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Prevalence and characteristics of misreporting of energy intake in US children and adolescents: National Health and Nutrition Examination Survey (NHANES) 2003–2012

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Abstract

Using data from the National Health and Nutrition Examination Survey (NHANES) 2003–2012, we investigated the prevalence and characteristics of under- and over-reporting of energy intake (EI) among 14 044 US children and adolescents aged 2–19 years. For the assessment of EI, two 24-h dietary recalls were conducted with the use of the US Department of Agriculture Automated Multiple-Pass Method. Under-, plausible and over-reporters of EI were identified using two methods: based on the 95 % confidence limits (1) for agreement between the ratio of EI:BMR and a physical activity level for sedentary lifestyle (1·55) and (2) of the expected ratio of EI:estimated energy requirement (EER) of 1·0. BMR was calculated using Schofield's equations. EER was calculated using equations from the US Dietary Reference Intakes, assuming 'low active' level of physical activity. The risk of being an under- or over-reporter compared with a plausible reporter was analysed using multiple logistic regression. Percentages of under-, plausible and over-reporters were 13·1, 81·5 and 5·4 %, respectively, based on EI:BMR and 18·8, 72·3 and 8·8 %, respectively, based on EI:EER. Under-reporting was associated with older age, non-Hispanic blacks (compared with non-Hispanic whites) and overweight and obesity (compared with normal weight). Over-reporting was associated with younger age, lower family poverty income ratio, normal weight and the first survey cycle. Similar findings were obtained when analysing only the first 24-h recall data from NHANES 1999–2012 (*n* 22 949). In conclusion, we found that EI misreporting remains prevalent and differential in US children and adolescents.

Key words: Energy intake: Misreporting: Children: National Health and Nutrition Examination Survey

Misreporting of dietary intake is a common phenomenon that appears to occur both randomly and non-randomly[1–3] and may be selective for different kinds of foods and nutrients[4,5] The resulting potential for differential errors in dietary data complicates the interpretation of studies on diet and health and, at worst, might produce spurious diet–health relations[1,3,5]. Thus, the identification of the characteristics associated with misreporting (under- and over-reporting) of dietary intake is important to increase the understanding of this issue.

The measurement of dietary intake in children and adolescents is an integral component for monitoring the nutritional status of these age groups and for conducting epidemiological and clinical research on the links between diet and health. However, it is made particularly challenging by the many unique respondent and observer considerations that surface at different ages from early childhood to late adolescence, including cognitive abilities and dietary habits[6,7]. Nevertheless, investigations of the misreporting of energy intake (EI), a surrogate measurement of the total quantity of food intake, in children and adolescents are limited[1,6,7,8–23]. It is conceivable that the way in which survey participants comply with dietary assessment procedures may differ by country and over time.

In the continuous National Health and Nutrition Examination Survey (NHANES), the US Department of Agriculture (USDA) Automated Multiple-Pass Method is used for collecting 24-h dietary recall information. Although this method has been validated against total energy expenditure measured by doubly labelled water[24,25] and against observed actual intake[26,27] in adult populations, the validity in children and adolescents is largely unknown. In the current study, the prevalence and characteristics of under- and over-reporting of EI among US children and adolescents were evaluated using data from the NHANES.

Abbreviations: EER, estimated energy requirement; EI, energy intake; NHANES, National Health and Nutrition Examination Survey; PAL, physical activity level; USDA, US Department of Agriculture.

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Methods

Survey design

The present cross-sectional analysis was based on public domain data from NHANES, a continuing population-based survey that uses a complex, stratified multistage probability sample design to create a representative sample of the non-institutionalised civilian US population[28,29]. Beginning in 1999, the survey examines about 5000 persons each year and the data are released every 2 years. Each survey consists of questionnaires administered in the home, followed by a standardised health examination, including an in-person 24-h dietary recall interview, in a mobile examination centre. Since 2002, a second 24-h dietary recall was also obtained by telephone; two 24-h dietary recall data are publicly available since 2003. The unweighted response rates for the examined persons aged 1–19 years for NHANES 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, 2009–2010 and 2011–2012 were 84, 87, 84, 84, 83, 86 and 77 %, respectively[30]. The documentation and data for each of these surveys can be downloaded from the NHANES website[31]. The NHANES was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by National Center for Health Statistics Research Ethics Review Board. Written informed consent was obtained from all subjects or from their proxies.

Analytic sample

The analytic sample was limited to children and adolescents aged 2–19 years with two complete and reliable 24-h dietary recall data (*n* 15 279). After excluding pregnant (*n* 96) and lactating (*n* 15) respondents as well as those with missing information on the variables of interest (family income: *n* 882; body height or weight: *n* 242), the final analytic sample included 14 044 respondents from NHANES 2003–2012. An additional analysis was also conducted using only the first dietary recall data in 22 949 respondents from NHANES 1999–2012. There were no significant differences in EI misreporting variables between the subjects included in the analysis and those excluded from the analysis (data not shown).

Assessment of energy intake

All surveys collected dietary information with the use of a 24-h dietary recall administered by a trained interviewer in the mobile examination centre. Beginning with 2002, a second 24-h dietary recall was also obtained via telephone 3–10 d after the first recall. The dietary recalls collected for the NHANES 1999–2000 and 2001 survey years used a computer-assisted interview that included a four-step multiple-pass approach. Since 2002, the dietary data were collected with the use of an automated five-step multiple-pass approach, namely the USDA Automated Multiple-Pass Method[24–27,31]. This method consists of the following: (1) a quick list pass, in which the respondent is asked to list everything eaten or drunk the previous day; (2) a forgotten foods list pass, in which a standard list of foods or beverages – often forgotten – is read to prompt recall; (3) a time and occasion pass, in which the time of and the name for the eating occasion are collected; (4) a detail and review pass, in which detailed descriptions and portion sizes are collected and the time interval between meals is reviewed to check for additional foods; and (5) the final probe pass, one last opportunity to remember foods consumed. Proxies, most commonly a parent, reported dietary intake for children aged 2–5 years and assisted with the dietary interview for children aged 6–11 years; dietary intake was self-reported by adolescents aged 12–19 years. Estimates of EI from all reported foods and beverages were calculated using the USDA food composition databases. In 1999–2000, the USDA 1994–1998 Survey Nutrient Database was the food composition database used; in subsequent surveys, the USDA Food and Nutrient Database for Dietary Studies was used[31]. The average of EI over the 2 d for each participant was used for the present analysis.

Assessment of non-dietary variables

Consistent with NHANES sample-selection methods, age was categorised as 2–5, 6–11 and 12–19 years. Race/ethnicity was categorised as non-Hispanic white, non-Hispanic black, Mexican American and others. As an indicator of socio-economic status, we used family income as a percentage of the federal poverty threshold, which was categorised as <130, 130–349 and ≥350 %. The hours of screen time were determined from questions on television/video watching (h/d) or computer use (h/d) over the past 30 d (except for adolescents aged 12–19 years in NHANES 2007–2008 and 2009–2010 for which information on sedentary activity was used), which were categorised as <2, ≥2 to <4, ≥4 to <6 and ≥6 h/d. Body weight and height were measured by trained interviewers using standardised procedures with calibrated equipment. BMI (kg/m^2) was calculated as weight (kg) divided by height squared (m^2). The percentile of BMI for age was calculated using the SAS program for growth charts available from the Centers for Disease Control and Prevention[32,33]. Weight status was defined on the basis of the percentile of BMI for age as follows[34]: underweight (<5th percentile), normal (≥5th to <85th percentile), overweight (≥85th to <95th percentile) and obese (≥95th percentile).

Evaluation of the accuracy of energy intake reporting

Misreporting of EI was evaluated on the basis of the ratio of EI:BMR (the Goldberg's cut-off)[35] and the ratio of EI:estimated energy requirement (EER), namely the procedure proposed by Huang *et al.*[36]. Subjects were identified as plausible, under- and over-reporters of EI according to whether the individual's ratio was within, below or above the 95 % confidence limits for agreement between EI:BMR and the respective physical activity level (PAL) or of the expected EI:EER of 1·0. For the principles of the Goldberg's cut-off, the PAL for sedentary lifestyle (i.e. 1·55)[35] was applied for all subjects, because of a lack of an objective measure of physical activity in the present study. BMR was estimated using Schofield's sex- and age-specific equations based on body height and weight[37]. The 95 % confidence limits for agreement (upper and lower cut-off values) between

EI:BMR and the PAL were calculated, taking into account CV in intakes and other components of energy balance (i.e. the within-subject variation in EI: 23 %; the precision of the estimated BMR relative to the measured BMR: 8·5 %; the between-subject variation in PAL: 15 %)[35]. Consequently, under-, plausible and over-reporters were defined as having EI: BMR of <0·96, 0·96–2·49 and >2·49 for 2 d data and <0·87, 0·87–2·75 and >2·75 for 1 d data, respectively.

EER was calculated using sex-, age- and weight status-specific equations published in the US Dietary Reference Intakes, based on sex, age, body height and weight and physical activity[38]. Because of a lack of an objective measure of physical activity as mentioned above, we assumed 'low active' level of physical activity (i.e. PAL ≥1·4 to <1·6)[38] for all subjects during this calculation. The 95 % confidence limits of the expected EI:EER ratio of 0 on the natural log scale were calculated, taking into account CV in intakes and other components of energy balance (i.e. the within-subject variation in EI: 23 %; the error in the EER equations: 4·8 %; the day-to-day variation in total energy expenditure: 8·2 %)[36]. Consequently, under-, plausible and over-reporters were defined as having EI:EER of <0·69, 0·69 – 1·46 and >1·46 for 2 d data and <0·61, 0·61 – 1·64 and >1·64 for 1 d data, respectively.

Statistical analysis

Statistical analyses were performed using SAS statistical software (version 9.2; SAS Institute). All reported P values are two-tailed, and $P<0·01$ was considered statistically significant to reduce the likelihood of making a type 1 error. All of the analyses used the NHANES-provided sampling weights that were calculated to take into account unequal probabilities of selection resulting from the sample design, non-response and planned oversampling of selected subgroups, so that the results are representative of the US community-dwelling population[29,39]. For EI, BMR, EER, EI:BMR and EI:EER, sample-weighted means (with their standard errors) were generated using PROC SURVYMEANS procedure. Differences in these variables across categories of each of the characteristics were examined by Wald's F test using PROC SURVEYREG procedure. Proportions (with their standard errors) of under-, plausible and over-reporters of EI were calculated using PROC SURVEYFREQ procedure. Differences in proportions of under-, plausible and over-reporters across categories of each of the characteristics were examined by χ^2 test using PROC SURVEYFREQ procedure.

The risk of being classified as an under-reporter of EI compared with being a plausible reporter or as an over-reporter compared with being a plausible reporter, was estimated using logistic regression. First, with the use of PROC SURVEY-LOGISTIC procedure, crude OR and 99 % CI for the risk of being classified as an under- or over-reporter were calculated for each category of factors that are possibly associated with EI mis-reporting, namely sex (reference: boys), age group (reference: 2–5 years), race/ethnicity (reference: non-Hispanic white), family poverty income ratio (reference: <130 %), weight status (reference: normal), watching television and computer use (reference: <2 h/d) and survey cycle (reference: 2003–2004). Multivariate-adjusted OR and 99 % CI were then calculated by entering all variables simultaneously into the regression model to assess the independent associations.

These analyses were conducted for boys and girls separately. The results on the association between EI reporting and the variables examined were essentially the same in boys and girls. The following six interaction terms were also examined: age by sex, age by weight status, age by survey cycle, sex by weight status, sex by survey cycle and weight status by survey cycle. There was an interaction between age and sex for EI:BMR ($P=0·0005$), an interaction between age and weight status for EI:BMR and EI:EER (both $P<0·0001$) and an interaction between sex and weight status for EI:EER ($P=0·001$). Multivariate analyses stratified by sex (boys and girls), age group (2–5, 6–11 and 12–19 years) or weight status (under-weight and normal weight combined and overweight and obese combined), however, provided similar findings (except for no association of weight status with both under- and over-reporting based on EI:BMR in subjects aged 2–5 years and female sex associated with a lower risk of over-reporting based on EI:BMR in subjects aged 12–19 years). The present paper thus presents the results for the whole analytic sample combined.

Results

Among 14 044 subjects with 2 d dietary data, the sample-weighted mean EI:BMR was 1·55, whereas the corresponding value for EI:EER was 0·99 (Table 1). Boys had a higher mean EI: BMR than that of girls. Mean EI:BMR differed significantly among age groups, with the highest in the youngest group (2–5 years) and the lowest in the oldest group (12–19 years), among race/ethnicity groups, with the lowest in non-Hispanic blacks and among survey cycles, with the highest in 2003–2004 and the lowest in 2007–2008. Mean EI:BMR in obese and overweight subjects was lower compared with that in normal-weight and underweight subjects. Watching television and computer use was inversely associated with EI:BMR. Similar associations of these characteristics with EI:EER were also observed. Multiple regression analyses showed that 22 % of the variance in EI:BMR and 21 % of the variance in EI:EER were explained by the variables examined here (i.e. sex, age group, race/ethnicity, family poverty income ratio, weight status, watching television and computer use and survey cycle).

The sample-weighted percentages of under-, plausible and over-reporters of EI were 13·1, 81·5 and 5·4 %, respectively, on the basis of EI:BMR and 18·8, 72·3 and 8·8 %, respectively, on the basis of EI:EER (Table 2). Using EI:BMR, the percentages of under-reporters and over-reporters did not differ between boys and girls. With regard to age, there were more under-reporters among the oldest group, whereas there were more over-reporters among the youngest group. For race/ethnicity, there were more under-reporters in non-Hispanic blacks and fewer over-reporters in non-Hispanic whites. The family poverty income ratio was inversely associated with the percentages of both under- and over-reporters. There were more under-reporters and fewer over-reporters among overweight and

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Table 1. Characteristics of the subjects: National Health and Nutrition Examination Survey 2003–2012 (*n* 14 044)*
(Numbers and percentages; mean values with their standard errors)

				EI (kJ/d)†		BMR (kJ/d)‡		EER (kJ/d)§		EI:BMR		EI:EER	
	n	%	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
All	14 044	100	0	8212	44	5566	30	8643	44	1·55	0·009	0·99	0·005
Sex													
Boys	7114	51·1	0·8	8957	73	5987	46	9316	69	1·58	0·013	1·01	0·008
Girls	6930	48·9	0·8	7433	47	5127	27	7939	37	1·52	0·011	0·97	0·007
P‖				<0·0001		<0·0001		<0·0001		0·0008		0·004	
Age group (years)													
2–5	3247	21·5	0·6	6621	51	3590	13	5828	25	1·85	0·013	1·15	0·009
6–11	4390	33·4	0·7	8198	65	5018	22	7833	33	1·66	0·014	1·06	0·009
12–19	6407	44·1	0·9	8980	84	6916	32	10 587	50	1·32	0·012	0·86	0·008
P‖				<0·0001		<0·0001		<0·0001		<0·0001		<0·0001	
Race/ethnicity													
Non-Hispanic white	4146	60·0	1·8	8369	70	5617	46	8737	68	1·56	0·013	1·00	0·008
Non-Hispanic black	3940	14·3	1·1	8024	76	5694	45	8857	67	1·50	0·015	0·96	0·010
Mexican American	3825	13·3	1·0	8042	83	5459	53	8419	71	1·56	0·017	1·00	0·010
Others	2133	12·3	0·8	7846	88	5287	48	8179	67	1·55	0·017	1·00	0·010
P‖				0·0002		<0·0001		<0·0001		0·009		0·002	
Family poverty income ratio (%)													
<130	6197	32·8	1·3	8121	90	5473	48	8491	72	1·57	0·016	1·00	0·010
130–349	4897	35·7	1·1	8156	72	5593	51	8693	80	1·53	0·017	0·98	0·011
≥350	2950	31·5	1·4	8369	90	5634	53	8744	77	1·55	0·017	0·99	0·011
P‖				0·14		0·06		0·04		0·24		0·23	
Weight status¶													
Underweight	452	3·2	0·2	8484	201	4756	107	7459	167	1·80	0·035	1·15	0·021
Normal	8832	65·3	0·8	8257	55	5159	28	8099	45	1·65	0·011	1·05	0·007
Overweight	2158	15·3	0·6	8061	95	5984	56	9103	75	1·41	0·014	0·91	0·009
Obese	2602	16·1	0·6	8118	79	6982	72	10 647	99	1·24	0·017	0·80	0·010
P‖				0·08		<0·0001		<0·0001		<0·0001		<0·0001	
Watching television and computer use (h/d)													
<2	3490	25·1	0·8	7618	79	4883	49	7650	73	1·63	0·017	1·03	0·010
≥2 to <4	4853	33·9	0·7	8173	72	5234	39	8178	61	1·63	0·013	1·04	0·008
≥4 to <6	2739	18·5	0·6	8630	109	5928	57	9201	86	1·53	0·019	0·98	0·012
≥6	2962	22·6	0·8	8585	104	6527	58	9983	88	1·36	0·016	0·89	0·010
P‖				<0·0001		<0·0001		<0·0001		<0·0001		<0·0001	
Survey cycle													
2003–2004	3251	19·8	1·2	8722	90	5564	75	8640	109	1·65	0·021	1·05	0·013
2005–2006	3414	20·3	1·2	8436	99	5605	71	8706	106	1·57	0·017	1·00	0·010
2007–2008	2327	19·9	1·2	7864	103	5531	74	8562	110	1·50	0·021	0·96	0·013
2009–2010	2494	16·4	1·2	7975	83	5547	52	8606	71	1·51	0·019	0·97	0·011
2011–2012	2558	20·6	1·3	8057	115	5583	59	8697	88	1·53	0·022	0·97	0·014
P‖				<0·0001		0·94		0·82		<0·0001		<0·0001	

EI, energy intake; EER, estimated energy requirement.
* All percentages and mean values are weighted to reflect the survey design characteristics. Analyses are based on subjects with complete data on two 24-h dietary recalls as well as complete information on the variables of interest.
† Based on average values of two 24-h dietary recalls.
‡ Estimated using Schofield's sex- and age-specific equations based on body height and weight[34].
§ Calculated using sex-, age- and weight status-specific equations from the US Dietary Reference Intakes based on sex, age and body height and weight assuming 'low active' level of physical activity for all subjects[35].
‖ Based on Wald's *F* test.
¶ Defined based on the percentile of BMI for age: <5th percentile for underweight, ≥5th to <85th percentile for normal, ≥85th to <90th percentile for overweight and >95th percentile for obese subjects[31].

obese subjects. Longer hours of television watching and computer use were associated with higher percentage of under-reporters and lower percentage of over-reporters. The proportion of under- and over-reporters differed among survey cycles, with more under-reporters in 2007–2008 and more over-reporters in 2003–2004. The results were similar on the basis of using EI:EER to estimate misreporters.

OR and 99 % CI for the risk of being an under-reporter compared with a plausible reporter are shown in Table 3. The results for the crude and multivariate-adjusted models were generally similar except for watching television and computer use. In the multivariate analyses, on the basis of EI:BMR and EI:EER, a higher risk of being an under-reporter was associated with ages 6–11 years (EI:BMR only) and 12–19 years (compared with age 2–5 years), non-Hispanic blacks (compared with non-Hispanic white), overweight and obesity (compared with normal weight) and the survey cycle 2007–2008 (EI:BMR only) (compared with 2003–2004). A lower risk of being an under-reporter was associated with underweight (EI:EER only).

Table 4 lists OR and 99 % CI for the risk of being an over-reporter compared with a plausible reporter. The results for the

Table 2. Proportion of under-reporters, plausible and over-reporters of energy intake (EI): National Health and Nutrition Examination Survey 2003–2012 (*n* 14 044)*
(Numbers and percentages with their standard errors)

	Based on EI:BMR†										Based on EI:EER‡									
	Under-reporters			Plausible reporters			Over-reporters				Under-reporters			Plausible reporters			Over-reporters			
	n	%	SE	*n*	%	SE	*n*	%	SE	*P*§	*n*	%	SE	*n*	%	SE	*n*	%	SE	*P*§
All	2050	13·1	0·5	11 210	81·5	0·5	784	5·4	0·3		2868	18·8	0·6	9864	72·3	0·7	1312	8·8	0·5	
Sex										0·02										0·10
Boys	1018	12·2	0·7	5667	81·7	0·8	429	6·1	0·4		1430	17·8	0·9	5005	72·7	0·9	679	9·5	0·6	
Girls	1032	14·0	0·7	5543	81·4	0·8	355	4·6	0·5		1438	19·9	0·8	4859	72·0	1·0	633	8·1	0·7	
Age group (years)										<0·0001										<0·0001
2–5	72	1·8	0·3	2811	87·4	0·9	364	10·7	0·8		217	5·8	0·6	2471	78·3	1·0	559	15·9	1·0	
6–11	293	5·4	0·6	3859	89·1	0·7	238	5·5	0·6		465	8·7	0·6	3513	81·7	0·9	412	9·6	0·8	
12–19	1685	24·1	0·9	4540	73·2	0·8	182	2·7	0·4		2186	32·6	1·1	3880	62·6	1·0	341	4·8	0·5	
Race/ethnicity										<0·0001										<0·0001
Non-Hispanic white	468	11·6	0·7	3450	83·5	0·8	228	5·0	0·5		681	17·5	0·9	3092	74·2	1·0	373	8·3	0·7	
Non-Hispanic black	731	17·7	1·0	2988	76·6	1·0	221	5·6	0·6		1005	24·2	1·1	2569	66·7	1·1	366	9·1	0·6	
Mexican American	563	14·3	1·0	3049	79·5	1·1	213	6·2	0·7		781	19·7	1·0	2679	69·8	1·2	365	10·6	0·9	
Others	288	13·7	1·0	1723	80·3	1·3	122	6·1	0·7		401	18·1	1·1	1524	72·7	1·4	208	9·3	0·9	
Family poverty income ratio (%)										<0·0001										<0·0001
<130	915	15·1	0·9	4852	77·6	1·1	430	7·2	0·7		1289	20·4	0·9	4216	68·4	0·9	692	11·2	0·8	
130–349	766	13·3	0·9	3889	81·7	1·1	242	4·9	0·6		1047	19·4	1·1	3444	72·7	1·0	406	7·9	0·8	
≥350	369	10·7	0·9	2469	85·4	1·0	112	3·9	0·6		532	16·6	1·1	2204	76·0	1·3	214	7·4	1·0	
Weight status‖										<0·0001										<0·0001
Underweight	16	2·6	1·3	396	90·3	2·0	40	7·1	1·6		32	5·0	1·4	340	79·2	3·1	80	15·8	2·7	
Normal	730	7·6	0·5	7488	85·8	0·6	614	6·6	0·4		1178	12·7	0·7	6616	76·6	0·8	1038	10·8	0·6	
Overweight	423	19·3	1·3	1657	77·3	1·3	78	3·4	0·5		558	25·2	1·4	1482	69·8	1·5	118	5·0	0·6	
Obese	881	31·3	1·4	1669	66·8	1·4	52	2·0	0·4		1100	40·5	1·4	1426	56·3	1·4	76	3·2	0·6	
Watching television and computer use (h/d)										<0·0001										<0·0001
<2	403	9·3	0·8	2865	84·9	1·0	222	5·8	0·7		590	14·7	1·1	2513	75·1	1·2	387	10·2	0·9	
≥2 to <4	540	8·8	0·6	4026	84·9	1·0	287	6·3	0·7		792	13·2	0·8	3584	76·4	1·1	477	10·3	0·8	
≥4 to <6	417	15·0	1·1	2166	79·6	1·2	156	5·4	0·7		579	20·7	1·3	1909	70·6	1·3	251	8·7	1·0	
≥6	690	22·1	1·0	2153	74·4	1·0	119	3·5	0·5		907	30·3	1·4	1858	64·5	1·3	197	5·2	0·5	
Survey cycle										<0·0001										<0·0001
2003–2004	459	10·5	0·9	2562	81·4	1·2	230	8·2	0·9		650	15·7	1·1	2234	71·2	1·5	367	13·1	1·2	
2005–2006	523	12·6	1·1	2711	82·4	1·2	180	4·9	0·5		705	17·2	1·2	2413	75·1	1·4	296	7·7	0·6	
2007–2008	364	15·9	1·3	1836	80·0	1·3	127	4·0	0·5		492	21·5	1·6	1628	70·7	1·4	207	7·8	1·3	
2009–2010	357	13·2	0·7	2028	82·4	0·6	109	4·4	0·5		528	19·9	1·1	1763	73·0	1·2	203	7·1	0·6	
2011–2012	347	13·2	1·0	2073	81·5	1·2	138	5·3	0·6		493	20·0	1·5	1826	71·6	1·8	239	8·4	1·1	

EER, estimated energy requirement.

* All percentage values are weighted to reflect the survey design characteristics. Analyses are based on subjects with complete data on two 24-h dietary recalls as well as complete information on the variables of interest. Average EI values of two 24-h dietary recalls were used.

† Under-reporters were defined as subjects with EI:BMR <0·96; plausible reporters as subjects with EI:BMR 0·96–2·49; over-reporters as subjects with EI:BMR >2·49. BMR was estimated using Schofield's sex- and age-specific equations based on body height and weight[34].

‡ Under-reporters were defined as subjects with EI:EER <0·69; plausible reporters as subjects with EI:EER 0·69–1·46; over-reporters as subjects with EI:EER >1·46. EER was calculated using sex-, age- and weight status-specific equations from the US Dietary Reference Intakes based on sex, age and body height and weight assuming 'low active' level of physical activity for all subjects[35].

§ Based on χ^2 test.

‖ Defined based on the percentile of BMI for age: <5th percentile for underweight, ≥5th to <85th percentile for normal, ≥85th to <95th percentile for overweight and ≥95th percentile for obese subjects[31].

Table 3. Risk of being an under-reporter of energy intake (EI) compared with being a plausible reporter of EI: National Health and Nutrition Examination Survey 2003–2012*
(Numbers; odds ratios and 99 % confidence intervals)

	Based on EI:BMR (*n* 13 260)†					Based on EI:EER (*n* 12 732)‡				
		Crude model§		Multivariate model‖			Crude model§		Multivariate model‖	
	Under-reporters/plausible reporters (*n*)	OR	99 % CI	OR	99 % CI	Under-reporters/plausible reporters (*n*)	OR	99 % CI	OR	99 % CI
Sex										
Boys	1018/5667	1	Reference	1	Reference	1430/5005	1	Reference	1	Reference
Girls	1032/5543	1·16	0·94, 1·43	1·13	0·91, 1·42	1438/4859	1·13	0·93, 1·36	1·11	0·90, 1·37
Age group (years)										
2–5	72/2811	1	Reference	1	Reference	217/2471	1	Reference	1	Reference
6–11	293/3859	2·91	1·69, 5·01	2·55	1·47, 4·43	465/3513	1·43	1·004, 2·05	1·29	0·89, 1·88
12–19	1685/4540	15·70	9·58, 25·73	15·75	9·17, 27·05	2186/3880	6·99	5·15, 9·49	7·12	5·08, 10·00
Race/ethnicity										
Non-Hispanic white	468/3450	1	Reference	1	Reference	681/3092	1	Reference	1	Reference
Non-Hispanic black	731/2988	1·67	1·32, 2·12	1·49	1·14, 1·96	1005/2569	1·54	1·25, 1·89	1·42	1·14, 1·78
Mexican American	563/3049	1·30	0·98, 1·74	1·16	0·86, 1·58	781/2679	1·19	0·94, 1·51	1·07	0·82, 1·40
Others	288/1723	1·23	0·90, 1·68	1·40	0·94, 2·07	401/1524	1·05	0·82, 1·36	1·14	0·81, 1·59
Family poverty income ratio (%)										
<130	915/4852	1	Reference	1	Reference	1289/4216	1	Reference	1	Reference
130–349	766/3889	0·84	0·64, 1·08	0·88	0·64, 1·22	1047/3444	0·89	0·74, 1·07	0·95	0·77, 1·16
≥350	369/2469	0·64	0·46, 0·88	0·71	0·50, 1·01	532/2204	0·73	0·56, 0·95	0·79	0·59, 1·08
Weight status¶										
Underweight	16/396	0·33	0·08, 1·25	0·29	0·08, 1·13	32/340	0·38	0·17, 0·84	0·35	0·15, 0·78
Normal	730/7488	1	Reference	1	Reference	1178/6616	1	Reference	1	Reference
Overweight	423/1657	2·81	2·14, 3·68	2·86	2·14, 3·84	558/1482	2·18	1·71, 2·79	2·27	1·75, 2·95
Obese	881/1669	5·25	4·12, 6·71	5·41	4·16, 7·05	1100/1426	4·34	3·47, 5·43	4·67	3·66, 5·95
Watching television and computer use (h/d)										
<2	403/2865	1	Reference	1	Reference	590/2513	1	Reference	1	Reference
≥2 to <4	540/4026	0·95	0·69, 1·31	0·78	0·56, 1·08	792/3584	0·89	0·69, 1·14	0·74	0·56, 0·98
≥4 to <6	417/2166	1·72	1·26, 2·35	0·87	0·59, 1·29	579/1909	1·50	1·12, 2·01	0·82	0·60, 1·13
≥6	690/2153	2·72	2·03, 3·63	0·92	0·64, 1·33	907/1858	2·40	1·82, 3·16	0·90	0·65, 1·24
Survey cycle										
2003–2004	459/2562	1	Reference	1	Reference	650/2234	1	Reference	1	Reference
2005–2006	523/2711	1·19	0·83, 1·71	1·20	0·88, 1·63	705/2413	1·04	0·75, 1·44	1·05	0·77, 1·42
2007–2008	364/1836	1·55	1·09, 2·21	1·66	1·15, 2·40	492/1628	1·38	0·996, 1·91	1·47	0·997, 2·16
2009–2010	357/2028	1·25	0·94, 1·67	1·30	0·97, 1·73	528/1763	1·24	0·93, 1·66	1·33	0·95, 1·86
2011–2012	347/2073	1·26	0·90, 1·76	1·25	0·87, 1·79	493/1826	1·27	0·91, 1·77	1·33	0·91, 1·94

EER, estimated energy requirement.
* Analyses are based on subjects with complete data on two 24-h dietary recalls as well as complete information on the variables of interest. Average EI values of two 24-h dietary recalls were used.
† Under-reporters were defined as subjects with EI:BMR <0·96; plausible reporters as subjects with EI:BMR 0·96–2·49. Over-reporters (subjects with EI:BMR > 2·49; *n* 784) were excluded from the analysis. BMR was estimated using Schofield's sex- and age-specific equations based on body height and weight[34].
‡ Under-reporters were defined as subjects with EI:EER <0·69; plausible reporters as subjects with EI:EER 0·69–1·46. Over-reporters (subjects with EI:EER >1·46; *n* 1312) were excluded from the analysis. EER was calculated using sex-, age- and weight status-specific equations from the US Dietary Reference Intakes based on sex, age and body height and weight assuming 'low active' level of physical activity for all subjects[35].
§ Each of the variables listed was entered into the model separately.
‖ All the variables listed were entered into the model simultaneously.
¶ Defined based on the percentile of BMI for age: <5th percentile for underweight, ≥5th to <85th percentile for normal, ≥85th to <95th percentile for overweight and ≥95th percentile for obese subjects[31].

Table 4. Risk of being an over-reporter of energy intake (EI) compared with being a plausible reporter of EI: National Health and Nutrition Examination Survey 2003–2012*
(Numbers; odds ratios and 99 % confidence intervals)

	Based on EI:BMR (*n* 11 994)†					Based on EI:EER (*n* 11 176)‡				
		Crude model§		Multivariate model‖			Crude model§		Multivariate model‖	
	Over-reporters/plausible reporters (*n*)	OR	99 % CI	OR	99 % CI	Over-reporters/plausible reporters (*n*)	OR	99 % CI	OR	99 % CI
Sex										
Boys	429/5667	1	Reference	1	Reference	679/5005	1	Reference	1	Reference
Girls	355/5543	0·76	0·53, 1·10	0·76	0·53, 1·09	633/4859	0·86	0·64, 1·18	0·84	0·62, 1·14
Age group (years)										
2–5	364/2811	1	Reference	1	Reference	559/2471	1	Reference	1	Reference
6–11	238/3859	0·50	0·35, 0·73	0·53	0·36, 0·77	412/3513	0·58	0·43, 0·78	0·62	0·46, 0·84
12–19	182/4540	0·30	0·19, 0·47	0·30	0·19, 0·48	341/3880	0·38	0·27, 0·54	0·40	0·28, 0·57
Race/ethnicity										
Non-Hispanic white	228/3450	1	Reference	1	Reference	373/3092	1	Reference	1	Reference
Non-Hispanic black	221/2988	1·23	0·81, 1·87	0·98	0·64, 1·52	366/2569	1·22	0·87, 1·70	1·07	0·77, 1·49
Mexican American	213/3049	1·30	0·82, 2·06	1·09	0·71, 1·65	365/2679	1·36	0·93, 1·97	1·22	0·85, 1·73
Others	122/1723	1·26	0·80, 2·01	1·09	0·69, 1·74	208/1524	1·14	0·78, 1·67	1·04	0·72, 1·51
Family poverty income ratio (%)										
<130	430/4852	1	Reference	1	Reference	692/4216	1	Reference	1	Reference
130–349	242/3889	0·65	0·39, 1·08	0·68	0·41, 1·14	406/3444	0·66	0·47, 0·94	0·70	0·50, 0·98
≥350	112/2469	0·49	0·29, 0·83	0·53	0·30, 0·95	214/2204	0·60	0·39, 0·92	0·64	0·42, 0·97
Weight status¶										
Underweight	40/396	1·02	0·53, 1·95	1·11	0·57, 2·16	80/340	1·42	0·86, 2·33	1·56	0·93, 2·62
Normal	614/7488	1	Reference	1	Reference	1038/6616	1	Reference	1	Reference
Overweight	78/1657	0·58	0·39, 0·87	0·56	0·37, 0·85	118/1482	0·51	0·36, 0·72	0·49	0·35, 0·68
Obese	52/1669	0·39	0·22, 0·67	0·35	0·20, 0·60	76/1426	0·40	0·24, 0·66	0·37	0·22, 0·60
Watching television and computer use (h/d)										
<2	222/2865	1	Reference	1	Reference	387/2513	1	Reference	1	Reference
≥2 to <4	287/4026	1·09	0·66, 1·81	1·16	0·72, 1·89	477/3584	1·00	0·74, 1·35	1·09	0·82, 1·44
≥4 to <6	156/2166	1·00	0·64, 1·56	1·21	0·76, 1·92	251/1909	0·91	0·61, 1·35	1·07	0·72, 1·58
≥6	119/2153	0·69	0·43, 1·13	1·21	0·72, 2·04	197/1858	0·60	0·41, 0·86	0·93	0·61, 1·41
Survey cycle										
2003–2004	230/2562	1	Reference	1	Reference	367/2234	1	Reference	1	Reference
2005–2006	180/2711	0·60	0·40, 0·90	0·60	0·42, 0·85	296/2413	0·56	0·39, 0·82	0·55	0·38, 0·78
2007–2008	127/1836	0·50	0·33, 0·78	0·48	0·32, 0·73	207/1628	0·60	0·36, 1·01	0·58	0·34, 0·98
2009–2010	109/2028	0·53	0·35, 0·81	0·50	0·34, 0·76	203/1763	0·53	0·37, 0·77	0·51	0·36, 0·73
2011–2012	138/2073	0·65	0·42, 1·03	0·62	0·40, 0·96	239/1826	0·64	0·40, 1·02	0·59	0·38, 0·94

EER, estimated energy requirement.

* Analyses are based on subjects with complete data on two 24-h dietary recalls as well as complete information on the variables of interest. Average EI values of two 24-h dietary recalls were used.

† Over-reporters were defined as subjects with EI:BMR >2·49; plausible reporters as subjects with EI:BMR 0·96–2·49. Under-reporters (subjects with EI:BMR <0·96; *n* 5633) were excluded from the analysis. BMR was estimated using Schofield's sex- and age-specific equations based on body height and weight[34].

‡ Over-reporters were defined as subjects with EI:EER >1·46; plausible reporters as subjects with EI:EER 0·69–1·46. Under-reporters (subjects with EI:EER <0·69; *n* 2868) were excluded from the analysis. EER was calculated using sex-, age- and weight status-specific equations from the US Dietary Reference Intakes based on sex, age and body height and weight assuming 'low active' level of physical activity for all subjects[35].

§ Each of the variables listed was entered into the model separately.

‖ All the variables listed were entered into the model simultaneously.

¶ Defined based on the percentile of BMI for age: <5th percentile for underweight, ≥5th to <85th percentile for normal, ≥85th to <95th percentile for overweight and ≥95th percentile for obese subjects[31].

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crude and multivariate-adjusted models were again generally similar. In multivariate analyses, a lower risk of being an over-reporter was associated with ages 6–11 and 12–19 years, higher family poverty income ratio, overweight and obese and all later survey cycles.

We repeated all the analyses using 22 949 subjects with the first dietary recall data. The sample-weighted mean EI:BMR was 1·59, whereas the corresponding value for EI:EER was 1·02 (online Supplementary Table S1). The sample-weighted percentages of under-, plausible and over-reporters of EI were 11·6, 83·0 and 5·4 %, respectively, on the basis of EI:BMR and 14·7, 77·9 and 7·3 %, respectively, on the basis of EI:EER (online Supplementary Table S2). Factors significantly associated with the risk of being an under-reporter or being an over-reporter compared with being a plausible reporter were generally similar (online Supplementary Tables S3 and S4, respectively), except for girls having a higher risk of being an under-reporter and having a lower risk of being an over-reporter.

Discussion

Using two 24-h dietary recall data from NHANES 2003–2012, we found that misreporting of EI was prevalent and differential in US children and adolescents aged 2–19 years. Percentages of under- and over-reporters of EI were 13·1 and 5·4 %, respectively, on the basis of EI:BMR and 18·8 and 8·8 %, respectively, on the basis of EI:EER. A higher risk of being an under-reporter of EI compared with being a plausible reporter was associated with older age, non-Hispanic blacks (compared with non-Hispanic whites) and overweight and obesity (compared with normal weight). A higher risk of being an over-reporter compared with being a plausible reporter was associated with younger age, lower family poverty income ratio, normal weight and the first survey cycle. Similar findings were observed when analysing based on the first 24-h dietary recall only (NHANES 1999–2012). To our knowledge, this is the first study to examine the prevalence and characteristics of misreporting of EI in a representative sample of US children and adolescents.

Only a few national studies have examined the misreporting of EI among children and adolescents. A French study evaluated the EI assessed using a 7-d diet record among 1455 boys and girls aged 3–17 years on the basis of the Goldberg's principles[16]. The prevalence of under- and over-reporters was 4·9 and 1·4 % for children aged 3–10 years and 26·0 and 0 % for adolescents aged 11–17 years, respectively. In Australian boys and girls aged 2–16 years (n 4800), the EI estimated using a 24-h dietary recall was similarly evaluated, and the prevalence of under- and over-reporters was 5·0 and 3·0 %, respectively[17]. Additionally, the prevalence of under-reporters of EI (obtained from a 24-h dietary recall) was 7 % in 653 children aged 3–12 years and 32 % in 517 adolescents aged 13–18 years in Greece (over-reporters not defined)[21]. Among 1636 boys and girls aged 4–18 years in Britain, the EI assessed using a 7-d weighed dietary record was evaluated according to EI:EER[18]. The prevalence of under- and over-reporters was 19 and 0·7 %, respectively, for children aged 4–10 years and 52 and 0·4 %, respectively, for adolescents aged 11–18 years. In this analysis based on NHANES, the prevalence of under-reporting (13·1 % on the basis of EI:BMR and 18·8 % on the basis of EI:EER) was within the range of those observed in other countries, whereas the prevalence of over-reporting (5·4 % on the basis of EI:BMR and 8·8 % on the basis of EI:EER) was somewhat higher. Although it is difficult to determine whether the difference in the prevalence among countries reflects the true difference in the accuracy of reporting or is merely due to differences in the criteria used to identify misreporters, dietary assessment instruments, food composition databases and population characteristics, these national studies clearly show that misreporting of EI is a serious problem in dietary surveys among children and adolescents.

In the present study, overweight and obese subjects were more likely to under-report EI, which has been consistently observed in many studies[8,10,11,16,22]. Additionally, older age was associated with under-reporting of EI, which is again consistent with previous studies[12,13,22,36]. In adolescents, the additional demands imposed on reporting by increased energy requirements, unstructured eating patterns, a significant degree of out-of-home eating, concerns with self-image and rebellion against authority may contribute to poor compliance in a dietary assessment[7], resulting mainly in dietary under-reporting. For other correlates of misreporting, research is limited or the results are generally inconsistent[1]. For race/ethnicity, we found that a higher risk of under-reporting was associated with non-Hispanic blacks (compared with non-Hispanic whites), which had also been observed among US adults from NHANES 1988–1991[40]. In the present study, sex was not associated with EI misreporting. Several previous studies have found a similar degree of misreporting of EI in boys and girls[8,12,22], although there is some evidence that under-reporting is more prevalent in girls than in boys[1,18,19]. Characteristics associated with over-reporting of EI are less understood. We found that over-reporting was associated with younger age, lower family poverty income ratio and normal weight. One study has shown that over-reporting is prevalent at a younger age[36]. In an analysis of Irish adults, lower social class was associated with a higher risk of over-reporting[41]. Although these variables may not always be associated with EI misreporting, and the association should be dependent on the population characteristics, dietary assessment methods and the procedure for identifying misreporters, the accumulating literature clearly indicates that misreporting occurs non-randomly in children and adolescents. Specific to NHANES, we found that survey cycle was associated with both under- and over-reporting of EI. Although this observation may be explained, at least partly, by the survey design (such as oversampling of non-Hispanic black persons in NHANES 2007–2012), this differential reporting may severely distort the validity of trend analyses using dietary intake data. Thus, previous trend analyses should be cautiously interpreted in this regard, and future analyses should properly take into account misreporting of EI. Alternatively, given the decline in food and beverage purchases in the 2003–2011 period, especially in households with children[42], combined with the most recent statistics about obesity indicating no increase or decrease[43–45], the decline in EI in the later years observed in this study may not totally be misreporting but a true trend[46].

Several limitations of the present study are acknowledged. At present, the only way to obtain unbiased information on energy requirements in free-living settings is to use doubly labelled water as a biomarker. This technique is expensive and impractical for the application to large-scale epidemiological studies, and thus alternative procedures are used[3,5,8–10,12,15–19,35,36]. In the present study, EER was calculated with the use of equations from the US Dietary Reference Intakes, which have been developed based on a large number of measurements of total energy expenditure by the doubly labelled water method and are highly accurate ($R^2 \geq 0{\cdot}95$)[38]. In the absence of actual, measured total energy expenditure, these equations should serve as the best proxy. Because of constraints within the data set, we did not have a validated and individualised measure of physical activity. Instead, we assumed 'low active' level of physical activity for all subjects in the calculation of EER (as well as using the PAL for sedentary lifestyle for all subjects when using the Goldberg's principles). This seems adequate for most US children and adolescents, based on accelerometer data in NHANES 2003–2006[47,48]. Nevertheless, in very active individuals (e.g. those aged 6–11 years, as has been reported)[48], EER would be underestimated, resulting in an overestimation of EI:EER and retention of those in plausible or over-reporters. We conducted additional analyses where we assumed 'active' level of physical activity (i.e. PAL ≥1·6 to <1·9)[35] for subjects aged 6–11 years during the calculation of EER as well as using the PAL for active lifestyle (1·75)[35] when using the Goldberg's cut-off. Compared with the original analysis, the percentage of under-reporters (14·5 % on the basis of EI:BMR and 21·0 % on the basis of EI:EER) was higher, whereas that of over-reporters (4·1 % on the basis of EI:BMR and 6·8 % on the basis of EI:EER) was lower, with that of plausible reporters (81·4 % on the basis of EI:BMR and 72·1 % on the basis of EI:EER) being unchanged. However, factors significantly associated with the risk of being an under-reporter or being an over-reporter compared with being a plausible reporter were generally similar (data not shown). Further, we do not know the sensitivity and specificity of the procedures for identifying under- and over-reporters of EI used; additionally, there is currently not enough information on relative merits of the different methods (i.e. EI:BMR and EI:EER) for detecting misreporters, although EI:EER may be better given that the magnitude of misreporting can be estimated without information on the exact PAL value. Thus, we are unable to determine whether the associations found between misreporting of EI and several characteristics are true, or were artifacts caused by the procedure used to identify misreporters, as well as errors associated with food composition databases used and differences in the dietary interview methodology (i.e. a four-step multiple-pass approach in NHANES 1999–2000 and 2001 survey years *v.* an automated five-step multiple-pass approach in subsequent survey years). Finally, the cross-sectional nature of the study does not permit the assessment of causality, owing to the uncertain temporality of the association.

In conclusion, in this comprehensive analysis based on data from NHANES 2003–2012, we found that misreporting of EI assessed using two 24-h dietary recalls was too prevalent to ignore in US children and adolescents aged 2–19 years: 18·5 % on the basis of EI:BMR and 27·7 % on the basis of EI:EER. More importantly, such EI misreporting was differential among populations. Under-reporting was associated with older age, non-Hispanic blacks (compared with non-Hispanic whites) and overweight and obesity (compared with normal weight), whereas over-reporting was associated with younger age, lower family poverty income ratio, normal weight and the first survey cycle. The results were similar when only the first 24-h dietary recall was assessed based on data from NHANES 1999–2012. Thus, it is essential to consider this differential misreporting of EI when investigating diet–disease associations or conducting trend analyses based on NHANES. For example, it may be useful to examine whether the dietary variable of interest is associated with EI misreporting and, if so, to conduct analyses including and excluding EI misreporters or those with and without adjustment for EI misreporting[3,5,18,36,49] so that the influence of EI misreporting on the research results can be acknowledged. For practice, the routine application of some procedures to identify and separately treat those who report data of poor validity would improve the precision and accuracy of results from dietary surveys. As differential misreporting of EI is the inevitable end result of differential misreporting of foods, future research is needed to understand which foods are misreported (in addition to the development of biomarkers suitable for food intake) and, more fundamentally, why people misreport food intake (with the development of a conceptual framework of misreporting) so that dietary assessments are to be improved.

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K. M. contributed to the concept and design of the study, statistical analysis, data interpretation and manuscript writing. M. B. E. L. critically reviewed the manuscript. All authors read and approved the final manuscript.

The authors declare that there are no conflicts of interest.

Supplementary material

For supplementary material/s referred to in this article, please visit http://dx.doi.org/doi:10.1017/S0007114515004304

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