
overweight. This finding suggests that the results of validation studies undertaken on a
specific NPS might apply to adaptations of the same NPS. Our results also suggest two
avenues to improve the health impact of NPS adaptations. On the one hand, testing the
prospective associations with health may determine whether the adaptation yields significant
improvements from the original, in particular in the view of preventing NCDs. On the other
hand, a specific method to improve NPSs specifically to take their prospective associations
with health into account could be developed, to ensure that adaptation leads to significant
health gains.

Strengths of the study include its prospective design and the large sample of participants.
Moreover, the dietary data collected in the NutriNet-Santé cohort using 24h dietary records
were validated against an interview by a trained dietitian and blood and urinary biomarkers
(25,28,29). Regarding anthropometric measurements, self-reported online data were
demonstrated to be consistent with face-to-face declarations (26). Furthermore, very few other
studies have investigated the associations between nutrient profiling systems and health
outcomes, nor the potential impact of specific modifications of an original nutrient profiling
system on these associations.

However, limitations should be acknowledged. First, participants in the NutriNet-Santé cohort
have higher educational level and monthly incomes, with more health conscious behaviour
and thereby may have healthier dietary indexes resulting in less weight gain and overweight
or obesity, as compared to the general French population. Second, the relatively short follow-
up period (median of 5.32 ± 2.90 years) may partly explain the absence of significant results
for obesity risk. Repeating these analyses with a longer duration of follow-up would allow us
to validate our findings, in particular for obesity. Third, the presence of residual confounding
related to our exposure and outcomes measurement cannot be excluded. These issues may
have resulted in underestimation of the associations between dietary indexes and health
outcomes, and may have impaired our ability to detect an association with obesity. However,
such underestimation impacts all the indexes equally and therefore should not be considered
as a bias in the comparison of the nutrient indexes. Another limitation which could be
highlighted is the use of weight gain as health outcome which does not always reflect an unhealthy fat mass gain. Thus, it might be notably interesting to conduct similar analyses using other indicators than BMI, such as waist circumference measuring adiposity more precisely. Finally, the study was conducted among a French cohort, while the original FSA-NPS was adapted for use in United Kingdom and the NPSC and HSR-NPS in New-Zealand and Australia, where the local food supply and nutritional recommendations differ. These adaptations specific to a particular context may limit the extrapolation of the observed associations in populations from United Kingdom, New-Zealand and Australia.

In conclusion, the original FSA-NPS and the three systems adapted for specific application (HCSP, NPSC and HSR) all appear to be associated with weight gain and the risk of overweight. Thus, public health policies based on the NPSs represent efficient tools to improve the health status of consumers, by informing and encouraging individuals towards healthier food choices and improving the food environment. With respect to the prospective aspect of NPS validity, modifications of the FSA system on scoring and use of categories seem to have marginal – though significant – impact on the association with weight outcomes.
ACKNOWLEDGMENTS

We also thank Cédric Agaesse, Vrísti Desan and Cynthia Perlin (dietitians); Thi Hong Van Duong, Younes Esseddik (IT manager), Paul Flanzy, Régis Gatibelza, Jagatjit Mohinder and Aladi Timera (computer scientists); Julien Allegre, Nathalie Arnault, Laurent Bourhis and Fabien Szabo de Edelenyi, PhD (supervisor) (data-manager/statisticians) for their technical contribution to the NutriNet-Santé study and Nathalie Druesne-Pecollo, PhD (operational manager). We thank all the volunteers of the NutriNet-Santé cohort. The authors declare no conflict of interest.

BN, CNM, MR, AJ, MT, EKG, SH and JC designed research; ME and CJ conducted research, ME performed statistical analyses in collaboration with LS and CJ; all authors interpreted the data; ME drafted the paper in collaboration with CJ and all authors critically revised the paper for important intellectual content. All authors read and approved the final manuscript.


45. Townsend MS. Where is the science? What will it take to show that nutrient profiling systems work? Am J Clin Nutr. 2010;91:1109S–1115S.
<table>
<thead>
<tr>
<th>Table 1. Description of the population by sex-specific tertile of individual dietary indices (NutriNet-Santé sample N=71,403)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original FSA-DI</strong></td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>26-46</td>
</tr>
<tr>
<td>&gt;65</td>
</tr>
<tr>
<td><strong>Educational level</strong></td>
</tr>
<tr>
<td>Primary</td>
</tr>
<tr>
<td>Secondary</td>
</tr>
<tr>
<td>University</td>
</tr>
<tr>
<td>Marital status</td>
</tr>
<tr>
<td>In couple</td>
</tr>
<tr>
<td>Single/divorced/widowed</td>
</tr>
<tr>
<td>Income per household unit (€/month)</td>
</tr>
<tr>
<td>≤900</td>
</tr>
<tr>
<td>900-2700</td>
</tr>
<tr>
<td>&gt;2700</td>
</tr>
<tr>
<td>No answer</td>
</tr>
<tr>
<td>Smoking status</td>
</tr>
<tr>
<td>Current</td>
</tr>
<tr>
<td>Former</td>
</tr>
<tr>
<td>Never</td>
</tr>
<tr>
<td>BMI category (kg/m²)</td>
</tr>
<tr>
<td>&lt;18.5</td>
</tr>
<tr>
<td>18.5-25</td>
</tr>
<tr>
<td>25-29</td>
</tr>
<tr>
<td>≥30</td>
</tr>
<tr>
<td>Physical activity</td>
</tr>
<tr>
<td>High</td>
</tr>
<tr>
<td>Moderate</td>
</tr>
<tr>
<td>Low</td>
</tr>
</tbody>
</table>

<sup>*</sup>P-values from chi square or Mantel-Haenszel tests as appropriate.

DI: Dietary Index; FSA: Food Standards Agency; HCSP: High Council for Public Health; HSR: Health Star Rating; NPSC: Nutrient Profiling System Criterion
Table 2. Nutrient intakes across sex-specific tertile of individual dietary indices (NutriNet-Santé sample N=71,403)

<table>
<thead>
<tr>
<th></th>
<th>FSA-NPS DI</th>
<th>Tertile 1</th>
<th>Tertile 2</th>
<th>Tertile 3</th>
<th>Tertile 1</th>
<th>Tertile 2</th>
<th>Tertile 3</th>
<th>Tertile 1</th>
<th>Tertile 2</th>
<th>Tertile 3</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy, kcal/d</td>
<td>1741.41</td>
<td>1745.66</td>
<td>1745.03</td>
<td>&lt;0.0001</td>
<td>1880.43</td>
<td>1879.04</td>
<td>&lt;0.0001</td>
<td>1745.13</td>
<td>1881.87</td>
<td>&lt;0.0001</td>
<td>2022.77</td>
</tr>
<tr>
<td>Carbohydrate, % energy</td>
<td>46.07</td>
<td>46.28</td>
<td>45.78</td>
<td>&lt;0.0001</td>
<td>43.49</td>
<td>43.55</td>
<td>&lt;0.0001</td>
<td>40.64</td>
<td>41.08</td>
<td>&lt;0.0001</td>
<td>40.64</td>
</tr>
<tr>
<td>Fat, % energy</td>
<td>35.59</td>
<td>35.51</td>
<td>35.85</td>
<td>&lt;0.0001</td>
<td>39.6</td>
<td>39.5</td>
<td>&lt;0.0001</td>
<td>43.64</td>
<td>43.35</td>
<td>&lt;0.0001</td>
<td>39.71</td>
</tr>
<tr>
<td>Protein, % energy</td>
<td>18.34</td>
<td>18.21</td>
<td>18.37</td>
<td>&lt;0.0001</td>
<td>16.91</td>
<td>16.9</td>
<td>&lt;0.0001</td>
<td>15.72</td>
<td>15.57</td>
<td>&lt;0.0001</td>
<td>16.98</td>
</tr>
<tr>
<td>Alcohol, g/d</td>
<td>7.35</td>
<td>7.31</td>
<td>7.48</td>
<td>&lt;0.0001</td>
<td>8.55</td>
<td>8.59</td>
<td>&lt;0.0001</td>
<td>9.44</td>
<td>9.23</td>
<td>&lt;0.0001</td>
<td>8.74</td>
</tr>
<tr>
<td>Cholesterol, mg/d</td>
<td>286.14</td>
<td>283.74</td>
<td>286.33</td>
<td>&lt;0.0001</td>
<td>316.49</td>
<td>316.24</td>
<td>&lt;0.0001</td>
<td>339.87</td>
<td>337.53</td>
<td>&lt;0.0001</td>
<td>317.95</td>
</tr>
<tr>
<td>Saturated fat, g/d</td>
<td>26.08</td>
<td>26.73</td>
<td>27.82</td>
<td>&lt;0.0001</td>
<td>33.91</td>
<td>33.9</td>
<td>&lt;0.0001</td>
<td>40.31</td>
<td>40.22</td>
<td>&lt;0.0001</td>
<td>34.24</td>
</tr>
<tr>
<td>Polysaturated fat, g/d</td>
<td>12.67</td>
<td>12.81</td>
<td>12.99</td>
<td>&lt;0.0001</td>
<td>11.69</td>
<td>11.65</td>
<td>&lt;0.0001</td>
<td>11.19</td>
<td>11.06</td>
<td>&lt;0.0001</td>
<td>11.58</td>
</tr>
<tr>
<td>Fibers, g/d</td>
<td>24.4</td>
<td>24.33</td>
<td>24.26</td>
<td>&lt;0.0001</td>
<td>19.34</td>
<td>19.37</td>
<td>&lt;0.0001</td>
<td>16.27</td>
<td>16.24</td>
<td>&lt;0.0001</td>
<td>19.46</td>
</tr>
<tr>
<td>Simple sugars, g/d</td>
<td>99.55</td>
<td>100.84</td>
<td>99.51</td>
<td>&lt;0.0001</td>
<td>95.29</td>
<td>95.17</td>
<td>&lt;0.0001</td>
<td>89.65</td>
<td>91.09</td>
<td>&lt;0.0001</td>
<td>93.87</td>
</tr>
<tr>
<td>Added sugars, g/d</td>
<td>32.73</td>
<td>33.84</td>
<td>33.16</td>
<td>&lt;0.0001</td>
<td>41.14</td>
<td>40.85</td>
<td>&lt;0.0001</td>
<td>45.73</td>
<td>46.71</td>
<td>&lt;0.0001</td>
<td>39.59</td>
</tr>
<tr>
<td>Sodium, mg/d</td>
<td>2718.63</td>
<td>2702.17</td>
<td>2691.3</td>
<td>&lt;0.0001</td>
<td>2747.37</td>
<td>2753.36</td>
<td>&lt;0.0001</td>
<td>2776.59</td>
<td>2781.46</td>
<td>&lt;0.0001</td>
<td>2767.43</td>
</tr>
<tr>
<td>Beta-carotene, µg/d</td>
<td>4308.32</td>
<td>4279.05</td>
<td>4265.68</td>
<td>&lt;0.0001</td>
<td>3351.8</td>
<td>3371.56</td>
<td>&lt;0.0001</td>
<td>2815.53</td>
<td>2809.13</td>
<td>&lt;0.0001</td>
<td>3411.32</td>
</tr>
<tr>
<td>Vitamin C, µg/d</td>
<td>141.27</td>
<td>141.56</td>
<td>140.42</td>
<td>&lt;0.0001</td>
<td>117.97</td>
<td>118.55</td>
<td>&lt;0.0001</td>
<td>97.66</td>
<td>98.22</td>
<td>&lt;0.0001</td>
<td>118.02</td>
</tr>
<tr>
<td>Vitamin E, µg/d</td>
<td>12.95</td>
<td>13.1</td>
<td>13.23</td>
<td>&lt;0.0001</td>
<td>11.76</td>
<td>11.74</td>
<td>&lt;0.0001</td>
<td>10.91</td>
<td>10.8</td>
<td>&lt;0.0001</td>
<td>11.67</td>
</tr>
<tr>
<td>Vitamin B6, µg/d</td>
<td>2.02</td>
<td>2.03</td>
<td>2.04</td>
<td>0.49</td>
<td>1.74</td>
<td>1.74</td>
<td>0.49</td>
<td>1.51</td>
<td>1.49</td>
<td>0.49</td>
<td>1.74</td>
</tr>
<tr>
<td>Folic acid, µg/d</td>
<td>384.12</td>
<td>383.39</td>
<td>383.34</td>
<td>&lt;0.0001</td>
<td>325.37</td>
<td>325.99</td>
<td>&lt;0.0001</td>
<td>285.37</td>
<td>284.8</td>
<td>&lt;0.0001</td>
<td>327.43</td>
</tr>
<tr>
<td>Vitamin B12, µg/d</td>
<td>5.58</td>
<td>5.49</td>
<td>5.58</td>
<td>&lt;0.0001</td>
<td>5.18</td>
<td>5.19</td>
<td>&lt;0.0001</td>
<td>4.75</td>
<td>4.65</td>
<td>&lt;0.0001</td>
<td>5.66</td>
</tr>
<tr>
<td>Vitamin D, µg/d</td>
<td>2.95</td>
<td>2.93</td>
<td>2.97</td>
<td>&lt;0.0001</td>
<td>2.66</td>
<td>2.64</td>
<td>&lt;0.0001</td>
<td>2.5</td>
<td>2.47</td>
<td>&lt;0.0001</td>
<td>2.66</td>
</tr>
<tr>
<td>Calcium, mg/d</td>
<td>960.71</td>
<td>950.01</td>
<td>948.55</td>
<td>&lt;0.0001</td>
<td>920.05</td>
<td>922.73</td>
<td>&lt;0.0001</td>
<td>915.84</td>
<td>914.61</td>
<td>&lt;0.0001</td>
<td>930.27</td>
</tr>
<tr>
<td>Potassium, mg/d</td>
<td>3429.56</td>
<td>3429.15</td>
<td>3428.52</td>
<td>&lt;0.0001</td>
<td>2963.51</td>
<td>2965.88</td>
<td>&lt;0.0001</td>
<td>2600.04</td>
<td>2598.31</td>
<td>&lt;0.0001</td>
<td>2972.79</td>
</tr>
<tr>
<td>Phosphorus, mg/d</td>
<td>1373.5</td>
<td>1364.81</td>
<td>1372.37</td>
<td>&lt;0.0001</td>
<td>1253.72</td>
<td>1253.61</td>
<td>&lt;0.0001</td>
<td>1183.45</td>
<td>1176</td>
<td>&lt;0.0001</td>
<td>1258.68</td>
</tr>
<tr>
<td>Zinc, µg/d</td>
<td>11.52</td>
<td>11.42</td>
<td>11.54</td>
<td>&lt;0.0001</td>
<td>10.77</td>
<td>10.78</td>
<td>&lt;0.0001</td>
<td>10.16</td>
<td>10.03</td>
<td>&lt;0.0001</td>
<td>10.82</td>
</tr>
<tr>
<td>Iron, µg/d</td>
<td>15.22</td>
<td>15.19</td>
<td>15.28</td>
<td>&lt;0.0001</td>
<td>13.43</td>
<td>13.43</td>
<td>&lt;0.0001</td>
<td>12.37</td>
<td>12.28</td>
<td>&lt;0.0001</td>
<td>13.46</td>
</tr>
</tbody>
</table>

*P-values for trend across tertiles derived from unadjusted ANOVAs. Nutrient intakes are adjusted for energy using the residual method. NS: Non-significant p-value, before and after correction for multiple testing. DI: Dietary Index; FSA: Food Standards Agency; HCSP: High Council for Public Health; HSR: Health Star Rating; NPS: Nutrient Profiling System Criterion.
Table 3. Association between the four individual dietary indices and weight gain (NutriNet-Santé sample N=71,403)

<table>
<thead>
<tr>
<th></th>
<th>Original FSA-DI</th>
<th>NPSC-DI</th>
<th>HSR-DI</th>
<th>HCSP-DI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β (95% CI)</td>
<td>P-value</td>
<td>β (95% CI)</td>
<td>P-value</td>
</tr>
<tr>
<td>Tertile 2 (BMI difference at baseline with the reference – T1)</td>
<td>0.85 (0.58-1.13)</td>
<td>&lt;0.0001</td>
<td>0.93 (0.66-1.20)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Tertile 3 (BMI difference at baseline with the reference – T1)</td>
<td>1.12 (0.83-1.41)</td>
<td>&lt;0.0001</td>
<td>0.98 (0.69-1.26)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Time (weight gain / year in the reference – T1)</td>
<td>0.09 (0.07-0.10)</td>
<td>&lt;0.0001</td>
<td>0.11 (0.09-0.12)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Time*tertile 2 (additional BMI gain / year compared to T1)</td>
<td>0.05 (0.02-0.07)</td>
<td>0.0001</td>
<td>0.05 (0.03-0.08)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Time*tertile 3 (additional BMI gain / year compared to T1)</td>
<td>0.14 (0.11-0.16)</td>
<td>&lt;0.0001</td>
<td>0.09 (0.06-0.11)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

* Models were adjusted for age, sex, level of monthly income, educational level, marital status, physical activity, energy intake, alcohol intake, and season of dietary data collection. Analyses were computed overall, and by sex.

b Estimates β of parameters, corresponding to the modelling of log(BMI), were thus transformed as follows: β’=[Exponential(β)-1]*100, interpreted as a variation of BMI in percentage.

CI: Confidence Interval; DI: Dietary Index; FSA: Food Standards Agency; HCSP: High Council for Public Health; HSR: Health Star Rating; NPSC: Nutrient Profiling System Criterion; T: Tertile
### Table 4. Prospective associations between the four individual dietary indices and overweight or obesity risk

<table>
<thead>
<tr>
<th></th>
<th>Original FSA-DI</th>
<th>NPSC-DI</th>
<th>HSR-DI</th>
<th>HCSP-DI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cases / person-years</td>
<td>HR[95% CI]</td>
<td>P-trend</td>
<td>Cases / person-years</td>
</tr>
<tr>
<td><strong>Overweight (NutriNet-Santé sample N=40,096)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td>4488/199045</td>
<td>1.03 [1.02-1.05]</td>
<td>&lt;0.0001</td>
<td>4488/199045</td>
</tr>
<tr>
<td>Tertile 1</td>
<td>1335/68010</td>
<td>1 (ref)</td>
<td>&lt;0.0001</td>
<td>1327/67637</td>
</tr>
<tr>
<td>Tertile 2</td>
<td>1505/67364</td>
<td>1.08 [1.00-1.17]</td>
<td></td>
<td>1550/66578</td>
</tr>
<tr>
<td><strong>Obesity (NutriNet-Santé sample N=50,569)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous</td>
<td>1582/269051</td>
<td>1.03 [1.00-1.05]</td>
<td>0.03</td>
<td>1582/269051</td>
</tr>
<tr>
<td>Tertile 1</td>
<td>476/91288</td>
<td>1 (ref)</td>
<td>0.1</td>
<td>474/90892</td>
</tr>
<tr>
<td>Tertile 2</td>
<td>524/90962</td>
<td>1.03 [0.91-1.17]</td>
<td></td>
<td>525/90346</td>
</tr>
<tr>
<td>Tertile 3</td>
<td>582/86802</td>
<td>1.10 [0.97-1.25]</td>
<td></td>
<td>583/87813</td>
</tr>
</tbody>
</table>

*Models were adjusted for age (time-scale), sex, level of monthly income, educational level, physical activity, energy intake, alcohol intake, number of dietary records, and season of dietary data collection.
HR: Hazard Ratio; CI: Confidence Interval
DI: Dietary Index; FSA: Food Standards Agency; HCSP: High Council for Public Health; HSR: Health Star Rating; NPSC: Nutrient Profiling System Criterion
Table 5. Comparisons of the associations between the four individual FSA dietary indexes and overweight risk (NutriNet-Santé sample N=40,096)

<table>
<thead>
<tr>
<th></th>
<th>RR [95%IC]</th>
<th>P-trend</th>
<th>P Wald</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCSP-DI</td>
<td>1.17 [1.11-1.23]</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Original FSA-DI</td>
<td>0.89 [0.84-0.94]</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>HSR-DI</td>
<td>0.96 [0.93-0.99]</td>
<td>0.008</td>
<td>0.0005</td>
</tr>
<tr>
<td>Original FSA-DI</td>
<td>1.09 [1.05-1.14]</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>NPSC-DI</td>
<td>0.96 [0.93-1.00]</td>
<td>0.04</td>
<td>0.004</td>
</tr>
<tr>
<td>Original FSA-DI</td>
<td>1.08 [1.03-1.13]</td>
<td>0.0006</td>
<td></td>
</tr>
<tr>
<td>HCSP-DI</td>
<td>1.11 [1.07-1.14]</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>HSR-DI</td>
<td>0.95 [0.93-0.97]</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>HCSP-DI</td>
<td>1.10 [1.06-1.13]</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>NPSC-DI</td>
<td>0.95 [0.93-0.98]</td>
<td>0.0005</td>
<td></td>
</tr>
<tr>
<td>HSR-DI</td>
<td>0.98 [0.92-1.03]</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>NPSC-DI</td>
<td>1.05 [0.99-1.12]</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

To test whether the $\beta$ coefficients for two dietary indices were different, the method of Chiuve et al. was used: the Wald statistic was calculated using the following formula $X^2 = \left( (\beta_1 - \beta_2) / \sqrt{\text{var}(\beta_1 - \beta_2)} \right)^2$ where $\beta_1$ is the $\beta$ coefficient of the first dietary index, $\beta_2$ the $\beta$ coefficient of the second dietary index and $\text{var}(\beta_1 - \beta_2) = \text{var}(\beta_1) + \text{var}(\beta_2) - 2 \cdot \text{cov}(\beta_1, \beta_2)$. 
Figure 1. Flow chart of the study populations

Figure 2. Change in BMI over time in years, by tertile of dietary indice