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Citation:
Huybrechts, Inge, Lioret, Sandrine, Mouratidou, Theodora, Gunter, Marc J., Manios, Yannis, Kersting, Mathilde, Gottrand, Frederic, Kafatos, Anthony, De Henauw, Stefaan, Cuenca-García, Magdalena, Widhalm, Kurt, Gonzales-Gross, Marcela, Molnar, Denes, Moreno, Luis A. and McNaughton, Sarah A. 2017, Using reduced rank regression methods to identify dietary patterns associated with obesity: a cross-country study among European and Australian adolescents*, British journal of nutrition*, vol. 117, no. 2, pp. 295-305.

DOI: https://doi.org/10.1017/S0007114516004669

British Journal of Nutrition (2017), **117**, 295–305 doi:10.1017/S0007114516004669

Using reduced rank regression methods to identify dietary patterns associated with obesity: a cross-country study among European and Australian adolescents

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(Submitted 18 August 2016 – Final revision received 7 December 2016 – Accepted 21 December 2016 – First published online 7 Febraury 2017)

Abstract

This study aims to examine repeatability of reduced rank regression (RRR) methods in calculating dietary patterns (DP) and cross-sectional associations with overweight (OW)/obesity across European and Australian samples of adolescents. Data from two cross-sectional surveys in Europe (2006/2007 Healthy Lifestyle in Europe by Nutrition in Adolescence study, including 1954 adolescents, 12–17 years) and Australia (2007 National Children's Nutrition and Physical Activity Survey, including 1498 adolescents, 12–16 years) were used. Dietary intake was measured using two non-consecutive, 24-h recalls. RRR was used to identify DP using dietary energy density, fibre density and percentage of energy intake from fat as the intermediate variables. Associations between DP scores and body mass/fat were examined using multivariable linear and logistic regression as appropriate, stratified by sex. The first DP extracted (labelled 'energy dense, high fat, low fibre') explained 47 and 31 % of the response variation in Australian and European adolescents, respectively. It was similar for European and Australian adolescents and characterised by higher consumption of biscuits/cakes, chocolate/confectionery, crisps/savoury snacks, sugar-sweetened beverages, and lower consumption of yogurt, high-fibre bread, vegetables and fresh fruit. DP scores were inversely associated with BMI *z*-scores in Australian adolescent boys and borderline

Abbreviations: %BF, body fat percentage; ALSPAC, Avon Longitudinal Study of Parents and Children; DED, dietary energy density; DP, dietary pattern; FD, fibre density; HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence study; MVPA, moderate to vigorous physical activity; NCNPAS, National Children's Nutrition and Physical Activity Survey; OW, overweight; PA, physical activity; RRR, reduced rank regression; SB, sedentary behaviour; SES, socio-economic status.

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inverse in European adolescent boys (so as with %BF). Similarly, a lower likelihood for OW in boys was observed with higher DP scores in both surveys. No such relationships were observed in adolescent girls. In conclusion, the DP identified in this cross-country study was comparable for European and Australian adolescents, demonstrating robustness of the RRR method in calculating DP among populations. However, longitudinal designs are more relevant when studying diet–obesity associations, to prevent reverse causality.

Key words: **Dietary patterns: Adolescents: Reduced rank regression analysis: Healthy Lifestyle in Europe by Nutrition in Adolescence study: Australian National Children's Nutrition and Physical Activity Survey**

Obesity is a major public health concern in both developed and developing countries[1] with nutrition-related factors being one of the main determinants[2]. Individual foods and nutrients are part of the overall diet, with some arguing that this is one of the reasons why studies assessing diet–diseases associations, on the basis of individual foods and/or nutrients, fail to identify strong associations as the impact of many other dietary factors might be neglected[3]. Instead, studying dietary patterns (DP) is suggested as a complementary and more comprehensive and powerful method to investigate such associations[4–7].

There are a number of methods to derive DP, namely the development of diet quality scores or indices based on *a priori* knowledge of dietary guidelines or the use of multivariate statistical methods[8]. These statistical methods are *a posteriori* data reduction techniques, which summarise the variation in food intakes into a small number of patterns or clusters. Principal component analysis and cluster analysis are commonly used techniques to derive patterns and were shown to have good reproducibility across studies[9]. However, a newer method called reduced rank regression (RRR) is increasingly used in studies[4–7,10–13]. The RRR technique is often considered a hybrid method as it combines multivariate approaches with existing knowledge of diet–disease associations, and may provide novel understanding of the pathways through which diet influences disease.

RRR has been used with a wide range of health outcomes and intermediate markers in adults[4–7,14–19]. However, its use in adolescents is less widespread[11–13]. Furthermore, a significant methodological issue facing dietary pattern research is reproducibility of DP across cohorts when such data-driven techniques are used. Few studies have, however, attempted to replicate the findings of other studies and investigate previously identified RRR DP[11,12,20,21].

Using data from 5- to 9-year-old children in the Avon Longitudinal Study of Parents and Children (ALSPAC), Johnson *et al.*[13] identified a dietary pattern that predicted dietary energy density (DED), fibre density (FD) and percentage of energy intake from fat (used as intermediate marker in the RRR analysis) and demonstrated that this was prospectively associated with fat mass (FM) and adiposity. This 'energy-dense, high-fat, low-fibre' dietary pattern was replicated at 7, 10 and 13 years in a subsequent study on the basis of same data set[20], showing similar, though attenuated longitudinal associations with adiposity measured up to 15 years of age. Appannah *et al.*[11,12] obtained a similar dietary pattern using the same RRR methodology in adolescents at 14 and 17 years of age from the Raine Study, a population-based cohort recruited in Perth, Western Australia, suggesting some reproducibility across these two cohorts.

The aim of this study was to further examine the repeatability of RRR methods across European and Australian samples of adolescents, using the Healthy Lifestyle in Europe by Nutrition in Adolescence study (HELENA) and the Australian National Children's Nutrition and Physical Activity Survey (NCNPAS), both collected in 2007. In addition, we tested a positive cross-sectional relationship hypothesised between the dietary pattern and obesity risk in the European and Australian samples of adolescents.

Methods

Study population

This study is based on the analysis of two cross-sectional surveys performed in 2007 among European (HELENA) and Australian (NCNPAS) adolescents, using similar dietary assessment method.

Healthy Lifestyle in Europe by Nutrition in Adolescence study. The HELENA study is a multicentre study focusing on lifestyle habits and nutritional status by region, cultural background, socio-economic status (SES), age and sex among European adolescents (12·5–17·5 years old) from ten European cities (Athens, Heraklion, Dortmund, Ghent, Lille, Pecs, Rome, Stockholm, Vienna and Zaragoza), and was conducted between 2006 and 2007. A random cluster sampling (all pupils, from a random selection of classes, from all schools in the ten European cities) of 3528 adolescents, stratified by geographical location, age and SES, was carried out. Because of logistical reasons, data from Heraklion and Pecs were not included in the dietary intake analysis (7 % of the total sample). Considering all the variables included in the models used in these analyses, data were available from 1954 participants aged 12·5–17·5 years. The study was approved by the Research Ethics Committees of each city involved. More details on operational and sampling procedures have been published elsewhere[22].

Dietary intake assessment. Dietary intake was assessed using the self-administered, computerised 24-h recalls HELENA-Dietary Assessment Tool (DIAT) on the basis of Young Adolescents' Nutrition Assessment software (YANA-C). The validity of the tool in European adolescents for all nutrients and energy intakes, expressed as Spearman correlations, ranged from rs 0·86 to 0·91[23,24]. The adolescents completed the 24-h recalls twice[25] during school time and within a time span of 2 weeks; both times, trained dietitians were present. To calculate energy and nutrient intakes, data of the HELENA-DIAT were linked to

the German Food Code and Nutrient Database (Bundeslebensmittelschlussel (BLS) version II.3.1, 2005). For this purpose, culture-specific composite dishes were disaggregated into their basic food components, all of which were available in the German database.

Physical activity and sedentary behaviour assessments. Patterns of physical activity (PA) were assessed using the International Physical Activity Questionnaire for Adolescents (IPAQ-A)[26,27]. Data were cleaned and truncated following the guidelines provided by the IPAQ group (www.ipaq.ki.se)[26,27]. Variables obtained by the IPAQ-A for the current study were the time spent (min/week) in moderate PA, vigorous PA and moderate to vigorous physical activity (MVPA). Only the MVPA indicator was used in this paper. A binary indicator 'meeting PA recommendations' was created by dividing those who comply with the WHO recommendation of 60 min MVPA/d *v.* those who do not comply with this recommendation[28].

Sedentary behaviour (SB) was assessed by a self-reported HELENA questionnaire that was shown to be a reliable tool to be used in adolescents[29]. The questionnaire included daily minutes of the following sedentary items: television viewing, playing with computer, playing with console games, use of Internet for non-study reasons and use of Internet for study and studying/homework (lessons not included). The average time spent per day in each of those sedentary activities was calculated. In this analysis, total screen time (the sum of average min/d television viewing + playing with computer + playing with console games + use of Internet for non-study reasons + use of Internet for study), divided in quintiles, was used as indicator for screen SB.

Anthropometric measurements. Height, weight and six skinfolds were measured using standard procedures as described elsewhere[30]. BMI was calculated by dividing body weight in kilograms by squared body height in metres and then transformed to age- and sex-specific *z*-scores. BMI *z*-scores and overweight (OW) status (OW/obese *v.* thin/normal weight) were defined using age- and sex-specific cut-off values according to Cole *et al.*[31,32]. Skinfold thickness was measured at the triceps, biceps, subscapular, suprailiac, thigh and calf on the left side of the body using a Holtain Caliper (Holtain Ltd). Body fat percentage (%BF) and FM were calculated from skinfold thicknesses (triceps and subscapularis) using the equation of Slaughter *et al.*[33].

Socio-economic status. Among the various variables allowing the characterisation of SES in the HELENA study, we used maternal education level, defined in three categories, that is low education, high secondary education and university degree.

Australian National Children's Nutrition and Physical Activity Survey. The 2007 NCNPAS study aimed to assess food and nutrient intakes, PA participation, and to measure weight and height of a national sample of Australian children and adolescents aged 2–16 years. The sampling, selection and recruitment methodology are described in detail elsewhere[34]. Households were selected using random digit dialling of telephone numbers from within clusters based on postcode (stratified by state/territory and capital city/rest of state) and one child from each selected household was invited to participate. A total of 4487 children completed the entire survey with approximately equal representation of boys and girls in each of four age groups (2–3, 4–8, 9–13 and 14–16 years) from February to August 2007. Data were available from 1647 participants aged 12–16 years for this analysis.

Dietary intake assessment. Intake of foods and beverages was assessed using 24-h recall methodology using a computer-assisted interviewing system. The three-pass method consisted of the completion of a quick list of food and beverage items consumed, followed by the collection of detailed information for each item listed in the quick recall; and finally a review phase to allow respondents to report any foods that may have been forgotten. A food model booklet was provided to estimate food portion sizes. Each child completed 1 × 24-h recall during a home visit (via computer-assisted personal interview (CAPI)) and a second 24-h recall 7–21 days later by telephone (via computer-assisted telephone interview (CATI)). In order to capture intakes and activity patterns that would represent all types of days, the CAPI and the CATI were collected on different day types when possible. Nutrient intake was calculated by using a customised food composition database[35].

Physical activity and sedentary behaviour assessments. PA was measured using a previously validated computerised 24-h recall known as the Multimedia Activity Recall for Children and Adolescents[36]. Each child recalled 4 d worth of activity, 2 d before the CAPI and 2 d before the CATI. Children reported everything they did in the previous 48 h. Activity data collected as part of the children's survey include each child's PA level and the number of minutes per day spent in the following categories: MVPA, vigorous activity level, organised sport and play, free play, active transport, out of school hours screen time, television, video games, computer use, passive transport, non-screen SB and sleep. The number of minutes spent in these activities was calculated for each child on each of the 4 sampled days. Consistent with the variables used from the HELENA study, the average daily number of minutes children spent in MVPA (treated as binary, meeting the recommendation of 60 min MVPA/d) and average screen time (the sum of television, video games and computer times), divided in quintiles, were used in this analysis.

Anthropometric measurements. Weight and height were measured for all participants during the home visit[37]. BMI *z*-scores were calculated and categorised in the same way as outlined for HELENA[32].

Socio-economic status. Socio-demographic information about the households of the participants included in the children's survey was collected during the home visit, including information about the children and the parents or up to two caregivers. Consistent with the definition used in the HELENA study, maternal education (low education, high secondary education and university degree) was used as a proxy of SES.

Both the HELENA study and the Australian NCNPAS survey were conducted according to the guidelines laid down in the Declaration of Helsinki.

Statistical analysis

Harmonisation and preparation of dietary data in Healthy Lifestyle in Europe by Nutrition in Adolescence study and National Children's Nutrition and Physical Activity Survey. Food intake data were collapsed into forty-seven food groups according to usage or differences in energy density and fat and fibre contents as described for the ALSPAC study[13] with the addition of alcohol for these adolescent samples. Average absolute intakes (g/d) were computed for each food group. Consistent with the ALSPAC study[13], we estimated total energy intake (kJ/d), percentage of energy intake from fat, FD (g/MJ) and DED (kJ/g). DED was calculated, excluding drinks, by dividing total food energy (kJ) by total food weight (g) and FD by dividing NSP fibre intake (g) by total EI (MJ).

As under-reporting of energy intake is common, particularly among adolescents[38,39] and in OW populations, under-reporters were considered as individuals with a ratio of energy intake over estimated BMR, calculated with the equation of Schofield[40], lower than 0·96 according to the Goldberg cut-offs. The sensitivity and specificity of the Goldberg criterion to identify diet reports of poor validity has been previously tested[41,42]. Rather than excluding energy under-reporters, and consistent with Johnson *et al.*[13], a categorical variable indicating under-reporters *v.* plausible reporters was included as a potential confounder in statistical models.

All lifestyle and socio-demographic variables were harmonised, using the same indicators, as previously described. Extra inclusion criteria for the purpose of the current analysis included: having complete SES, PA and SB variables and having provided two 24-h dietary recalls resulting in 1954 adolescents for HELENA and 1498 for NCNPAS.

'Exploratory' reduced rank regression analysis. DP were determined using RRR in both HELENA and NCNPAS as previously described by Johnson *et al.*[13]. RRR determines factors from food intake data that maximise the explained variation in the intermediate markers that are hypothesised to be related to the health outcome. DED, percentage of energy intake from fat and FD were used as the intermediate markers. RRR analysis was conducted using SAS (version 9; SAS Institute). The number of DP extracted using RRR analysis is determined by the number of intermediate markers/variables. The first pattern explained 47 % for the Australian adolescents and 31 % for the European adolescents of the response variation in each cohort and was used in the subsequent analyses, as per Johnson *et al.*[13]. The cumulated explained variance by patterns 2 and 3 was rather low in both the European and Australian data set (<22 %) and was therefore not further considered in our analysis. RRR was run in the whole sample and separately in boys and girls. Because the sex-specific patterns were qualitatively the same as those derived from the whole sample, indicated by similar pattern loadings, the factor loadings derived from the whole sample were used in the present analysis (Table 1). Dietary pattern scores were calculated for each adolescent as a linear combination of all food group intakes with factor loadings' absolute value >0·15. Indeed, to interpret the results and calculate the scores, we retained the items most strongly related to each pattern, as recommended by Schulze *et al.*[43], that is those for which the absolute value of the loading coefficient was >0·15. This threshold was chosen accounting for the overall range of loadings observed in our data (i.e. the ranking of foods in the pattern) and both the interpretability and differentiation of each pattern.

The resulting DP were qualitatively compared between the two studies included in this paper (HELENA and NCNPAS) and also with the identified patterns from the ALSPAC cohort[13]. Associations were examined between dietary pattern scores and both BMI *z*-scores and OW using multivariable linear and logistic regression as appropriate. In addition, in HELENA, the association between dietary pattern scores and %BF was investigated via multivariable linear regression analysis. Analyses were stratified by sex due to observed significant differences in dietary intakes (e.g. energy intakes, etc.) between boys and girls and adjusted for the same covariates in both data sets, namely age, energy under-reporting status, meeting PA recommendations, screen sedentary time and maternal education level. Possible interactions between DP scores and under-reporting status were tested. STATA version 12 was used to perform the regression analysis. *P* values <0·05 were considered to be statistically significant.

Results

Characteristics of the study populations

This analysis included 1954 participants in the HELENA study (45 % boys; mean age of 14·6 (SD 1·2) years) and 1498 participants from the NCNPAS study (50 % boys; mean age 14·2 (SD 1·3) years). Table 1 shows the descriptive analysis of the studied variables stratified by sex, in both studies. Although not formally tested, few differences were identified between the populations of European *v.* Australian adolescents: energy intake was higher among Australian adolescents whereas the degree of under-reporting of energy intake was higher in European adolescents. Furthermore, screen time use was higher among European adolescents, whereas MVPA was higher among Australian adolescents. The prevalence of OW/obesity was higher in Australia. Sex differences were very similar in both studies: energy intake and DED were higher in boys whereas under-reporting was higher in girls; fibre intake was lower and DP scores were higher in boys; MVPA and screen time were higher in boys. However, OW and obesity prevalence was higher in European boys (HELENA study) only.

Dietary pattern scores in relation to diet

Table 2 shows the derived dietary pattern including the factor loadings of all food groups. The dietary pattern scores were highly correlated with DED (*r* 0·68 and 0·73 for HELENA and NCNPAS, respectively) and inversely with FD (*r* –0·59 and –0·65 for HELENA and NCNPAS, respectively) and low to moderately correlated with percentage of energy intake from fat (*r* 0·15 and 0·32 for HELENA and NCNPAS, respectively). Factor loadings from both surveys indicated that a high pattern score was associated with higher consumption of biscuits and cakes,

Table 1. Description of the adolescent population included in the analyses, stratified for the Healthy Lifestyle in Europe by Nutrition in Adolescence study (HELENA) and the Australian National Children's Nutrition and Physical Activity Survey (NCNPAS)
(Percentages and 95 % confidence intervals; mean values and standard deviations; medians and interquartile ranges)

	HELENA							NCNPAS						
	All (*n* 1954)		Boys (*n* 886)		Girls (*n* 1068)			All (*n* 1498)		Boys (*n* 742)		Girls (*n* 756)		
	%	95 % CI	%	95 % CI	%	95 % CI	*P*	%	95 % CI	%	95 % CI	%	95 % CI	*P*
Age (years)							0·28							0·23
Mean	14·6		14·6		14·6			14·2		14·2		14·15		
SD	1·2		1·2		1·2			1·3		1·3		1·31		
Maternal education level														
Low	31·5	29·5, 33·6	32·4	29·3, 35·5	30·8	28·0, 33·6		30·4	28·1, 32·8	31·8	28·4, 35·2	29·1	25·9, 32·3	
Intermediate	31·1	29·0, 33·1	29·5	26·4, 32·5	32·4	29·6, 35·2		39·1	36·6, 41·6	36·2	32·8, 39·7	41·9	38·4, 45·4	
High	37·4	35·3, 39·6	38·1	34·9, 41·3	36·8	33·9, 36·7	0·37	30·4	28·1, 32·8	31·9	28·6, 35·3	29·0	25·7, 32·2	0·079
Energy intake (kJ/d)							<0·0001							<0·0001
Mean	9081·9		10 470·6		7929·8			9488·9		10 821·3		8181·2		
SD	3281·7		3617·9		2434·3			3025·2		3104·6		2286·6		
Fibre intake (mg/kJ)							<0·0001							<0·0001
Mean	2·1		1·9		2·2			2·5		2·4		2·6		
SD	0·8		0·7		0·8			0·8		0·7		0·8		
Fat contribution to energy intake (%)							0·58							0·41
Mean	33·8		33·7		33·9			31·1		31·3		31·0		
SD	8·4		8·5		8·4			0·1		5·5		6·0		
Energy density of food intake (kJ/g)							<0·0001							<0·0001
Mean	7·9		8·2		7·6			7·9		8·1		7·6		
SD	1·9		2·0		1·9			1·7		1·6		1·7		
Dietary pattern score							<0·0001							<0·0001
Mean	−0·0		0·2		−0·2			0·0		0·2		−0·2		
SD	1·0		1·1		0·9			1·2		1·3		1·1		
Energy under-reporting status (under-reporters)	21·5	19·7, 23·3	19·5	16·9, 22·1	23·1	20·6, 25·7	0·054	12·7	11·1, 14·4	9·6	7·4, 11·7	15·9	13·3, 18·5	<0·0001
Screen time (min/d)							<0·0001							<0·0001
Median	242·1		286·1		214·3			227·5		258·7		196·2		
Interquartiles	160·7–368·6		186·4–398·6		146·8–330·0			156·2–306·2		183·7–338·7		131·9–276·9		
MVPA (min/d)							<0·0001							<0·0001
Median	81·4		96·4		70·0			97·5		118·1		79·4		
Interquartiles	40·0–150·7		51·4–171·4		35·0–132·9			56·2–148·7		75·0–170·0		45·0–126·2		
Meeting MVPA recommandations	62·1	59·9, 64·2	68·6	65·6, 71·7	56·6	53·7, 59·6	<0·0001	73·8	71·6, 76·1	82·2	79·4, 85·0	65·6	62·2, 69·0	<0·0001
Weight status														
Normal weight	79·0	77·2, 80·8	76·5	73·7, 79·3	81·1	78·7, 83·4		75·7	73·4, 77·7	76·0	72·9, 79·1	75·1	72·0, 78·2	
OW	15·8	14·2, 17·4	16·6	14·1, 19·0	15·2	13·0, 17·3		18·4	16·4, 20·3	18·6	15·8, 21·4	18·1	15·4, 20·9	
Obese	5·2	4·2, 6·1	6·9	5·2, 8·6	3·7	2·6, 4·9	0·004	6·1	4·9, 7·3	5·4	3·8, 7·0	6·7	5·0, 8·5	0·54
Body fat (%)							<0·0001							
Mean	22·7		19·1		25·7									
SD	10·2		11·8		7·5									

MVPA, moderate to vigorous physical activity; OW, overweight.

Table 2. Reduced rank regression factor loadings for the dietary patterns derived from the dietary intake assessments in European (Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA)) and Australian (National Children's Nutrition and Physical Activity Survey (NCNPAS)) adolescents

	HELENA	NCNPAS
High-fat milk and cream	0·018	0·151
Low-fat milk	−0·028	−0·108
Yogurts	−0·215†	−0·152†
Cheese	0·141	0·114
Butter and animal fat	0·139	0·118
Margarine and vegetable oils	0·107	0·081
Egg and egg dishes	0·037	0·081
Low-fibre bread	0·135	0·177†
High-fibre bread	−0·178†	−0·216†
Other bread products	0·093	0·054
High-fibre breakfast cereals	0·016	−0·156†
Other breakfast cereals	−0·101	0·001
Rice, pasta and other grains	−0·019	−0·166†
Cereal-based mixed meals		−0·018
Pizza		0·095
Biscuits and cakes	0·204†	0·159†
Puddings	0·066	0·032
Ice creams	0·050	0·079
Chocolate and confectionery	0·237†	0·216†
Spreads	0·001	−0·045
Meat and poultry	0·120	−0·011
Meat-mixed dishes		0·090
Processed meat	0·142	0·175†
Coated or breaded meat and fish	0·036	0·151†
Meat substitutes	−0·116	−0·069
Fish	−0·004	−0·052
Fried or roast potatoes	0·057	0·206†
Boiled or baked potatoes	−0·003	−0·128
Vegetables	−0·427†	−0·354†
Legumes	−0·177†	−0·125
Vegetable mixed dishes		−0·049
Fresh fruits	−0·570†	−0·474†
Other fruits	−0·054	−0·102
Nuts and seeds	−0·020	−0·035
Crisps and savoury snacks	0·180†	0·197†
Soups	−0·128	−0·216†
Sauces (low energy dense)	−0·012	−0·084
Sauces (high energy dense)	0·126	−0·003
Condiments		−0·055
Sugar-sweetened beverages	0·210†	0·198†
Low-energy beverages	0·060	0·062
Fruit juice	0·042	−0·052
Hot and powdered drinks	−0·051	0·001
Water	−0·108	−0·176†
Percentage contribution to the total inertia	30·5	46·6
Correlation with DED	0·68*	0·73*
Correlation with FD	−0·59*	−0·65*
Correlation with percentage of energy from fat	0·15*	0·32*

DED, dietary energy density; FD, fibre density.
* $P < 0·0001$.
† Factor loadings >0·15.

chocolate and confectionery, crisps and savoury snacks, sugar-sweetened beverages, and lower consumption of yogurt, high-fibre bread, vegetables, fresh fruit. In NCNPAS, a high pattern score was additionally associated with higher consumption of full-fat milk and cream, low-fibre bread, processed meat, fried potatoes, coated or breaded meat and fish and lower consumption of breakfast cereals, rice, pasta and other grains, soups and water as a beverage whereas a high pattern score was associated with a lower consumption of legumes in HELENA.

Dietary pattern scores in relation to social and lifestyle factors (potential confounders)

Dietary pattern scores were found to be positively associated with screen time (in both studies), whereas an inverse association was observed with meeting PA recommendations (in Europe only) (Table 3). Significant inverse associations were also found with maternal education in both data sets. No associations were found between the dietary pattern scores and energy intake or energy under-reporting among the Australian adolescents. However, among European adolescents a strong inverse association was found between the dietary pattern scores and under-reporting, and a positive association between the dietary pattern scores and energy intake.

Dietary pattern scores in relation to adolescents' BMI and body weight percentage

The multivariable regression analysis indicated that dietary pattern scores were inversely associated with BMI *z*-scores in Australian adolescent boys and borderline in European adolescent boys (Table 4). This inverse association was also borderline significant for %BF among European boys. Similarly, a lower likelihood for OW in boys was observed with higher DP scores in both surveys (though only significant in Australian boys $P = 0·03$). No such relationships were observed in adolescent girls in either data sets.

Social and lifestyle factors in relation to adolescents' BMI and body fat percentage

Maternal education level was inversely associated with any of the outcomes used (BMI *z*-scores, OW and %BF). Under-reporting was positively associated with all anthropometric outcomes and more in particular among boys, especially for %BF.

Among European girls, screen time was found to be positively associated with %BF only. In European boys, meeting MVPA recommendations was inversely associated with %BF. Although screen time was also positively associated with BMI *z*-scores and a higher risk for OW in Australian boys, no significant relationships were found with PA in the Australian data set.

There was no significant interaction between dietary pattern scores and under-reporting status in the multivariable analyses addressing the anthropometric measurements as dependent variables (Table 4), so therefore we did not stratify our analyses by under-reporting status. Besides, the factors loadings were similar across normal- and under-reporters (results not shown). Further adjustment for energy intake in the multivariable models hardly changed the associations between dietary pattern scores and any of BMI *z*-scores, OW and %BF (results not shown).

Discussion

This study aimed at comparing DP derived using RRR with energy density, percentage of energy intake from fat and FD as the intermediate variables from two wide-scale samples with

Table 3. Results from the multivariable linear regression analyses, with the energy-dense, low-fibre, high-fat dietary pattern as the dependent variable and lifestyle (dietary patterns scores, meeting physical activity (PA) recommendations, screen sedentary behaviour, energy under-reporting status) and socio-economic factors as the independent variables of interest in European (Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA)) and Australian (National Children's Nutrition and Physical Activity Survey (NCNPAS)) adolescents, respectively
(Linear regression coefficients and 95 % confidence intervals)

	Age-adjusted models							
	HELENA				NCNPAS			
	Boys (*n* 886)		Girls (*n* 1068)		Boys (*n* 742)		Girls (*n* 756)	
	Linear regression coefficient	95 % CI	Linear regression coefficient	95 % CI	Linear regression coefficient	95 % CI	Linear regression coefficient	95 % CI
Meeting PA recommandations								
No	0		0		0		0	
Yes	−0·30	−0·46, −0·14	−0·17	−0·29, −0·06	0·03	−0·22, 0·28	−0·20	−0·38, −0·03
P	<0·0001		0·004		0·83		0·025	
Screen sedentary behaviour								
Quintile 1	0		0		0		0	
Quintile 2	0·13	−0·13, 0·38	0·02	−0·14, 0·18	0·49	0·15, 0·83	0·24	0·01, 0·47
Quintile 3	0·18	−0·06, 0·42	0·13	−0·04, 0·29	0·66	0·34, 0·99	0·36	0·11, 0·60
Quintile 4	0·33	0·10, 0·56	0·24	0·06, 0·42	0·58	0·26, 0·90	0·39	0·14, 0·64
Quintile 5	0·56	0·33, 0·79	0·36	0·18, 0·54	0·63	0·32, 0·93	0·59	0·31, 0·87
P	<0·00001		0·0002		0·0005		0·0003	
Energy under-reporting status								
Normal reporters	0		0		0		0	
Under-reporters	−0·47	−0·65, −0·29	−0·29	−0·42, −0·16	−0·18	−0·50, 0·14	−0·12	−0·35, 0·10
P	<0·0001		<0·0001		0·26		0·29	
Maternal education level								
Low	0		0		0		0	
Intermediate	−0·33	−0·52, −0·15	−0·16	−0·30, −0·02	−0·05	−0·27, 0·17	0·03	−0·16, 0·23
High	−0·42	−0·59, −0·25	−0·34	−0·48, −0·21	−0·47	−0·70, −0·24	−0·42	−0·64, −0·21
P	<0·00001		<0·00001		0·0001		<0·00001	
Energy intake (kJ/d)	0·00045	0·00037, 0·00053	0·00041	0·00032, 0·00050	0·000027	−0·0000028, 0·000058	0·000034	0·0000018, 0·000070
P	<0·0001		<0·0001		0·075		0·06	

Table 4. Results from the multivariable linear and logistic regression analyses, with BMI *z*-scores, body fat percentage (%BF) and overweight (OW) as the dependent variables and lifestyle (dietary patterns scores, meeting physical activity (PA) recommendations, screen sedentary behaviour, energy under-reporting status) and socio-economic factors as the independent variables of interest in European (Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA)) and Australian (National Children's Nutrition and Physical Activity Survey (NCNPAS)) adolescents, respectively
(β Values and standard deviations; odds ratios (OR) and 95 % confidence intervals)

Studies	HELENA												NCNPAS							
Dependent variables	BMI *z*-scores				%BF				OW				BMI *z*-scores				OW			
	Boys		Girls		Boys		Girls		Boys		Girls		Boys		Girls		Boys		Girls	
	β	SD	β	SD	β	SD	β	SD	OR	95 % CI	OR	95 % CI	β	SD	β	SD	OR	95 % CI	OR	95 % CI
Age	−0·07	0·03	−0·05	0·03	−1·14	0·28	0·49	0·17	0·83	0·72, 0·96	0·85	0·74, 0·97	0·02	0·03	−0·06	0·03	1·03	0·89, 1·20	0·94	0·82, 1·08
P	0·015		0·07		<0·0001		0·005		0·01		0·02		0·62		0·055		0·66		0·41	
Dietary patterns scores	−0·06	0·03	−0·06	0·04	−0·62	0·32	−0·25	0·23	0·87	0·73, 1·03	1·04	0·87, 1·25	−0·08	0·03	0·00	0·03	0·85	0·73, 0·98	1·04	0·89, 1·22
P	0·057		0·11		0·052		0·28		0·10		0·65		0·008		0·97		0·03		0·62	
Meeting PA recommandations																				
No	0		0		0		0		1		1		0		0		1		1	
Yes	−0·09	0·08	0·05	0·07	−1·80	0·73	−0·17	0·44	0·71	0·49, 1·03	0·91	0·65, 1·27	0·06	0·10	−0·01	0·09	1·33	0·80, 2·23	1·11	0·76, 1·64
P	0·27		0·42		0·014		0·69		0·07		0·58		0·54		0·87		0·28		0·58	
Screen sedentary behaviour																				
Quintile 1	0		0		0		0		1		1		0		0		1		1	
Quintile 2	−0·02	0·13	0·02	0·09	−0·10	1·18	0·86	0·61	0·96	0·52, 1·76	0·88	0·54, 1·42	0·21	0·14	0·03	0·11	2·04	0·93, 4·46	1·34	0·81, 2·20
Quintile 3	−0·15	0·12	0·02	0·10	−0·87	1·13	1·45	0·64	0·65	0·36, 1·18	0·96	0·59, 1·56	0·35	0·13	0·03	0·12	2·14	1·00, 4·57	1·09	0·63, 1·87
Quintile 4	0·06	0·12	0·11	0·10	1·06	1·09	2·02	0·67	0·85	0·49, 1·49	1·28	0·78, 2·11	0·29	0·13	0·16	0·12	2·61	1·25, 5·45	1·67	0·98, 2·82
Quintile 5	0·04	0·12	0·15	0·10	0·25	1·11	1·39	0·68	1·05	0·61, 1·82	1·05	0·63, 1·76	0·42	0·13	0·07	0·14	3·38	1·64, 6·97	1·21	0·65, 2·25
P	0·35		0·55		0·43		0·006		0·45		0·68		0·003 (P_{trend})		0·76		0·001 (P_{trend})		0·37	
Energy under-reporting status																				
Normal reporters	0		0		0		0		1		1		0		0		1		1	
Under-reporters	1·04	0·09	0·55	0·08	9·11	0·85	3·53	0·50	5·99	4·11, 8·73	3·06	2·16, 4·31	1·49	0·13	0·78	0·11	12·59	7·06, 22·47	3·63	2·38, 5·53
P	<0·0001		<0·0001		<0·0001		<0·0001		<0·0001		<0·0001		<0·0001		<0·0001		<0·0001		<0·0001	
Maternal education level																				
Low	0		0		0		0		1		1		0		0		1		1	
Intermediate	−0·15	0·09	−0·05	0·08	−1·61	0·86	−0·03	0·53	0·71	0·47, 1·08	1·03	0·71, 1·50	−0·13	0·09	−0·11	0·09	0·80	0·52, 1·22	0·66	0·44, 0·97
High	−0·33	0·09	−0·43	0·08	−4·16	0·82	−1·62	0·52	0·39	0·25, 0·60	0·42	0·27, 0·64	−0·35	0·10	−0·29	0·10	0·50	0·31, 0·81	0·37	0·23, 0·60
P	0·0008		0·0001		<0·0001		0·002		0·0001		<0·0001		<0·0001		0·006 (P_{trend})		0·005 (P_{trend})		<0·0001	

%BF, percentage body fat; OW, overweight.

different geographical, cultural and socio-economic characteristics. The DP identified in European and Australian adolescents exhibited similarities in their food characterisation and were also consistent with the 'energy-dense, high-fat, low-fibre' dietary pattern found in both the ALSPAC study from Avon (UK)[13] and the Raine Study from Perth (Western Australia)[11,12]. In the later, a similar dietary pattern was obtained using two different tools to assess dietary intakes, that is a FFQ and a 3-d food record[11]. Overall, high scores on this pattern indicated adherence to a diet with a low consumption of fresh fruit and vegetables and a high consumption of crisps and snacks, chocolate and confectionery[11–13,20]. This suggests that when using nutrient intakes as the intermediate markers for obesity and similar food groupings, the resulting RRR DP can be replicated in other study samples of adolescents from Western environments.

Analyses investigating associations between the 'energy-dense, high-fat, low-fibre' dietary pattern scores and covariates confirmed previous findings that this dietary pattern was inversely associated with the educational level of the mother and positively associated with screen time. For example, a high maternal education was considered as a positive influencing factor for a healthy food intake, especially in childhood[44], and also in adolescents[45,46]. Previous studies also identified associations between low SES, using family income parameters instead of education of the mother, and 'unhealthy dietary pattern' in developed countries[45–49]. Therefore, considering that we identified associations consistent with previous literature regarding the DP and SES and lifestyle factors, it suggests that the inverse associations between the dietary pattern and adiposity/OW in adolescent boys and the absence of significant association in girls was not due to poor data quality. Rather, this association is more likely explained by the cross-sectional design of the HELENA and NCNPAS studies. Indeed, the review by Ambrosini[6], which included studies with longitudinal design only, provides evidence for a prospective and positive association between empirically derived DP in childhood and adolescence that are high in energy-dense, high-fat, low-fibre foods and later obesity risk.

These contradictory regression results found in our study *v.* those earlier published from the ALSPAC study (positive association between the same dietary pattern and FM index in children)[13] may also partly be due to increased misreporting with increasing age. In the follow-up of the ALSPAC study, a decline could be seen in the association between the dietary pattern scores and later adiposity when comparing the children at the age of 7 *v.* 13 years old[20]. The authors suggested that this might be due to increasing levels of dietary measurement error with age of the child as the prevalence of dietary under-reporting increased with age and was most prevalent at 13 years of age. Further, given that body image becomes more important with age, adolescents are more likely to follow a restrictive diet as compared with their younger counterparts in the presence of obesity, possibly attenuating any associations between obesity and energy-dense diets in cross-sectional studies[50]. In fact, another important result was that the energy under-reporters scored low in the 'energy-dense, high-fat, low-fibre' dietary pattern and were also more likely to experience excessive weight, in particular boys (especially for FM). Therefore under-reporting of energy-dense, high-fat, low-fibre foods due to social desirable answers among the obese and/or true under-consumption of these specific foods in order to lose weight[39,50], could have contributed to reversing the cross-sectional association under study, especially in boys.

The strengths of the study include the use of two adolescent wide-scale samples of Europe and Australia (part of two continents with different geographical, cultural and socio-economic characteristics), respectively, using similar assessment methods and measurements and the large number of adolescents included in both surveys. Few studies so far have used population-based surveys with large sample size to identify DP in adolescents[47]. Also, both studies have similar study aims and used comparable methods to assess dietary intake. Furthermore, RRR analysis demonstrated a similar DP in European and Australian adolescents that was also consistent with the 'energy-dense, high-fat, low-fibre' DP obtained in the ALSPAC study, as well as with the one derived in the Raine study[11,12]. Finally, both studies included anthropometric, SES and lifestyle data (including PA and SB) obtained via standardised procedures.

Some limitations of the analysis should be considered. We used two cross-sectional studies, which did not allow the assessment of temporal relations and thus neither causal inference. Differences in food habits and culinary use between Europe and Australia and in food composition tables should be acknowledged. However, we harmonised the food groupings as far as possible using the same nutritional composition criteria, in accordance with the ALSPAC classification. In addition, while the two studies were comparable with respect to some covariates (e.g. maternal education level), there were slight differences regarding the definition of PA and SB. In particular, the more detailed categories of behaviour for sedentary time questions in HELENA *v.* NCNPAS might have tended to over-estimate the duration and be partly responsible for the higher sedentary time found in HELENA. Possible differences in the study protocol for dietary intake assessments between HELENA and NCNPAS (self-reported *v.* interview based) might also have contributed to the higher level of under-reporting in the HELENA study. These differences in study protocols might partly explain the minor differences found in the associations with the 'energy-dense, high-fat, low-fibre' dietary pattern between the European and Australian adolescents samples.

In conclusion, the DP identified in these Australian and European studies were very similar and comparable to those identified in a previous study of DP using RRR along with energy density, FD and percentage of energy intake from fat as the intermediate variables. This demonstrates the generalisability and robustness of the RRR method in calculating DP among populations. However, this cross-country study confirms that when studying diet–obesity relationships in adolescents, longitudinal designs are more relevant to prevent reverse causality.

Acknowledgements

The authors acknowledge all the adolescents who made the HELENA study possible and the families participating in the NCNPAS study.

The HELENA study received funding from the European Union's Sixth RTD Framework Programme (contracts FOOD-CT-2007-036196-2 and FOODCT-2005-007034, respectively). Additional support was obtained from the Spanish Ministry of Education (AGL2007-29784-E/ALI). S. A. M. is supported by an NHMRC Career Development Fellowship Level 2, ID1104636 and was previously supported by an ARC Future Fellowship (2011–2015, FT100100581). S. L. is supported by a French National Research Agency (grant no. ANR-12-DSSA-0001) and was previously supported by an Alfred Deakin postdoctoral Fellowship (Deakin University, 2010–2012). None of the funders had any role in the design, analysis or writing of this article.

I. H. and S. L. contributed to the designed research, analysed data, performed statistical analysis and wrote the paper; S. M. contributed to the design of the analysis, advised on the dietary analysis of the NCNPAS data, assisted with the interpretation of data analysis and critically revised the draft manuscript. T. M. contributed with analysed data and critically revised the paper drafts. L. M. and the rest of the authors contributed to the HELENA study data collection and handling. All authors have read and approved the final manuscript.

None of the authors has declared conflicts of interest.

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