Effect of Energy Under-Reporting on Secular Trends of Dietary Patterns in a Mediterranean Population

Anna N. Funtikova¹,²,³, Santiago F. Gomez¹,⁴, Montserrat Fitó¹,⁵, Roberto Elosua⁶, Alejandra A. Benítez-Arciniega⁷, Helmut Schröder¹,²*  

¹ Cardiovascular Risk and Nutrition Research Group (CARIN-ULEC), IMIM (Hospital del Mar Medical Research Institute), Barcelona, Spain, ² CIBER Epidemiology and Public Health (CIBERESP), Instituto de Salud Carlos III, Madrid, Spain, ³ PhD program “Foods and Nutrition”, University of Barcelona, Barcelona, Spain, ⁴ Fundación THAO, Barcelona, Spain, ⁵ CIBER Physiopathology of Obesity and Nutrition (CIBEROBN), Instituto de Salud Carlos III, Madrid, Spain, ⁶ Cardiovascular Epidemiology and Genetics (EGEC-ULEC), IMIM (Hospital del Mar Medical Research Institute), Barcelona, Spain, ⁷ Faculty of Medicine, Autonomous University of Mexico State, Toluca, Mexico  

* hschroeder@imim.es

Abstract

Background
Diet is an important factor in the prevention of chronic diseases. Analysis of secular trends of dietary patterns can be biased by energy under-reporting. Therefore, the objective of the present study was to analyse the impact of energy under-reporting on dietary patterns and secular trends in dietary patterns defined by cluster analysis.

Design and methods
Two cross-sectional population-based surveys were conducted in Spain, in 2000 and 2005, with 3058 and 6352 participants, respectively, aged 25 to 74 years. Validated questionnaire was used to collect dietary data. Cluster analysis was run separately for all participants, plausible energy reporters (PER), and energy under-reporters (EUR) to define dietary patterns.

Results
Three clusters, “healthy”, “mixed” and “western”, were identified for both surveys. The “mixed” cluster was the predominant cluster in both surveys. Excluding EUR reduced the proportion of the “mixed” cluster up to 6.40% in the 2000 survey; this caused secular trend increase in the prevalence of the “mixed” pattern. Cross-classification analysis of all participants and PER’s data showed substantial agreement in cluster assignments: 68.7% in 2000 and 84.4% in 2005. Excluding EUR did not cause meaningful (≥15%) changes in the “healthy” pattern. It provoked changes in consumption of some food groups in the “mixed” and “western” patterns: mainly decreases of unhealthy foods within the 2000 and increases of unhealthy foods within the 2005 surveys. Secular trend effects of EUR were similar to
those within the 2005 survey. Excluding EUR reversed the direction of secular trends in consumption of several food groups in PER in the “mixed” and “western” patterns.

Conclusions
EUR affected distribution of participants between dietary patterns within and between surveys, secular trends in food group consumption and amount of food consumed in all, but not in the “healthy” pattern. Our findings emphasize threats from energy under-reporting in dietary data analysis.

Introduction
Diet is a key factor in the prevention of chronic diseases [1]. Identification and promotion of healthy diets is paramount for evaluation and planning of national dietary intervention programs. Dietary pattern analysis takes into account the entire food intake and the interactions between all consumed nutrients, and has become widespread for exploring diet-disease relationships. An example of this approach is cluster analysis, which creates easily interpretable dietary patterns that are mutually exclusive [2]. This makes cluster analysis an interesting tool to explore secular trends of dietary patterns in populations. Secular trends in dietary patterns performed with cluster analysis have been analysed mainly among adolescents [3,4]. To date, only one study has been performed in the adult population [5].

All dietary assessment methods are biased by implausibly low self-reported energy intakes, a major challenge for nutritional epidemiologists [6]. Furthermore, energy under-reporting of foods seems to be selective [7]. This in turn affects dietary pattern analysis, which is based on biased dietary assessment methods. Few studies have investigated this issue and results to date are inconsistent [8].

Although the effect of energy under-reporting on secular trends of dietary pattern is unknown, it is well known that energy under-reporters tend to report healthier food choices. Additionally, it is reasonable to assume that the proportion of energy under-reporters will differ between dietary patterns. Therefore, we hypothesized that energy under-reporting might bias the time trends of dietary patterns. The aim of the present study was to explore the impact of energy under-reporting, first, on post-hoc dietary pattern analysis and, second, on secular trends of dietary patterns obtained by cluster analysis.

Materials and Methods
Study design and participants
Data were obtained from two population-based cross-sectional surveys of the REGICOR study (Registre Gironí del Cor) conducted in Girona (Spain) in 2000 and 2005 [9]. The 2000 survey examined a random population-based sample of 3058 men and women aged 24 to 77 years (participation rate: 71.0%); the second survey included 6352 non-institutionalized men and women older than 33 years (participation rate: 72.0%). No participants were repeated in the second survey. The present study selected only REGICOR participants aged 35 to 74 years and excluded individuals with extreme energy intake values (defined as <800 and >4200 kcal/day for men and <600 and >3500 kcal/day for women)[10]. Based on the characteristics of participants reporting extreme energy intakes according to the criteria of Willett [10], especially age and BMI, it is reasonable to assume that these values are actual outliers. Furthermore, cluster
analysis is very sensitive to outliers. Therefore, we decided to exclude extreme energy intakes to avoid biased cluster formation. The exclusion of extreme intakes reduced the number of energy over-reporters; however, other surveys reported similar or even smaller proportions of energy over-reporters to the proportion defined in our study [11–13]. In total, 7373 participants (2188 from 2000 and 5185 from 2005) remained. Exclusion criteria affected the following numbers of REGICOR 2000 and REGICOR 2005 participants: age, 518 and 665; missing values in energy intake, 1 and 28; extremely low energy intake, 112 and 30; and extremely high energy intake, 239 and 444, respectively. The project was approved by the local Ethics Committee (CEIC—PSMAR, Barcelona, Spain). All participants received the results of their examination.

**Anthropometric data**

Measurements were performed by a team of trained nurses and interviewers who used the same standard methods in both surveys. Weight was measured by a calibrated precision scale and rounded up to the nearest 200 g. Height was measured in the standing position and rounded up to the nearest 0.5 cm. Weight was divided by height squared (kg/m²) to establish the BMI. Obesity was considered with BMI ≥ 30 kg/m².

**Dietary intake data**

A validated [14,15] FFQ was administered by a trained interviewer to collect food consumption data. This 165-item food list, including alcoholic and non-alcoholic beverages, asked participants for their usual intakes over the preceding year. Individuals chose from 10 frequency categories, ranging from never or less than once per month to 6 or more times per day. Medium servings were defined by natural (e.g., 1 apple, 1 slice) or household units (e.g., 1 teaspoon, 1 cup).

Overall diet quality was determined by the modified Mediterranean diet score (mMDS) [16]; the published Pearson correlation for the energy-adjusted mMDS vs. multiple recalls was 0.48 [15]. The mMDS was calculated according to sex-specific, energy-adjusted tertile distribution of food consumption in the study population. For cereals, fruits, vegetables, legumes, fish, olive oil and nuts the lowest tertile was coded as 1, medium as 2, and highest as 3. For meat (including red meat, poultry and sausages) and for dairy products the score was inverted, with the highest tertile coded as 1 and lowest as 3. Moderate red wine consumption (up to 20 g) was included as a favourable component in the Mediterranean diet score, with a score of 3. Exceeding this upper limit or reporting no red wine consumption was coded as 0. Total mMDS scores ranged from 10 to 30.

**Implausible energy-reporting**

Implausible energy reporters were identified by the revised Goldberg method [17,18]. Basal metabolic rate (BMR) was calculated using the Mifflin equation [19]:

\[
BMR = (\text{Weight}_{\text{kg}} \times 9.99) + (\text{Height}_{\text{cm}} \times 6.25) - (\text{Age}_y \times 4.92) + 5 \quad \text{(among men)}
\]

\[
BMR = (\text{Weight}_{\text{kg}} \times 9.99) + (\text{Height}_{\text{cm}} \times 6.25) - (\text{Age}_y \times 4.92) + 161 \quad \text{(among women)}
\]

The index of variability (S) in components of energy balance was determined. The coefficients of variability (CV) in components of energy balance were approximate values for these CV parameters derived by pooling the means of several studies [20]. The applied values for intra-individual variations in repeated measures of energy intake (CV²_{wEI}), BMR (CV²_{wBMR}), and physical activity level (CV²_{wPA}), were 23%, 8.5%, and 15%, respectively [20]. The number of recording days was set to 365 because the FFQ captured one year of estimated food intake. An
individual physical activity level (PAL) was calculated and categorized according to quintile distribution of self-reported leisure-time physical activity (LTPA); sedentary = 1.35 (1st quintile), light = 1.55 (2nd quintile), moderately active = 1.75 (3rd quintile), active = 1.85 (4th quintile), and vigorous = 2.2 (5th quintile). Participants with BMR above or below the upper and lower 95% confidence interval limit of 1.96 standard deviations for plausible energy intake were characterized as implausible energy reporters.

The following formula was used:

\[
\text{Cut-off} = \text{PAL} \times \exp \left( \pm 1.96 \times \left( \frac{S}{100} \right) \right)
\]

where

\[
S = \sqrt{\frac{CV_d^2}{d} + CV_{\text{dEII}}^2 + CV_{\text{dBMR}}^2}
\]

Dietary patterns

The K-mean cluster algorithm, a non-hierarchical cluster analysis based on Euclidean distances, was used to derive dietary patterns. All individuals were placed in groups/clusters based on highest similarity and shortest distance to the cluster centre inside of the group and highest diversity and largest distance between cluster centres outside of the group.

The 165 food items of the FFQ were combined into 48 food groups according to similarities in their nutritional content. We used two methods to define clusters, based on absolute intakes of food groups and based on percentage of energy contribution of every food group. The results of both approaches did not differ significantly (not shown), therefore, according to the initial aims of the study we preferred the method using absolute intakes of food groups. To define the best cluster solution, several runs of cluster formation were performed. Criteria for cluster solutions were nutritional meaningfulness and a reasonable sample size (every cluster contained at least 5% of the study population). The final cluster solutions contained 7 and 5 clusters for 2000 and 2005, respectively. In both surveys, 3 meaningful clusters were retained and the rest of the clusters were removed as outliers due to insufficient size. In total, 32 (1.5%) and 20 (0.4%) participants in 2000 and 2005, respectively, were removed from further analysis. The same procedure was applied for separate cluster analyses in plausible energy reporters and in energy under-reporters. Among plausible energy reporters, 3 clusters remained after reaching a 5-cluster solution in both surveys and excluding from further analysis 10 (0.6%) and 15 (0.4%) participants in 2000 and 2005, respectively. Among energy under-reporters, 3 clusters remained after 6- and 5-cluster solutions in 2000 and 2005, respectively; 13 (2.2%) and 18 (1.3%) energy under-reporting participants, respectively, were excluded from further analysis.

We also performed cluster analysis in energy over-reporters, but, due to low prevalence of these participants (4.98% in the REGICOR 2000 and 4.96% in the REGICOR 2005), the cluster solutions were inconsistent. We joined the plausible energy reporters with energy over-reporters, and it resulted in similar clusters with those defined in only plausible energy reporters group. Therefore, we decided to include the energy over-reporters in the plausible energy reporters group. With fewer than 5% energy over-reporters, hardly comparable with the total proportion of plausible reporters, the combined group will be called "plausible energy reporters", without forgetting that it includes energy over-reporters for purposes of the cluster analysis.

We also performed cluster analysis with data pooled from both surveys. As explained above, we defined a three-cluster solution in the set of data with all participants and in the set of data with only plausible energy reporters.
Other variables

LTPA was measured by the validated Minnesota LTPA questionnaire administered by a trained interviewer [21,22]. Reported smoking habits and demographic and socioeconomic variables were obtained from structured standard questionnaires administered by trained personnel. Participants were categorized as never-smokers and ever-smokers. Maximum education level attained was elicited and recorded for analysis as primary school versus secondary school or university.

Statistical analysis

A univariate general linear model was used to define mean values of food consumption and other variables according to the cluster distribution. To define the p-value for linear trend, we used a univariate general linear model for continuous, logistic regression for categorical, and Kruskal-Wallis H test for non-parametric variables.

To compare characteristics of the clusters between surveys and between different categories of energy reporters, we used Student t-test for continuous, $\chi^2$ test for categorical, and Mann-Whitney U test for non-parametric variables.

Contingency tables were used for the cross-classification of clusters of all participants and clusters of plausible energy reporters. The proportion of subjects consistently categorized (same cluster) was calculated.

Fifteen percentage difference was considered as meaningful difference in food group consumption between different groups of participants[23].

Differences were considered significant if $p \leq 0.05$. Statistical analysis was performed using SPSS version 18.0. (SPSS Inc. Chicago, Ill., USA) and R.

Results

Three clusters were identified for each survey, according to main food consumption characteristics: “healthy”, “mixed”, and “western”. The distribution of the mMDS indicated the construct validity of these clusters. Significantly higher mMDS index scores were found in “healthy” cluster members, followed by mixed and western cluster members (Table 1). Therefore, the clusters were labelled according to the diet quality of every cluster measured by the mMDS.

In both surveys, the “mixed” cluster was the most prevalent, followed by the “western” and “healthy” clusters (Table 1). The highest proportion of energy under-reporting was found in the “mixed” cluster and the lowest in the “western” cluster in both surveys. Excluding energy under-reporters or analysing only this subgroup produced cluster solutions similar to the original data set (Table 1). Excluding energy under-reporters strongly decreased the proportion of the “mixed” cluster. Therefore, in plausible energy reporters “western” and “healthy” clusters had higher proportion of participants and the “mixed”—lower proportion in comparison with the original data set in the REGICOR 2000 survey. This was not the case in the REGICOR 2005 survey (Table 1). Cross-classification of individuals according to the original clusters and those obtained after excluding energy under-reporters showed that 68.7% in 2000 and 84.4% in 2005 were consistently placed into the same cluster.

Age and the proportion of women decreased across clusters (from “healthy” to “western”) in both surveys (Table 1). The opposite was observed for educational level and smoking. These findings were similar for cluster solutions of plausible and energy under-reporters (Table 1). The proportion of women increased in the “mixed” cluster of plausible and energy under-reporters of the 2000 survey, and was significantly higher compared to their 2005 peers. It is
Table 1. General characteristics of clusters in the REGICOR 2000 and 2005 surveys.a

| Variables                      | REGICOR 2000 |          |          |          | REGICOR 2005 |          |          |          |
|-------------------------------|--------------|----------|----------|----------|--------------|----------|----------|----------|
|                               | Healthy      | Mixed    | Western  | p<0.001  | Healthy      | Mixed    | Western  | p<0.001  |
| Clusters with all participants| 558 (25.9)   | 945 (43.8)| 653 (30.3)|          | 1276 (24.7) | 2349 (45.5)| 1540 (29.8)|          |
| Energy under-reporters        | 80 (14.3)    | 460 (48.7)| 57 (8.73)|          | 173 (13.6)  | 1071 (45.6)| 108 (7.01)|          |
| Clusters with energy plausible reporters | 616 (39.0) | 681 (54.6)|          |          | 988 (25.9)  | 1806 (47.3)| 1021 (26.8)|          |
| Clusters with energy under-reporters | 112 (19.1) | 235 (40.0)|          |          | 304 (22.7)  | 574 (42.9)| 459 (34.3)|          |
| Age, years                    |              |          |          |          |              |          |          |          |
| All participants              | 57.3         | 55.3*    | 49.3     | <0.001   | 58.0         | 56.4     | 49.2     | <0.001   |
| Plausible reporters           | 56.4, 58.2   | 54.7, 56.0| 48.5, 50.1|          | 57.4, 58.6   | 56.0, 56.8| 48.7, 49.7|          |
| Under-reporters               | 56.5, 58.1   | 53.5, 57.6| 49.7, 51.0|          | 57.0, 58.3   | 54.8, 55.7| 48.1, 49.4|          |
| Women, %                      | 65.6         | 55.4     | 26.3*    | <0.001   | 67.7         | 54.3     | 32.9     | <0.001   |
| Plausible reporters           | 66.9         | 70.3*    | 34.5*    | <0.001   | 69.5         | 57.6     | 28.6     | <0.001   |
| Under-reporters               | 61.6         | 67.1*    | 26.0     | <0.001   | 58.2         | 57.8     | 24.6     | <0.001   |
| High education, %             |              |          |          |          |              |          |          |          |
| All participants              | 24.7**       | 25.7**   | 38.6**   | <0.001   | 48.8         | 51.9     | 59.5     | <0.001   |
| Plausible reporters           | 24.8**       | 21.8**   | 37.0**   | <0.001   | 48.9         | 51.5     | 60.2     | <0.001   |
| Under-reporters               | 17.9**       | 22.5**   | 30.2**   | 0.008    | 48.0         | 49.1     | 63.6     | <0.001   |
| LTPA, METs min/d              |              |          |          |          |              |          |          |          |
| All participants              | 227*         | 195**    | 203      | 0.001    | 272          | 218      | 215      | <0.001   |
| Plausible reporters           | 113, 405     | 92.1, 336| 97.0, 371|          | 174, 451     | 113, 378 | 109, 397 |          |
| Under-reporters               | 196**        | 173      | 153**    | 0.01     | 249          | 171      | 203      | <0.001   |
| Smoking, %                    |              |          |          |          |              |          |          |          |
| All participants              | 12.5**       | 17.8**   | 35.8**   | <0.001   | 38.2         | 50.1     | 61.3     | <0.001   |
| Plausible reporters           | 11.9**       | 12.9**   | 31.8**   | <0.001   | 38.2         | 48.1     | 64.9     | <0.001   |
| Under-reporters               | 5.4**        | 12.9**   | 32.8**   | <0.001   | 46.4         | 45.3     | 63.4     | <0.001   |
| Obesity, %                    |              |          |          |          |              |          |          |          |
| All participants              | 28.7         | 29.6*    | 27.0**   | 0.48     | 28.1         | 25.3     | 18.6     | <0.001   |
| Plausible reporters           | 25.5         | 26.7     | 22.6*    | 0.20     | 25.5         | 19.6     | 18.9     | <0.001   |
| Under-reporters               | 40.2         | 40.4     | 40.0**   | 0.96     | 42.4         | 33.1     | 26.4     | <0.001   |
| Energy, kcal                  |              |          |          |          |              |          |          |          |
| All participants              | 2626         | 1914*    | 2852     | <0.001   | 2647         | 1975     | 2858     | <0.001   |
| Plausible reporters           | 2585, 2667   | 1882, 1946| 2814, 2891|          | 2621, 2673   | 1956, 1994| 2835, 2882|          |
| Under-reporters               | 2594**       | 2604**   | 2671**   | 0.008    | 2754         | 2359     | 2983     | <0.001   |
| Obesity, %                    |              |          |          |          |              |          |          |          |
| All participants              | 20.8**       | 19.2*    | 18.7     | <0.001   | 21.4         | 19.7     | 18.6     | <0.001   |
| Plausible reporters           | 20.5, 21.1   | 19.0, 19.4| 18.5, 18.9|          | 21.2, 21.5   | 19.5, 19.8| 18.4, 18.8|          |

(Continued)
important to note the considerable increase in the proportion of smokers from REGICOR 2000 to REGICOR 2005.

Obesity prevalence decreased across clusters only in the REGICOR 2005 survey (Table 1). The prevalence of obesity in nearly all clusters of plausible energy reporters decreased in comparison with all reporters in both surveys. More obese individuals were found in all clusters of energy under-reporters compared to plausible-reporter peers.

Diet quality measured by the mMDS decreased across clusters in both surveys, independently of energy reporting status and it was significantly higher among members of the “mixed” cluster in 2005 and of the “western” cluster in both surveys in energy under-reporters, compared to their plausible-reporter peers (Table 1). Overall dietary pattern characteristics identified by cluster analysis in all participants, plausible energy reporters and energy under-reporters were similar for both REGICOR surveys, 2000 and 2005 (Table 2). An inverse linear trend across clusters was observed for cooked and raw vegetables, pulses, cooked potatoes, fresh fish, olive oil, citrus and other fruits, nuts and low fat dairy (Table 2). A direct linear trend was found in fried potatoes, red meat, sausages, white bread, pastry, wine, fast food, soft drinks and high fat dairy.

### Energy under-reporting and dietary patterns within surveys

The amount of food consumption within the same survey was affected after excluding energy under-reporters from analysis (Fig 1). The “healthy” pattern did not have any meaningful changes in food consumption after exclusion of energy under-reporters, both in the REGICOR 2000 and 2005 surveys. Most of the changes occurred in the “mixed” pattern. The decreases occurred in consumption of such unhealthy food, as sausages, white bread, pastry, soft drinks and fast food, and such healthy food group, as pulses; and increases in such healthy food groups, as low fat dairy and citrus fruits, in the REGICOR 2000 survey. In the REGICOR 2005 survey the opposite was true. Energy consumption increased meaningfully only in the “mixed” pattern in both surveys (Fig 1). The “western” pattern was slightly affected by excluding energy

| Variables | REGICOR 2000 | REGICOR 2005 |
|-----------|--------------|--------------|
|           | Healthy      | Mixed        | Western      | p<sup>b</sup> | Healthy      | Mixed        | Western      | p<sup>b</sup> |
| Under-reporters<sup>g</sup> | 20.5<sup>*</sup> | 19.4 | 19.7 | 0.03 | 21.4 | 19.8 | 19.4 | <0.001 |
|           | 19.9, 21.1  | 19.0, 19.8  | 19.3, 20.1 |          | 21.1, 21.8  | 19.6, 20.1  | 19.1, 19.7 |          |

**Table 1.** (Continued)

LTPA, leisure-time physical activity; METs, metabolic equivalents; mMDS, modified Mediterranean diet score.

<sup>*</sup>p<0.05

<sup>**</sup>p <0.001 for differences between the REGICOR 2000 and 2005 surveys.

<sup>a</sup>Values are means and 95% C.I. or percentages (if specified).

<sup>b</sup>Polynomial contrasts were used to obtain p for linear trend in normal distributed continues variables (age, energy, mMDS), Kruskal-Wallis H test was used to obtain p value for non-parametric variables (LTPA), χ<sup>2</sup> test was used to obtain p for linear trend for categorical variables (women, high education, smoking, obesity).

<sup>c</sup>The proportion of energy under-reporters in the clusters of “all participants”.

<sup>d</sup>More than secondary school education.

<sup>e</sup>Median and 25th and 75th percentiles.

<sup>f</sup>Active smokers or ex-smokers less than 1 year.

<sup>g</sup>mMDS for plausible and energy under-reporters were calculated on the base of tertile distribution of food group consumption in all participants (according to survey).

doi:10.1371/journal.pone.0127647.t001
| Variables | Healthy | Mixed | Western | P-trend |
|-----------|---------|-------|---------|---------|
|           | 2000    | 2005  | 2000    | 2005    |         |
| Cooked vegetables, g/4.2 MJ | | | | |
| All participants | 61.6 | 56.9 | 37.4 | 37.3 | 27.8 | 26.5 | <0.001a |
| Plausible reporters | 58.6, 64.7 | 55.3, 58.4 | 35.0, 39.7 | 36.2, 38.5 | 25.0, 30.7 | 25.1, 28.0 | <0.001b |
| Under-reporters | 50.3, 56.0 | 52.2, 55.3 | 32.1, 34.6 | 31.8, 34.1 | 25.0, 29.7 | 24.0, 27.1 | <0.001b |
| Raw vegetables, g/4.2 MJ | | | | |
| All participants | 191 | 179 | 123* | 113 | 83.9 | 82.7 | <0.001a |
| Plausible reporters | 182, 199 | 174, 184 | 116, 129 | 109, 117 | 79.4, 94.5 | 78.3, 87.1 | <0.001b |
| Under-reporters | 168, 183 | 173, 183 | 94.8, 131 | 98.106 | 83.4, 95.6 | 75.5, 85.5 | <0.001b |
| Cooked potatoes, g/4.2 MJ | | | | |
| All participants | 34.5 | 33.9 | 26.7 | 27.1 | 24.1* | 21.8 | <0.001a |
| Plausible reporters | 32.0, 36.9 | 32.5, 35.3 | 24.8, 28.5 | 26.1, 28.1 | 21.9, 26.3 | 20.6, 23.1 | <0.001b |
| Under-reporters | 30.4, 34.7 | 30.4, 33.5 | 20.8, 31.3 | 25.2, 27.5 | 22.0, 25.6 | 20.0, 23.0 | <0.001b |
| Fried potatoes, g/4.2 MJ | | | | |
| All participants | 2.15 | 2.12 | 3.59* | 3.02 | 6.63** | 5.55 | <0.001a |
| Plausible reporters | 1.73, 2.57 | 1.89, 2.34 | 3.27, 3.92 | 2.85, 3.18 | 6.24, 7.02 | 5.34, 5.75 | <0.001b |
| Under-reporters | 1.96, 2.75 | 1.85, 2.35 | 2.86, 4.80 | 3.01, 3.38 | 5.46, 6.13 | 5.69, 6.18 | <0.001b |
| Pulses, g/4.2 MJ | | | | |
| All participants | 34.7 | 34.9 | 34.1** | 29.4 | 29.8* | 27.6 | <0.001b |
| Plausible reporters | 32.7, 36.8 | 33.9, 35.9 | 32.5, 35.6 | 28.7, 30.2 | 27.9, 31.6 | 26.7, 28.5 | <0.001b |
| Under-reporters | 32.8 | 33.6 | 28.4 | 28.0 | 29.3* | 27.6 | 0.001a |
| Red meat, g/4.2 MJ | | | | |
| All participants | 29.7* | 31.8 | 39.0 | 38.6 | 47.2 | 45.5 | <0.001a |
| Plausible reporters | 28.0, 31.4 | 30.7, 32.9 | 37.6, 40.3 | 37.8, 39.5 | 45.6, 48.8 | 44.5, 46.5 | <0.001b |
| Under-reporters | 30.4 | 31.8 | 34.7 | 37.6 | 45.4* | 47.8 | <0.001a |
| Sausages, g/4.2 MJ | | | | |
| All participants | 5.92* | 6.49 | 7.08* | 7.58 | 10.2 | 10.2 | <0.001a |
| Plausible reporters | 5.38, 6.45 | 6.13, 6.85 | 6.67, 7.49 | 7.31, 7.84 | 9.66, 10.7 | 9.88, 10.5 | <0.001b |

(Continued)
Table 2. (Continued)

| Variables                      | Healthy               | Mixed              | Western             | P-trend  |
|--------------------------------|-----------------------|--------------------|---------------------|----------|
|                                | 2000  | 2005  | 2000  | 2005  | 2000  | 2005  |        |
| Under-reporters                | 5.79,6.84  | 5.86,6.66  | 4.41,6.99  | 7.40,7.98  | 8.84,9.73  | 10.4,11.1  | <0.001<sup>b</sup> |
|                                | 5.74**  | 7.88  | 5.24**  | 7.08  | 9.82  | 9.16  | <0.001<sup>a</sup> |
|                                | 4.68,6.80  | 7.06,8.71  | 4.51,5.96  | 6.48,7.68  | 9.09,10.6  | 8.48,9.83  | <0.001<sup>b</sup> |
| Fresh fish, g/4.2 MJ           | 5.74**  | 7.88  | 5.24**  | 7.08  | 9.82  | 9.16  | <0.001<sup>a</sup> |
| All participants               | 31.2  | 28.9  | 20.5  | 20.2  | 16.4*  | 15.2  | <0.001<sup>a</sup> |
| Plausible reporters            | 29.6, 32.7  | 28.1, 29.7  | 19.3, 21.6  | 19.6, 20.8  | 15.0, 17.8  | 14.5, 16.0  | <0.001<sup>b</sup> |
| Under-reporters               | 25.7,28.2  | 27.0,28.7  | 16.6,23.0  | 17.3,18.5  | 15.4,17.6  | 14.2,15.9  | <0.001<sup>b</sup> |
| Rice & Pasta, g/4.2 MJ         | 31.2  | 28.9  | 20.5  | 20.2  | 16.4*  | 15.2  | <0.001<sup>a</sup> |
| All participants               | 26.9  | 27.8  | 19.8  | 17.9  | 16.5*  | 15.0  | <0.001<sup>a</sup> |
| Plausible reporters            | 24.0,27.0  | 26.2,28.7  | 23.1,30.4  | 25.6,27.5  | 23.6,26.1  | 26.6,29.0  | 0.723<sup>b</sup> |
| Under-reporters               | 25.7  | 27.9  | 31.4  | 31.2  | 29.5  | 31.1  | 0.261<sup>a</sup> |
| Olive oil, g/4.2 MJ            | 25.7  | 27.9  | 31.4  | 31.2  | 29.5  | 31.1  | 0.261<sup>a</sup> |
| All participants               | 31.2  | 28.9  | 20.5  | 20.2  | 16.4*  | 15.2  | <0.001<sup>a</sup> |
| Pastry, g/4.2 MJ               | 4.68,6.80  | 7.06,8.71  | 4.51,5.96  | 6.48,7.68  | 9.09,10.6  | 8.48,9.83  | <0.001<sup>b</sup> |
| All participants               | 31.2  | 28.9  | 20.5  | 20.2  | 16.4*  | 15.2  | <0.001<sup>a</sup> |
| Plausible reporters            | 29.6, 32.7  | 28.1, 29.7  | 19.3, 21.6  | 19.6, 20.8  | 15.0, 17.8  | 14.5, 16.0  | <0.001<sup>b</sup> |
| Under-reporters               | 25.7,28.2  | 27.0,28.7  | 16.6,23.0  | 17.3,18.5  | 15.4,17.6  | 14.2,15.9  | <0.001<sup>b</sup> |
| Under-reporters               | 29.0*  | 34.9  | 27.6  | 24.0  | 20.8*  | 17.3  | 0.003<sup>a</sup> |
| Citrus fruits, g/4.2 MJ        | 26.9  | 27.8  | 19.8  | 17.9  | 16.5*  | 15.0  | <0.001<sup>a</sup> |
| All participants               | 24.0,27.0  | 26.2,28.7  | 23.1,30.4  | 25.6,27.5  | 23.6,26.1  | 26.6,29.0  | 0.723<sup>b</sup> |
| Plausible reporters            | 25.7  | 27.9  | 31.4  | 31.2  | 29.5  | 31.1  | 0.261<sup>a</sup> |
| Under-reporters               | 26.8**  | 33.0,36.9  | 24.5,30.6  | 22.6,25.4  | 17.7,23.9  | 15.7,18.9  | <0.001<sup>b</sup> |
| White bread, g/4.2 MJ          | 29.0  | 34.9  | 27.6  | 24.0  | 20.8*  | 17.3  | 0.003<sup>a</sup> |
| All participants               | 26.9  | 27.8  | 19.8  | 17.9  | 16.5*  | 15.0  | <0.001<sup>a</sup> |
| Plausible reporters            | 24.0,27.0  | 26.2,28.7  | 23.1,30.4  | 25.6,27.5  | 23.6,26.1  | 26.6,29.0  | 0.723<sup>b</sup> |
| Under-reporters               | 25.7  | 27.9  | 31.4  | 31.2  | 29.5  | 31.1  | 0.261<sup>a</sup> |
| Under-reporters               | 26.8  | 33.0,36.9  | 24.5,30.6  | 22.6,25.4  | 17.7,23.9  | 15.7,18.9  | <0.001<sup>b</sup> |
| Olive oil, g/4.2 MJ            | 26.9  | 27.8  | 19.8  | 17.9  | 16.5*  | 15.0  | <0.001<sup>a</sup> |
| All participants               | 24.0,27.0  | 26.2,28.7  | 23.1,30.4  | 25.6,27.5  | 23.6,26.1  | 26.6,29.0  | 0.723<sup>b</sup> |
| Plausible reporters            | 25.7  | 27.9  | 31.4  | 31.2  | 29.5  | 31.1  | 0.261<sup>a</sup> |
| Under-reporters               | 26.8**  | 33.0,36.9  | 24.5,30.6  | 22.6,25.4  | 17.7,23.9  | 15.7,18.9  | <0.001<sup>b</sup> |
| Under-reporters               | 29.0*  | 34.9  | 27.6  | 24.0  | 20.8*  | 17.3  | 0.003<sup>a</sup> |
| Under-reporters               | 26.8**  | 33.0,36.9  | 24.5,30.6  | 22.6,25.4  | 17.7,23.9  | 15.7,18.9  | <0.001<sup>b</sup> |
| (Continued)
Table 2. (Continued)

| Variables                        | Healthy               | Mixed                  | Western                | P-trend |
|----------------------------------|-----------------------|------------------------|------------------------|---------|
|                                  | 2000 | 2005 | 2000 | 2005 | 2000 | 2005 | 2000 | 2005 |
| Other fruits, g/4.2 MJ           |      |      |      |      |      |      |      |      |
| All participants                 | 222  | 151  | 129  | 108  | 81.3 | 74.9 | 0.001 <a |
| Plausible reporters              | 213  | 147  | 122  | 105  | 73.2 | 79.6 | 0.001 <b |
| Under-reporters                  | 209  | 156  | 139  | 104  | 88.1 | 68.8 | 0.001 <a |
|                                  | 201  | 151  | 118  | 100  | 81.1 | 63.7 | 0.001 <b |
| Nuts, g/4.2 MJ                   |      |      |      |      |      |      |      |      |
| All participants                 | 6.42 | 7.60 | 4.46 | 4.51 | 4.32 | 2.22 | 0.001 <a |
| Plausible reporters              | 5.86 | 7.94 | 4.02 | 4.26 | 3.80 | 4.08 | 0.001 <b |
| Under-reporters                  | 6.05 | 8.18 | 5.01 | 4.63 | 4.50 | 3.17 | 0.001 <a |
| Wine, g/4.2 MJ                   |      |      |      |      |      |      |      |      |
| All participants                 | 17.0 | 15.8 | 33.8 | 28.3 | 46.6 | 29.9 | 0.001 <a |
| Plausible reporters              | 13.1 | 13.7 | 30.8 | 26.8 | 43.0 | 30.8 | 0.001 <b |
| Under-reporters                  | 17.3 | 15.2 | 22.5 | 25.6 | 44.7 | 31.7 | 0.001 <a |
| Softdrinks, g/4.2 MJ             |      |      |      |      |      |      |      |      |
| All participants                 | 6.06 | 5.24 | 10.8 | 11.5 | 21.1 | 28.7 | 0.001 <a |
| Plausible reporters              | 3.01 | 3.07 | 8.46 | 9.11 | 18.2 | 26.7 | 0.001 <b |
| Under-reporters                  | 6.41 | 5.01 | 7.37 | 11.5 | 19.3 | 33.0 | 0.001 <a |
| High fat dairy, g/4.2 MJ         |      |      |      |      |      |      |      |      |
| All participants                 | 30.5 | 31.6 | 55.0 | 46.1 | 59.4 | 62.6 | 0.001 <a |
| Plausible reporters              | 24.7 | 28.1 | 50.6 | 43.5 | 54.0 | 59.4 | 0.001 <b |
| Under-reporters                  | 33.8 | 30.0 | 52.4 | 55.4 | 65.5 | 59.3 | 0.001 <a |
| Low fat dairy, g/4.2 MJ          |      |      |      |      |      |      |      |      |
| All participants                 | 24.9 | 15.5 | 27.7 | 31.4 | 42.8 | 52.6 | 0.001 <a |
| Plausible reporters              | 104  | 107  | 81.9 | 91.4 | 30.1 | 37.7 | 0.001 <a |
| Under-reporters                  | 96.9 | 102 | 76.2 | 88.0 | 23.2 | 33.4 | 0.001 <b |
| Fast food, g/4.2 MJ              |      |      |      |      |      |      |      |      |
| All participants                 | 0.13 | 0.1  | 0.30 | 0.17 | 0.69 | 0.63 | 0.001 <b |

(Continued)
Energy under-reporting and secular trends, between surveys

Excluding energy under-reporters had consequences for secular trends of food consumption and prevalence of participants in the same type of cluster between surveys (Fig 2). Secular trends of carbohydrate, protein, and energy intake were increased for plausible reporters and under-reporters in both surveys (Table 2).

### Table 2. (Continued)

| Variables | Healthy | Mixed | Western | P-trend |
|-----------|---------|-------|---------|---------|
|           | 2000    | 2005  | 2000    | 2005    | 2000    | 2005    |         |
| Plausible reporters | 0.11 | 0.09 | 0.12 | 0.16 | 0.57* | 0.77 | <0.001a |
| Under-reporters | -0.01,0.24 | -0.01,0.19 | -0.19,0.44 | 0.08,0.23 | 0.46,0.67 | 0.68,0.87 | <0.001b |
| Carbohydrates, % | 0.01 | 0.08 | 0.37 | 0.08 | 0.53 | 0.25 | 0.099a |
|          | -0.33,0.52 | -0.02,0.17 | 0.08,0.66 | 0.007,0.15 | 0.24,0.82 | 0.17,0.33 | 0.008b |
| Under-reporters | 45.1 | 42.8 | 41.6 | 40.8 | 39.1 | 40.0 | <0.001a |
|          | 44.4,45.7 | 42.4,43.1 | 41.1,42.1 | 40.5,41.1 | 38.6,39.7 | 39.7,40.4 | <0.001b |
| Proteins, % | 44.9 | 43.1 | 40.6 | 40.8 | 39.4 | 39.6 | <0.001a |
|          | 44.3,45.5 | 42.7,43.6 | 39.2,42.1 | 40.5,41.1 | 38.9,39.9 | 39.2,40.0 | <0.001b |
| Under-reporters | 46.6 | 40.5 | 42.3 | 41.8 | 39.6 | 40.4 | <0.001a |
|          | 45.1,48.1 | 39.7,41.3 | 41.3,43.3 | 41.2,42.4 | 38.6,40.6 | 39.7,41.0 | 0.799b |
| Lipids, % | 18.5 | 18.7 | 17.9 | 17.5 | 17.2 | 16.9 | <0.001a |
|          | 18.3,18.8 | 18.5,18.8 | 17.7,18.1 | 17.4,17.6 | 17.0,17.4 | 16.7,17.0 | <0.001b |
| Proteins, % | 18.1 | 18.5 | 17.0 | 16.9 | 17.2 | 16.8 | <0.001a |
|          | 17.9,18.3 | 18.3,18.6 | 16.5,17.5 | 16.8,17.0 | 17.0,17.4 | 16.7,17.0 | <0.001b |
| Under-reporters | 19.1 | 20.1 | 18.8 | 18.4 | 18.0 | 17.3 | 0.006a |
|          | 18.4,19.7 | 19.7,20.4 | 18.4,19.3 | 18.1,18.6 | 17.5,18.4 | 17.0,17.5 | <0.001b |
| Lipids, % | 37.8 | 40.1 | 40.2 | 41.7 | 41.2 | 42.5 | <0.001a |
|          | 37.2,38.4 | 39.7,40.4 | 39.8,40.7 | 41.5,42.0 | 40.7,41.7 | 42.2,42.8 | <0.001b |
| Proteins, % | 38.3 | 39.9 | 42.9 | 42.5 | 41.5 | 42.5 | <0.001a |
|          | 37.8,38.9 | 39.6,40.3 | 41.5,44.2 | 42.2,42.8 | 41.4,19 | 42.2,42.9 | <0.001b |
| Under-reporters | 35.6 | 40.5 | 39.8 | 40.4 | 39.4 | 41.0 | <0.001a |
|          | 34.2,37.0 | 39.7,41.2 | 38.9,40.8 | 39.9,40.9 | 38.4,40.3 | 40.4,41.6 | 0.252b |
| Energy, MJ | 11.0 | 11.1 | 8.01* | 8.26 | 11.9 | 12.0 | <0.001a |
|          | 10.8,11.2 | 11.0,11.2 | 7.87,8.14 | 8.18,8.34 | 11.8,12.1 | 11.9,12.1 | <0.001b |
| Proteins, % | 10.9** | 11.5 | 10.9** | 9.87 | 11.2** | 12.5 | 0.008a |
|          | 10.7,11.0 | 11.4,11.6 | 10.5,11.3 | 9.78,9.96 | 11.0,11.3 | 12.4,12.6 | <0.001b |
| Under-reporters | 7.68* | 7.98 | 6.59 | 6.58 | 7.64 | 8.09 | 0.848a |
|          | 7.38,7.97 | 7.82,8.14 | 6.39,6.80 | 6.46,6.69 | 7.43,7.85 | 7.96,8.22 | 0.324b |

Values are means and 95% C.I. or percentages and 95% C.I. 
P for linear trend was obtained using polynomial contrasts.  
*p-trend for the REGICOR 2000 survey.  
**p-trend for the REGICOR 2005 survey.  
*p-value ≤ 0.05 and **p-value<0.001 for the comparison of the REGICOR 2000 and 2005.  

A multivariate analysis was undertaken to determine which factors were independently associated with energy under-reporting, taking into account age, sex, and education. Under-reporters had lower levels of education compared to plausible reporters. The percentage of under-reporters was significantly higher among participants with less education (p < 0.001) and lower among those with higher education (p < 0.001).  

Under-reporters, only low-fat dairy in the REGICOR 2000 survey, and soft drinks and fast food in the REGICOR 2005 survey were increased.

Energy under-reporting and secular trends, between surveys

Excluding energy under-reporters had consequences for secular trends of food consumption and prevalence of participants in the same type of cluster between surveys (Fig 2). Secular trends...
The trend of prevalence of the participants shifted towards higher prevalence of the “mixed” pattern with a 40.9% increase in the REGICOR 2005 survey, and subsequent decreases of the “healthy” and “western” patterns, 13.1% and 27.8%, respectively.

Less healthy perceived food. In the “healthy” cluster, all food groups with meaningful changes of secular trends had the same direction in both all reporters and plausible energy reporters (Fig 2). Among them, pastry, soft drinks, and fast food consumption decreased. Main changes in the food consumption occurred in the “mixed” dietary pattern. The direction of meaningful secular trends changed to the opposite direction in pastry and fast food in this pattern (Fig 2). In the “mixed” cluster six food groups showed meaningful changes only in plausible energy reporters, where the unhealthy food groups, such as sausages, white bread and soft drinks increased the consumption. In the same cluster high fat dairy only in all reporters and fried potatoes in both, all and plausible energy reporters decreased meaningfully (Fig 2). In the “western” cluster consumption of sausages, white bread, and pastry increased only in plausible energy reporters, and soft drinks in both all and plausible energy reporters (Fig 2).
**Healthy perceived foods.** In the “healthy” cluster all fruits consumption decreased and nuts consumption increased over time (Fig 2). Such food groups of the “mixed” clusters, as cooked vegetables, citrus fruits and low fat dairy decreased only in plausible energy reporters. However, consumption of olive oil increased in both all and plausible energy reporters (Fig 2). In the “western” pattern the direction of meaningful secular trends changed to the opposite direction in low fat dairy, it decreased in plausible energy reporters. Also, fruits and wine consumption decreased in plausible energy reporters only and in both all and plausible energy reporters, respectively (Fig 2).

**Pooled analysis.** Cluster analysis of the data pooled from both surveys gave similar cluster solutions to the clusters analysed separately in every survey (not shown). Clusters with all participants and only with plausible energy reporters had three-cluster solutions, with “healthy”, “mixed” and “western” patterns, similar to the cluster solutions with all participants and plausible energy reporters in each survey. In plausible energy reporters, we defined two sets of three-cluster solutions, which had similar clusters but different proportions. One set had similar proportions between clusters and another set had a very low proportion of participants in the “mixed” cluster (not shown).

**Discussion**

Using cluster analysis of both cross-sectional surveys, REGICOR 2000 and REGICOR 2005, we identified three dietary patterns: “healthy”, “mixed” and “western”. Similar dietary patterns were defined in all participants, plausible energy reporters, and energy under-reporters. Energy underreporting affected distribution of the participants between clusters, secular trends of food consumption and amounts of food consumed in the “mixed” and “western” dietary patterns.
Our study is the first to construct dietary patterns for energy under-reporters and analyse them separately from data for all participants and for plausible energy reporters.

The dietary patterns defined in our study population resembled those defined in other populations in Europe and the USA [24–34]. Most of these studies had analogues to our “healthy”, “mixed” and “western” patterns regarding sociodemographic, lifestyle and dietary characteristics. The proportion of energy under-reporters in our population (26%-27%) was comparable with some studies [35–37] but lower than others [29,32,38]. The distribution of energy under-reporters among dietary patterns also differed between studies. In several studies, a “healthy” dietary pattern had the highest proportion of energy under-reporters [32,38]. In another study, energy under-reporters among women were distributed evenly [29], but Martikainen et al. [37] reported uneven distribution. In the present study, the gender distribution between different dietary patterns was uneven in all groups of participants. Also, the “mixed” pattern had the highest proportion of energy under-reporters and the highest number of participants, similar to the “convenience” dietary pattern in men reported by Pryer et al. [29]. Therefore, the “mixed” pattern in the REGICOR 2000 survey was most affected by energy under-reporting.

Effect of under-reporting on post-hoc dietary pattern analysis within surveys

Excluding energy under-reporters did not alter the general structure of the dietary patterns. At the same time, excluding energy under-reporters affected socio-demographic and lifestyle characteristics, food consumption, and distribution of participants between patterns. Bailey et al. [35] showed that seven of 25 food groups of dietary patterns changed consistently after excluding energy under-reporters, in the present study we found nine and five groups out of twenty with meaningful changes within the REGICOR 2000 and 2005 surveys respectively. The “healthy” pattern was not affected meaningfully by exclusion of energy under-reporters, probably, due to low prevalence of energy under-reporters in this dietary pattern and similarity of diet quality, according to the mMDS measurement between all participants and energy under-reporters of the “healthy” cluster. The strongest impact the exclusion of energy under-reporters had on the “mixed” pattern, especially in the REGICOR 2000 survey. The dramatic decrease in the proportion of participants in the “mixed” pattern of the REGICOR 2000 after exclusion of energy under-reporters (43.8% vs. 6.40%) underlined the importance of considering energy under-reporters in the analysis of nutritional surveys data and in the construction of dietary patterns. In the “western” cluster just few food groups were affected by excluding energy under-reporters. This difference in effect of energy under-reporters on the dietary pattern partially could be due to different prevalence of energy under-reporters in the patterns. In a study using principal component analysis [36], nutrient intakes were slightly higher in the patterns with plausible energy reporters, but the association of nutrients with dietary patterns remained the same. In another study [32], the dietary patterns remained similar after exclusion of energy under-reporters and in one more study [37], 70% of plausible energy reporters fell into the same dietary patterns as in the analysis of all participants. This was comparable with the results obtained in the present study. It is of importance to note that the exclusion of energy under-reporters in the REGICOR 2000 caused meaningful changes both in healthy and unhealthy food groups and in different directions, with slight predominance of decreases in unhealthy food groups in the REGICOR 2000 and increases of those food groups in the REGICOR 2005 surveys. We did not reveal a constant pattern of changes, and we suppose, it was due to strong change in the proportion of participants between patterns after excluding the energy under-reporters in the REGICOR 2000.
Effect of under-reporting on secular trends between surveys

Secular trends, changes occurred between two different samples of the same population in a certain period of time, of dietary patterns found in the present study were stable in sociodemographic and lifestyle characteristics. We found increases only in two variables: physical activity, especially in the "healthy" (19.8%) and "mixed" (11.8%) patterns, and level of education in all patterns. Lifestyle characteristics were more stable than dietary characteristics. Several changes in quantity of food consumption occurred from 2000 to 2005, such as the increase of soft drinks consumption in the "western" pattern (36.0%). This increase paralleled a considerable decline in consumption of wine (35.8%).

Energy under-reporters affected secular trends in food consumption in several food groups mostly in the "mixed", in less proportion in the "western", but not in the "healthy" patterns. Secular trends in the "healthy" pattern maintained the same direction and similar meaningful changes in food consumption both in all and plausible energy reporters (≥15% change in comparison with the REGICOR 2000 survey). Excluding energy under-reporters, the "healthy" pattern kept similar food consumption characteristics as the "healthy" pattern in original data set. An explanation for this finding could be healthy dietary habits of energy under-reporters [35,39,40], similar diet quality between all and energy under-reporters in the "healthy" cluster, according to the mMDS measurement, and low prevalence of energy under-reporters in the "healthy" cluster of the original data. These results confirm the theory that energy under-reporters tend to report healthier dietary habits [35,39,40]. The strongest changes in secular trends were found in the "mixed" pattern, what was expected, as the energy under-reporting provoked dramatic change in the percentage of the participants in this dietary pattern in the REGICOR 2000 survey. The changes after excluding energy under-reporters were characterized mainly by increases in consumption of unhealthy food groups and decreases of healthy food groups. In the "western" cluster the effect was the same, but less food groups were affected. This was slightly different from the effect the energy under-reporters had on the "mixed" and "western" patterns within the REGICOR 2000 survey, but similar to the REGICOR 2005. Some food groups in the "mixed" and "western" dietary patterns even had different directions of secular trends between all participants and plausible energy reporters. Since the large proportion of the energy under-reporters were excluded from the "mixed" pattern, the healthy food groups consumption in this pattern decreased and unhealthy food groups increased. However, it is difficult to draw any strong conclusions, as the proportion of the participants in the "mixed" pattern of the REGICOR 2000 survey decreased dramatically. Therefore, secular trends of prevalence of participants within the "mixed" pattern substantially increased and within "healthy" and "western" patterns decreased. These results highlight an impact of energy under-reporting on time trends in nutritional surveys. Energy under-reporting influenced consumption of both healthy and unhealthy food groups in different directions, therefore, it is difficult to predict how under-reporting can influence nutritional survey data analysis. Consequently, public health investigators should pay more careful attention every time they make conclusions without taking in account energy under-reporting.

To the best of our knowledge, only one previous study in an adult population has used the cluster approach to investigate secular trends of dietary patterns [5]. The study was performed in Brazil and two dietary patterns were revealed through surveys. The patterns were stable when analysed for sociodemographic and lifestyle characteristics, and for food consumption. The diet quality index remained constant, although the timeframe for manifestation of greater changes was very short (2007–2009). The increase in soft drink consumption was similar to our findings. Two explored patterns were similar to our "healthy" and "western" patterns, but the distribution of the individuals was uneven between the patterns (86.4–90.5% vs. 9.5–12.5%,...
respectively). A study from Korea also used the cluster approach in secular trends analysis but it was performed in adolescents [4]. The authors defined three analogous dietary patterns and impairment of dietary habits over time. In another study in adolescents, this time in the USA [3], the authors found stable patterns with principal component analysis. The patterns changed only slightly between 1998–1999 and 2003–2004. The only difference of note was the emergence of a new “fast food” pattern in boys; the patterns in girls were almost identical at both time points.

Besides cluster analysis, a priori analysis of dietary patterns has also been used to define secular trends in population dietary habits. Two independent studies in the USA analysed secular trends of dietary patterns using Heart Disease Prevention Eating Index [41] and Revised Diet Quality Index [42]. The timeframes of both surveys were long (20 and 30 years, respectively), reasonably allowing for major changes in dietary habits. Both studies revealed an overall improvement in the diet. Another study analysed secular trends for the traditional diet in Italy [43], using the Mediterranean Adequacy Index. In contrast with the USA studies, the diet of one geographic area of the Italian study sample underwent dramatic changes in all age ranges. The Mediterranean Adequacy Index decreased from 8.2–10.6 in 1967 to 2.9–6.2 in 1999. None of the mentioned studies above took into account energy under-reporting.

To look more carefully at the effect of energy underreporting on the secular trends of food consumption, we performed an additional analysis with data pooled from both surveys. The clusters from the pooled data did not differ from the clusters of the separate surveys. In one cluster solution of the plausible energy reporters, the proportion of the “mixed” cluster was dramatically decreased, as well as in the REGICOR 2000 data. In this manuscript we decided to focus on the effect of the energy under-reporters on secular trends, and pooled analysis is a good additional analysis, but it cannot fully cover the topic. Therefore, we preferred to use separate analysis.

**General characteristics of energy under-reporters**

To the best of our knowledge the present study is the first to analyse dietary patterns of energy under-reporters separately from plausible energy reporters. Therefore, we briefly discuss the main features of energy under-reporters and dietary patterns associated with energy under-reporting. The characteristics of energy under-reporters in the present study were echoed in the earlier investigations. Bailey et al. [35] demonstrated that energy under-reporters had higher BMI and waist circumference, and lower education than plausible energy reporters, but unlike in our study they smoked more. Additionally, they reported lower lipids consumption, on average 400 kcal less than plausible energy reporters. Similar characteristics were found in another study [32], where energy under-reporters also had higher BMI and lower education. As in the present study, they were older and more active than plausible energy reporters. The reported dietary habits of energy under-reporters differed in comparison with all reporters in all dietary patterns, which highlights the importance of considering energy under-reporters in the analysis of dietary data in nutritional epidemiology.

Three separate dietary patterns were identified in the energy under-reporters. This demonstrates that energy under-reporters also reported different dietary habits, and not always trending toward the consumption of healthier foods. The “western” pattern, known as the least healthy pattern, was identified with a similar proportion of individuals in the dietary patterns of all participants, of plausible energy reporters and of energy under-reporters. It has been shown that healthy dietary patterns are more prevalent in energy under-reporters compared to plausible energy reporters [36,38]. Therefore, we expected the energy under-reporters to report a healthier diet than the plausible energy reporters [35,39,40]. However, energy-adjusted
mMDS showed higher diet quality in energy under-reporters than in plausible energy reporters only in the “western” pattern in the REGICOR 2000 survey and in the “mixed” and “western” patterns in the REGICOR 2005 survey. On the other hand, these results are not surprising because energy under-reporters usually report lower amounts of all consumed foods along with higher proportion of intakes from foods perceived as healthy. Therefore, the diet score based on relative amounts, as in case of the mMDS, showed the reasonable values.

A limitation of the present study is the use of the FFQ, which could cause recall bias and provides an approximate amount of the consumed foods using an absolute measurement. Cluster analysis has its own weaknesses, such as arbitrary decisions made during the process of dietary patterns derivation, including number of clusters, type and standardization of variables, formation of food groups, etc. Furthermore, the Goldberg method is an indirect measure of energy misreporting, but is considered a reasonable approach in the face of the impossibility of applying a technique such as doubly labeled water in large-scale epidemiological studies to objectively measure energy underreporting. Assignment of a single PAL of 1.55 was based on the assumption of low activity levels among study participants, which results in a poor sensitivity to detect energy underreporters [44]. Additionally, the Schofield equations have been found to underestimate energy underreporters in obese individuals [45]. Therefore, we used the Mifflin equation to calculate BMR and applied individual PAL values, which improved sensitivity [44]. Finally, the results obtained in this study are population-specific and cannot be compared directly with the results in other populations.

Strengths of our study include the population-based design and the use of validated questionnaires. To our knowledge, no study has reported the results of separate cluster analysis comparing three groups: all participants, plausible energy reporters, and energy under-reporters.

This study contributes to the growing knowledge about the role of energy under-reporting in the analysis of dietary data and, particularly, in the exploration of dietary patterns defined by cluster analysis. In conclusion, energy under-reporting did not affect the structure of dietary patterns derived in 2000 and 2005, but did have an impact on the distribution of participants between dietary patterns and surveys, and influenced secular trends of food consumption and amounts of food consumed in the “mixed” and “western” dietary patterns. Analogous studies in other populations are needed to obtain a deeper understanding of the impact of energy under-reporting on the exploration of dietary data.

Acknowledgments
The authors appreciate the English revision by Elaine Lilly, PhD (Writers First Aid).

This research was supported by a grant (2FD097-0297-C02-01) from Fondo Europeo de Desarrollo Regional (FEDER); by scholarship for PhD formation from national program of university professors formation, FPU, from Ministry of Education of Spain (AP2010-3198); by portions of grants from Spain’s Ministry of Health (Ministerio de Sanidad y Consumo, Instituto de Salud Carlos III: FEDER [PI11/01900], FEDER [CB06/02/0029] and Red Investigación Cardiovascular, Programa HERACLES [RD12/0042]), and by a joint contract (CP03/00115) between the Instituto de Salud Carlos III and the Health Department of the Catalan Government (Generalitat de Catalunya), and AGAUR (2014 SGR 240). The CIBERESP and CIBER-OBN are an initiative of the Instituto de Salud Carlos III, Madrid, Spain.

Author Contributions
Conceived and designed the experiments: SFG MF RE AABA HS. Analyzed the data: ANF. Wrote the paper: ANF HS.
References

1. Diet, nutrition and the prevention of chronic diseases: scientific background papers of the joint WHO/FAO expert consultation. Geneva. Public Health Nutr. 2002; 7.

2. Wirfalt AK, Jeffery RW. Using cluster analysis to examine dietary patterns: nutrient intakes, gender, and weight status differ across food pattern clusters. J Am Diet Assoc. 1997; 97: 272–279. PMID: 9069044

3. Cutler GJ, Flood A, Hannon P, Neumark-Sztainer D. Major patterns of dietary intake in adolescents and their stability over time. J Nutr. 2009; 139: 323–328. jn.108.090928 [pii]; doi: 10.3945/jn.108.090928

4. Song Y, Park MJ, Paik HY, Joung H. Secular trends in dietary patterns and obesity-related risk factors in Korean adolescents aged 10–19 years. Int J Obes (Lond). 2010; 34: 48–56. ijo2009203 [pii]; doi: 10.1038/ijo.2009.203

5. Souza AM, Bezerra IN, Cunha DB, Sichieri R. Evaluation of food intake markers in the Brazilian surveillance system for chronic diseases—VIGITEL (2007–2009). Rev Bras Epidemiol. 2011; 14 Suppl 1: 44–52. S1415-790X2011000500005 [pii]. PMID: 22002141

6. Subar AF, Kipnis V, Troiano RP, Midthune D, Schoeller DA, Bingham S, et al. Using intake biomarkers to evaluate the extent of dietary misreporting in a large sample of adults: the O’PEN study. Am J Epidemiol. 2005; 158: 1–13. PMID: 12935299

7. Nielsen BM, Nielsen MM, Toubro S, Pedersen O, Astrup A, Sorensen TI, et al. Past and current body size affect validity of reported energy intake among middle-aged Danes. Am J Clin Nutr. 2009; 139: 2337–2343. Jn.109.112599 [pii]; doi: 10.3945/jn.109.112599

8. Devlin UM, McNulty BA, Nugent AP, Gibney MJ. The use of cluster analysis to derive dietary patterns: methodological considerations, reproducibility, validity and the effect of energy mis-reporting. Proc Nutr Soc. 71: 593 – 609. Pn.02665112000729 [pii]; doi: 10.1017/S0029665112000729

9. Grau M, Subirana I, Elosua R, Solanas P, Ramos R, Masia R, et al. Trends in cardiovascular risk factor prevalence (1995-2000-2005) in northeastern Spain. Eur J Cardiovasc Prev Rehabil. 2007; 14: 653–659. doi: 10.1097/00013281764429 00149831-200710000-00009

10. Willett W. Nutritional epidemiology. Oxford University Press, New York. 1998.

11. Mullaney L, O’Higgins AC, Cawley S, Doolan A, McCartney D, Turner MJ. An estimation of periconceptional under-reporting of dietary intake energy. J Public Health (Oxf). 2014. fdu086 [pii]; doi: 10.1093/pubmed/fdu086

12. Azizi F, Esmailzadeh A, Mirmiran P. Correlates of under- and over-reporting of energy intake in Tehranians: body mass index and lifestyle-related factors. Asia Pac J Clin Nutr. 2005; 14: 54–59. PMID: 15734708

13. Livingstone MB, Robson PJ, Black AE, Coward WA, Wallace JM, McKinley MC, et al. An evaluation of the sensitivity and specificity of energy expenditure measured by heart rate and the Goldberg cut-off for energy intake: basal metabolic rate for identifying mis-reporting of energy intake by adults and children: a retrospective analysis. Eur J Clin Nutr. 2003; 57: 455–463. doi: 10.1038/sj.ejcn.1601563

14. Schroder H, Covas MI, Marrugat J, Vila J, Pena A, ALCANTARA M, et al. Use of a three-day estimated food record, a 72-hour recall and a food-frequency questionnaire for dietary assessment in a Mediterranean Spanish population. Clin Nutr. 2001; 20: 429–437. doi: 10.1054/clnu.2001.0460 S0261-5614(01)90460-1 [pii]. PMID: 11534938

15. Benitez-Arciniega AA, Mendez MA, Baena-Diez JM, Rovira Martori MA, Soler C, Marrugat J, et al. Concurrent and construct validity of Mediterranean diet scores as assessed by an FFQ. Public Health Nutr. 2011; 14: 2015–2021. S1368980011001212 [pii]; doi: 10.1017/S1368980011001212

16. Schroder H, Marrugat J, Vila J, Covas MI, Elosua R. Adherence to the traditional Mediterranean diet is inversely associated with body mass index and obesity in a Spanish population. J Nutr. 2004; 134: 3355–3361. 134/12/3355 [pii]. PMID: 15570037

17. Mendez MA, Popkin BM, Buckland G, Schroder H, Amiano P, Barricarte A, et al. Alternative methods of accounting for underreporting and overreporting when measuring dietary intake-obsesity relations. Am J Epidemiol. 2011; 173: 448–458. kwq380 [pii]; doi: 10.1093/aje/kwq380

18. Goldberg GR, Black AE, Jebb SA, Cole TJ, Murgatroyd PR, Coward WA, et al. Critical evaluation of energy intake data using fundamental principles of energy physiology: 1. Derivation of cut-off limits to identify under-recording. Eur J Clin Nutr. 1991; 45: 569–581. PMID: 1810719

19. Mifflin MD, StJeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. A new predictive equation for resting energy expenditure in healthy individuals. Am J Clin Nutr. 1990; 51: 241–247. PMID: 2305711
20. Black AE. Critical evaluation of energy intake using the Goldberg cut-off for energy intake: basal metabolic rate. A practical guide to its calculation, use and limitations. Int J Obes Relat Metab Disord. 2000; 24: 1119–1130. PMID: 11039980

21. Elosua R, Marrugat J, Molina L, Pons S, Pujol E. Validation of the Minnesota Leisure Time Physical Activity Questionnaire in Spanish men. The MARATHOM Investigators. Am J Epidemiol. 1994; 139: 1197–1209. PMID: 8209878

22. Elosua R, Garcia M, Aguilar A, Molina L, Covas MI, Marrugat J. Validation of the Minnesota Leisure Time Physical Activity Questionnaire In Spanish Women. Investigators of the MARATDON Group. Med Sci Sports Exerc. 2000; 32: 1431–1437. PMID: 10949009

23. Ammerman AS, Lindquist CH, Lohr KN, Hersey J. The efficacy of behavioral interventions to modify dietary fat and fruit and vegetable intake: a review of the evidence. Prev Med. 2002; 35: 25–41. S0091743502910285 [pii]. PMID: 12079438

24. Berg CM, Lappas G, Strandhagen E, Wolk A, Toren K, Rosengren A, et al. Food patterns and cardiovascular disease risk factors: the Swedish INTERGENE research program. Am J Clin Nutr. 2008; 88: 289–297. 88/2/289 [pii]. PMID: 18689363

25. Engeset D, Alsaker E, Ciampi A, Lund E. Dietary patterns and lifestyle factors in the Norwegian EPIC cohort: the Norwegian Women and Cancer (NOWAC) study. Eur J Clin Nutr. 2005; 59: 675–684. 1602129 [pii]; doi: 10.1038/sj.1601978

26. Hearty AP, Gibney MJ. Comparison of cluster and principal component analysis techniques to derive dietary patterns in Irish adults. Br J Nutr. 2009; 101: 598–608. S0007114508014128 [pii]; doi: 10.1017/S0007114508014128 PMID: 18577300

27. Liu E, McKeown NM, Newby PK, Meigs JB, Vasan RS, Quatromoni PA, et al. Cross-sectional association of dietary patterns with insulin-resistant phenotypes among adults without diabetes in the Framingham Offspring Study. Br J Nutr. 2009; 102: 576–583. S0007114509220836 [pii]; doi: 10.1017/S0007114509220836 PMID: 19216828

28. Oliveira A, Rodrigues-Artales JF, Gaio R, Santos AC, Ramos E, Lopes C. Major habitual dietary patterns are associated with acute myocardial infarction and cardiovascular risk markers in a southern European population. Am J Diet Assoc. 2001; 111: 241–250. S0002-8223(10)101823-7 [pii]; doi: 10.1016/j.jada.2010.10.042

29. Pryer JA, Nichols R, Elliott P, Thakrar B, Brunner E, Marmot M. Dietary patterns among a national random sample of British adults. J Epidemiol Community Health. 2001; 55: 29–37. PMID: 11112948

30. Quatromoni PA, Copenhafer DL, Demissie S, D’Agostino RB, O’Horo CE, Nam BH, et al. The internal validity of a dietary pattern analysis. The Framingham Nutrition Studies. J Epidemiol Community Health. 2002; 56: 381–388. PMID: 11964437

31. Villegas R, Salim A, Collins MM, Flynn A, Perry JJ. Dietary patterns in middle-aged Irish men and women defined by cluster analysis. Public Health Nutr. 2004; 7: 1017–1024. doi: 10.1079/PHN2004638 S1368980004001314 [pii]. PMID: 15548339

32. Winkwist A, Hornell A, Hallmans G, Lindahl B, Weinæll H, Johansson I. More distinct food intake patterns among women than men in northern Sweden: a population-based survey. Nutr J. 2009; 8: 12. 1475-2891-8-12 [pii]; doi: 10.1186/1475-2891-8-12 PMID: 19228378

33. Wirfalt E, Mattisson I, Gullberg B, Berglund G. Food patterns defined by cluster analysis and their utility as dietary exposure variables: a report from the Malmo Diet and Cancer Study. Public Health Nutr. 2000; 3: 159–173. PMID: 10945833

34. Wirfalt E, Hedblad B, Gullberg B, Mattisson I, Andreassen O, Rosander U, et al. Food patterns and components of the metabolic syndrome in men and women: a cross-sectional study within the Malmo Diet and Cancer cohort. Am J Epidemiol. 2001; 154: 1150–1159. PMID: 11474521

35. Bailey RL, Mitchell DC, Miller C, Smiciklas-Wright H. Assessing the effect of underreporting energy intake on dietary patterns and weight status. J Am Diet Assoc. 2007; 107: 64–71. S0002-8223(06)02283-8 [pii]; doi: 10.1016/j.jada.2006.10.009 PMID: 17197273

36. Krebs-Smith SM, Cleveland LE, Ballard-Barbash R, Cook DA, Kahle LL. Characterizing food intake patterns of American adults. Am J Clin Nutr. 1997; 65: 1264S–1268S. PMID: 9094931

37. Martikainen P, Brunner E, Marmot M. Socioeconomic differences in dietary patterns among middle-aged men and women. Soc Sci Med. 2003; 56: 1397–1410. S0277953602001375 [pii]. PMID: 12614692

38. Scaglìsi FB, Ferroli E, Pfrimer K, Laureano C, Cunha CS, Gualano B, et al. Under-reporting of energy intake is more prevalent in a healthy dietary pattern cluster. Br J Nutr. 2008; 100: 1060–1068. S0007114508971300 [pii]; doi: 10.1017/S0007114508971300 PMID: 18377688

39. Johnson RK, Goran MI, Poehlman ET. Correlates of over- and underreporting of energy intake in healthy older men and women. Am J Clin Nutr. 1994; 59: 1286–1290. PMID: 8198052
40. Lutomski JE, van den Broeck J, Harrington J, Shiely F, Perry IJ. Sociodemographic, lifestyle, mental health and dietary factors associated with direction of misreporting of energy intake. Public Health Nutr. 2011; 14: 532–541. S1368980010001801 [pii]; doi: 10.1017/S1368980010001801 PMID: 20707944

41. Lee S, Harnack L, Jacobs DR Jr., Steffen LM, Luepker RV, Arnett DK. Trends in diet quality for coronary heart disease prevention between 1980–1982 and 2000–2002: The Minnesota Heart Survey. J Am Diet Assoc. 2007; 107: 213–222. S0002-8223(06)02491-6 [pii]; doi: 10.1016/j.jada.2006.11.003 PMID: 17258957

42. Popkin BM, Zizza C, Siega-Riz AM. Who is leading the change?. U.S. dietary quality comparison between 1965 and 1996. Am J Prev Med. 2003; 25: 1–8. S0749379703000990 [pii]. PMID: 12818303

43. Alberti-Fidanza A, Fidanza F, Chiuchi MP, Verducci G, Fruttini D. Dietary studies on two rural Italian population groups of the Seven Countries Study. 3. Trend Of food and nutrient intake from 1960 to 1991. Eur J Clin Nutr. 1999; 53: 854–860. PMID: 10556997

44. Black AE. The sensitivity and specificity of the Goldberg cut-off for EI:BMR for identifying diet reports of poor validity. Eur J Clin Nutr. 2000; 54: 395–404. PMID: 10822286

45. Horgan GW, Stubbs J. Predicting basal metabolic rate in the obese is difficult. Eur J Clin Nutr. 2003; 57: 335–340. PMID: 12571669