

Shifts in the Recent Distribution of Energy Intake among U.S. Children Aged 2–18 Years Reflect Potential Abatement of Earlier Declining Trends^{1–3}

Michelle A. Mendez,^{4–7*} Daniela Sotres-Alvarez,^{4,8} Donna R. Miles,⁶ Meghan M. Slining,⁹ and Barry M. Popkin^{5–7}

⁵Department of Nutrition, ⁶Carolina Population Center, ⁷Lineberger Cancer Center, and ⁸Department of Biostatistics, University of North Carolina at Chapel Hill, Chapel Hill, NC; and ⁹Furman University, Greenville, SC

Abstract

Recent national surveys suggest that child obesity in the United States may have reached a plateau, but corresponding trends in energy intake have not been examined in depth. This article evaluates medium-term trends in children's reported energy intake by using 4 waves of national dietary surveillance from 2003–2004 to 2009–2010. The analysis uses up to 2 24-h dietary recalls, incorporating methods that address challenges in estimating usual intake, accounting for intraindividual variance and covariates such as the presence of atypical consumption days. Quantile regression was used to assess disparities in intake among sociodemographic subgroups at extremes of the distribution as well as at the median, and the potential influence of misreporting was evaluated. Results indicated that after an initial decline in intakes across all age groups through 2007–2008, there were significant increases of ~90 kcal/d at the median among adolescents in 2009–2010, whereas intakes in younger children remained steady. Among adolescent boys, the recent increase was larger at the 90th percentile than at the median. Intake trends did not vary by race/ethnic group, among whom intakes were similar at the upper end of the distribution. Misreporting did not influence trends over time, but intakes were lower in younger children and higher in older children after excluding misreporters. Overall, findings suggest that declines in children's energy intake from 2003–2004 through 2007–2008 were consistent with the obesity plateau observed in most age and gender subgroups through 2009–2010. However, there is evidence of increased intakes among adolescents in 2009–2010, which may threaten the earlier abatement in overweight in this older age group. *J. Nutr.* 144: 1291–1297, 2014.

Introduction

Energy intakes are thought to be a major driver of the obesity epidemic (1,2). Several studies indicate that the dramatic increase in U.S. child obesity that occurred over the past few decades was followed by a plateau in 2009–2010 (3–8). However, researchers have yet to examine to what extent this shift is reflected by concomitant changes in energy intake. The role of energy intake trends in population changes in obesity is a subject of debate, given a number of factors. First, numerous studies exploring longer-term

dietary trends corresponding to the timing of the increase in obesity reported substantial, albeit unexpected, declines in energy intake in both children and adults (9–12). It is uncertain to what extent this apparent inconsistency may be due in part to factors such as long-term changes in reporting biases or intake assessment methods, which may be less problematic in studies focused on medium-term dietary shifts. Concerns have also been expressed about the ability to estimate usual intakes from a limited number of dietary recalls, as well as the potential impact of reporting biases on the validity of these trends (13,14). Moreover, although analyses of trends generally focus on changes in the mean, shifts at extremes of the distribution may be more relevant for changes in weight status.

This study examines patterns of change in child energy intake in detail, with the aim of gaining insights on the extent to which trends in intake correspond to shifts in obesity. Rather than long-term trends, this study examines changes in energy intake among U.S. children and adolescents by using data from nationally representative cross-sectional surveys conducted between 2003–2004 and 2009–2010, coinciding with the timing of recently

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⁴ M.A.M. and D.S.-A. contributed equally to this work.

* To whom correspondence should be addressed. E-mail: mmendez@email.unc.edu.

reported shifts in child obesity trends (3,8). Unlike studies focused on long-term trends that pool multiple waves of data, each 2-y survey cycle is analyzed separately to capture shorter-term fluctuations that may contribute to the shifts observed in patterns of obesity. To provide the most valid assessment of intake trends, methods to address a number of other potential limitations were incorporated.

Previous literature on dietary trends using these surveillance data generally focused on changes in mean intake estimates based on a single dietary recall (9,10,15). However, because weight status is affected by habitual intake, this analysis incorporates methods to better estimate usual intake from 2 recalls, by accounting for intraindividual variability and covariates that influence reporting (16,17). Rather than mean intake, this article uses quantile regression to examine shifts in the upper, median, and lower ends of the distribution and provides greater insights on where the most notable changes are occurring. Long-term increases in child overweight and obesity have disproportionately affected minority and lower socioeconomic status subpopulations, which recent declines do not appear to have redressed (3,18,19). It was therefore considered important to explore evidence of inequalities in the magnitude of changes in intake across the caloric distribution by using quantile regression models to test for age, race/ethnicity group, gender, and socioeconomic status disparities in patterns of change. Finally, to address concerns that changes over time in misreporting of energy intake may be influential (13), the impact of under- and over-reporting on energy intake trends was assessed.

Participants and Methods

Dietary data on participants aged 2–18 y from 4 cycles (2003–2004, 2005–2006, 2007–2008, and 2009–2010) of What We Eat in America, the dietary component of the NHANES, were used. These multistage, stratified probability samples of the U.S. population all used the same USDA food composition data to estimate energy intake (20–29). Two nonconsecutive days of intake data were obtained from 24-h dietary recall interviews administered by using the USDA's Automated Multiple-Pass Method (30). The first recall was collected by trained interviewers in the mobile examination center, and the second recall was collected on most participants 3–10 d later by telephone. Dietary interviews were self-completed by adolescents aged 12–18 y, whereas children aged 6–11 y were assisted by an adult, and interviews were completed by proxy for children ages 2–5 y.

Participants were excluded from analyses if parental education was missing ($n = 477$) and if the indicators of whether reported energy intake were atypical were missing ($n = 32$), 0 kcal ($n = 5$), or >4 SDs beyond individual estimated energy requirements ($n = 136$) and thus physiologically implausible estimates of habitual intake. Estimated energy requirement was calculated according to equations provided by the Institute of Medicine's Dietary Reference Intakes (2005) (31), with SD values calculated to identify implausible dietary reports by using the formula provided by Huang et al. (32). Accelerometry data were available only for NHANES 2003–2006 (33), and self-report data have been shown to substantially overestimate activity levels (34,35). Therefore, to account for the contribution of physical activity to the estimates of energy needs used to identify implausible intake reports, SD bounds were estimated on the basis of sedentary physical activity levels (PALs)¹⁰ to identify under-reporters and very active PALs to identify over-reporters. Supplementary sensitivity analyses excluding children whose energy intakes did not fall within the 1.5-SD bounds of estimated requirements used less conservative assumptions, applying a low-active

PAL for the lower bound and an active PAL for the upper bound; results did not change meaningfully from the main findings presented (data not shown). The final sample included 12,909 children over all 4 survey cycles, with a total of 24,159 dietary recalls (88% of the sample had 2 recalls). The sociodemographic distribution of the sample is shown in detail in **Supplemental Table 1**.

The National Cancer Institute (NCI) method was used to estimate the distribution (means and percentiles) of usual energy intake in children by using multiple 24-h recalls (16,17). This method allows 1) estimating the within- and between-person variance components and correcting for the high intraindividual variation intrinsic to 24-h recalls and 2) adjusting for important covariates, which helps improve the estimates by explaining the variability (e.g., intake differences due to recall sequence, or weekend consumption). Specifically, a 1-part nonlinear mixed model for repeated 24-h recalls was fit by using the NCI MIXTRAN macro (17,36), applying Box-Cox transformations and adjusting by NHANES survey cycle, age group, gender, race/ethnicity, parental education, weekend (including Friday), season (November–April or May–October), self-report intake amount (more, same, or less than usual), and recall sequence. Regression coefficients from this model are provided in **Supplemental Table 2**. The distribution of usual intake was then estimated empirically with the NCI DISTRIB macro (16,17,36), which performs Monte Carlo simulation by using estimated parameters from the model fit in the NCI MIXTRAN macro. The usual energy intake distribution is estimated for the first recall adjusted for the second recall and for usual self-report amount (as opposed to less or more). The simulated population has the same covariate pattern as NHANES for gender, race/ethnicity, and education. Finally, the distribution of usual energy intake for each survey cycle was standardized to the NHANES 2003–2004 age distribution. Because NHANES uses a complex, multistage probability design, variance estimation was carried out via the Balanced Repeated Replication technique and a Fay coefficient of 0.3 (37).

One limitation of the NCI method is that the effect from covariates on usual intake is constant on the transformed scale for all percentiles, because the model specification is for the mean. In contrast, quantile regression (38,39) estimates regression coefficients in all parts of the distribution of a response variable and hence allows the estimation of different effects at different percentiles of the distribution. To apply quantile regression to assess changes in intake at specific percentiles, we first predicted usual energy intake for each individual with the NCI INDIVINT macro (16,17,36,40) by using previously estimated parameters. Note that even for individuals with only one 24-h recall, a predicted usual intake enhanced with the information from all other individuals is obtained, which therefore is not based solely on the single day that happens to be observed. Quantile regression was then used to test the significance of differences in changes in intake associated with age, gender, parental education, and race/ethnicity at the 10th, 50th, and 90th percentiles of predicted usual energy intake with the use of an α level of 0.05 to define significance. Specifically, interactions between survey cycle and each covariate were included, and global tests for each interaction performed. Models were reduced when global tests were not significant at a 0.05 α level. Race/ethnic group analyses focused on Mexican Americans, non-Hispanic blacks, and non-Hispanic whites (NHWs) because other groups were small and heterogeneous. Last, predicted margins from the quantile regression were obtained to illustrate the size of the effects; predicted estimates are shown for the 10th, 50th (median), and 90th percentiles. Analyses accounted for the complex survey design and sampling weights (dietary recall weights for day 1) by using SAS version 9.3 software (SAS Institute) and the `qreg2` command in STATA version 13.0 (StataCorp) to perform quantile regression with robust and clustered SEs.

Results

As shown in **Figure 1** for adolescents, usual energy intakes estimated by using the NCI method declined from 2003–2004 to 2007–2008, with a downward shift in the entire distribution. Similar declines were observed for younger age groups

¹⁰ Abbreviations used: NCI, National Cancer Institute; NHW, non-Hispanic white; PAL, physical activity level.

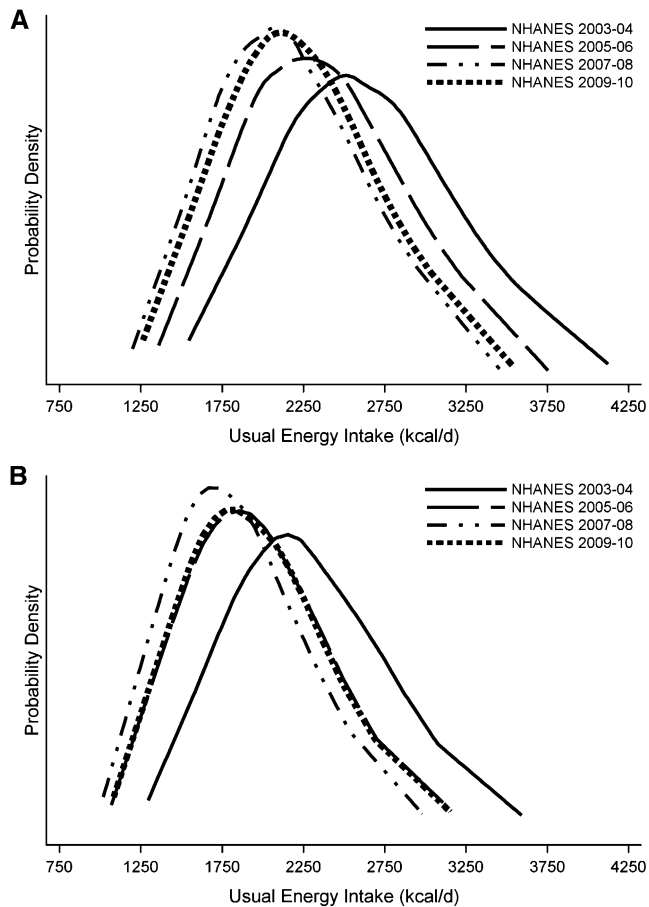


FIGURE 1 Estimated distributions of usual total energy intake among U.S. adolescents (aged 12–18 y) by NHANES survey (2003–2004 to 2009–2010) for boys (A) and girls (B) based on the National Cancer Institute method, described in detail in the Methods section (36).

(Supplemental Figs. 1 and 2). Figure 1 also shows that in 2009–2010, there was a substantial upward shift in the intake distribution among adolescents, with smaller changes among younger children (Supplement Figs. 1 and 2). Among adolescent boys, this shift led to intakes exceeding those in 2007–2008. In adolescent girls, there was a larger rightward shift in the intake distribution, which returned to 2005–2006 levels. As shown by using intakes at the 90th percentile, this pattern was similar across all race/ethnic groups (Fig. 2). There was a substantial reduction at the 90th percentile in intakes across all ages between 2003–2004 and 2007–2008 (Fig. 2A), followed by an increase in 2009–2010 among older children (Fig. 2B).

Quantile regression was used to test whether these shifts in intakes over time were significant, and whether they differed across population subgroups (coefficients shown in Supplemental Table 3). Predicted usual intakes (Table 1) from final models showed that overall, compared with the 2003–2004 survey, there was a large and significant reduction in intake at each percentile examined in 2007–2008. However, although reported intakes remained significantly lower than in 2003–2004, there were significant increases in intakes for 2009–2010 compared with 2007–2008 among older children ($P = 0.01$ for age group by year interactions, $P = 0.07$ for main effect). After declines between 2003–2004 and 2007–2008 of 159–240 kcal/d at the median, intakes in 2009–2010 among male and female adolescents increased by 72 and 100 kcal/d, 59 and 97 kcal/d, and 92 and 83 kcal/d at the 10th, 50th, and 90th percentiles, respectively. Similarly, among younger children, the substantial

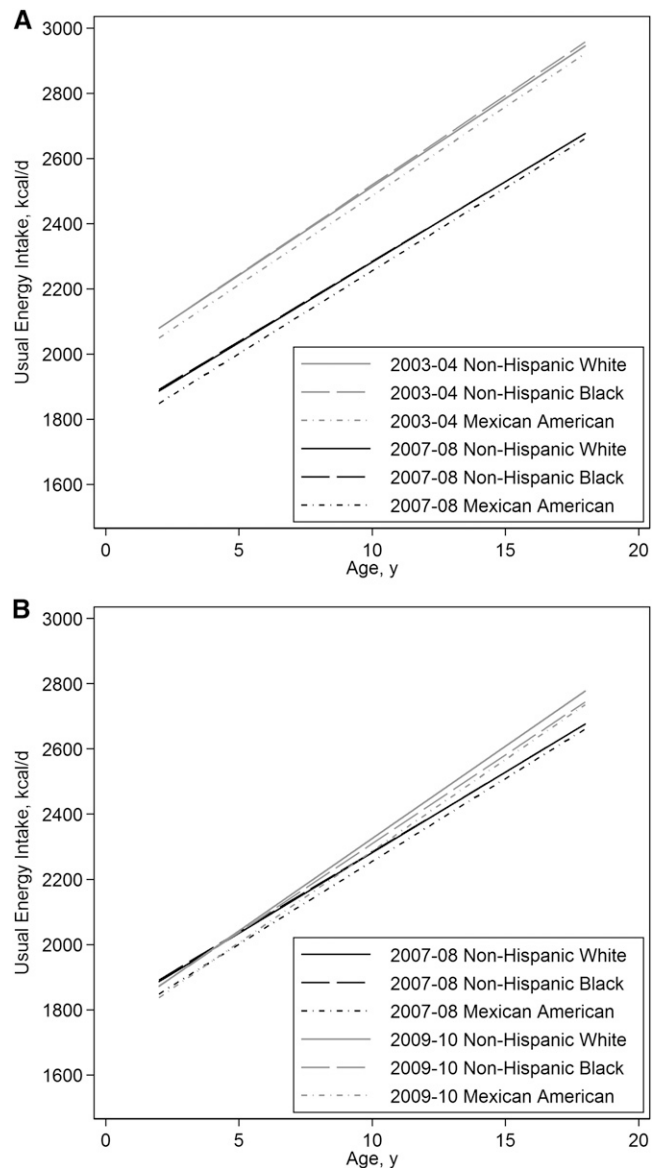


FIGURE 2 Estimated usual energy intakes at the 90th percentile by age group and race/ethnicity on the basis of quantile regression results shown in Table 1: NHANES 2003–2004 vs. 2007–2008 (A) and NHANES 2007–2008 vs. 2009–2010 (B). $P < 0.05$ for differences in intakes at the 90th percentile in 2003–2004 vs. 2007–2008 at all ages. $P < 0.05$ for differences in intakes at the 90th percentile for the 12–18 y age group only. $P > 0.10$ for all differences among race/ethnic groups.

declines in reported intake observed across earlier survey cycles halted in 2009–2010, although the subsequent increase in intake was more modest than that observed in older children.

There were no significant changes over this time period in the magnitude of energy intake disparities among vulnerable subgroups ($P > 0.10$ for all subgroup by survey cycle interaction terms). Moreover, coefficients from quantile regression models (Supplemental Table 3) showed that in contrast to the large and significant deficits in intake reported among non-Hispanic blacks and Mexican Americans compared with NHWs at lower percentiles, intake disparities at the 90th percentile (more relevant for obesity risk) were small and in some cases nonsignificant. Similarly, the absence of interactions indicated that parental education did not predict differences in how children's energy intakes changed over this time frame. Moreover, unlike race/ethnicity, parental educational level was not

TABLE 1 Usual energy intakes at the 10th, 50th, and 90th percentiles among U.S. children and adolescents: NHANES 2003–2004 to 2009–2010¹

	10th Percentile			50th Percentile (median)			90th Percentile		
	2003–2004	2007–2008	2009–2010	2003–2004	2007–2008	2009–2010	2003–2004	2007–2008	2009–2010
	<i>kcal/d</i>			<i>kcal/d</i>			<i>kcal/d</i>		
Age group									
2–5 y									
Boys	1481 ± 20	1373 ± 15	1360 ± 12	1863 ± 14	1654 ± 10	1643 ± 13	2235 ± 21	1967 ± 24	1990 ± 17
Girls	1251 ± 17	1120 ± 14	1134 ± 16	1533 ± 16	1375 ± 9	1401 ± 11	1811 ± 16	1671 ± 18	1686 ± 16
6–11 y									
Boys	1796 ± 22	1657 ± 23	1655 ± 21	2241 ± 13	2008 ± 12	2011 ± 12	2720 ± 27	2429 ± 22	2422 ± 26
Girls	1566 ± 21	1404 ± 21	1429 ± 19	1911 ± 13	1729 ± 14	1769 ± 13	2297 ± 27	2133 ± 23	2118 ± 17
12–18 y									
Boys	1815 ± 27	1631 ± 24	1704 ± 23	2357 ± 16	2117 ± 22	2177 ± 19	2995 ± 15	2655 ± 17	2747 ± 26
Girls	1585 ± 19	1378 ± 21	1478 ± 20	2027 ± 13	1838 ± 16	1935 ± 16	2571 ± 20	2360 ± 24	2443 ± 29
Race/ethnicity									
Non-Hispanic white	1658 ± 17	1527 ± 16	1542 ± 17	2054 ± 14	1895 ± 10	1922 ± 12	2481 ± 16	2340 ± 18	2355 ± 18
Non-Hispanic black	1590 ± 16	1458 ± 15	1473 ± 19	2007 ± 16	1848 ± 12	1875 ± 12	2473 ± 19	2332 ± 22	2347 ± 20
Mexican American	1598 ± 19	1467 ± 18	1482 ± 18	2007 ± 14	1848 ± 12	1875 ± 13	2444 ± 17	2304 ± 18	2318 ± 17
Other Hispanic	1600 ± 26	1468 ± 25	1483 ± 22	2027 ± 17	1869 ± 15	1895 ± 14	2464 ± 21	2324 ± 24	2339 ± 20
Other/mixed race	1608 ± 26	1477 ± 28	1491 ± 29	1999 ± 22	1841 ± 18	1867 ± 18	2441 ± 28	2300 ± 25	2315 ± 21

¹ Values are predicted estimates ± SEs of usual energy intake at each percentile from quantile regression models shown in detail in Supplemental Table 3.

strongly associated with disparities in children’s energy intake during this period. Associations between intake and parental education were significant only at the 10th percentile: at this percentile, intakes among children whose parents had less than a high school education were 39 kcal/d less than in those who were more educated.

Figure 3 highlights the large decline in intakes across all age groups from 2003–2004 to 2007–2008 and the subsequent increase among adolescents in 2009–2010, additionally showing that these trends were unchanged after excluding energy intake misreporters. Excluding misreporters tended to decrease energy intakes at the median among children ages 2–5 and 6–11 y in whom over-reporting was highly prevalent but to increase the median intake among adolescents due to the higher prevalence of under-reporting at older ages.

Discussion

By using nationally representative data and methods to improve the estimation of usual intake, we found that a decline in reported energy intakes between 2003–2004 and 2007–2008 was not maintained in 2009–2010. An estimated initial decline of 159–240 kcal/d at the median was observed across all age groups. However, there was a subsequent significant increase in 2009–2010 observed among adolescents aged 12–18 y (median increases of 59 and 97 kcal/d in boys and girls, respectively), whereas intakes in younger children appeared to reach a plateau (changes of –11 to 40 kcal/d). Although intakes leveled off in younger children, the recent upturn in estimated usual intakes among adolescents may pose a threat to abatement of obesity in this age group. Indeed, consistent with our findings, in contrast to the plateaus and declines in obesity observed in younger children, the most recent analyses of NHANES data showed small increases in obesity among adolescents (3,41). Importantly, to address concerns that a substantial proportion of reported energy intake data lacks validity as estimates of usual consumption (13), trends and age group disparities

were re-examined after excluding participants likely to have misreported their usual intake; no meaningful differences were found.

The magnitude of the recent increase in median energy intake among adolescents is cause for concern, because the estimated average energy deficit needed to prevent further weight increases for children is 41 kcal/d (67 kcal/d in adolescents) (42,43). The average energy deficit to reach the Healthy People 2010 goal (5% prevalence of obesity) by 2020 is estimated to be even larger, 120 kcal/d (177 kcal/d in adolescents). However, more so than changes at the mean or median, shifts at the upper end of the energy intake distribution are of particular concern given the persistently high levels of child obesity in the United States (3). With the skewed distributions commonly observed for dietary intake variables, focusing only on the mean may provide an incomplete picture of patterns of change. Among adolescent boys, the estimated upturn in intakes in 2009–2010 was larger at the 90th percentile than at the median (92 vs. 59 kcal/d).

As observed previously for long-term trends in reported intakes (10), race/ethnic group differences remained constant over this period. However, in contrast to large deficits in intake relative to NHWs at the 10th and 50th percentiles, the race/ethnic disparity in energy intake at the 90th percentile was either nonsignificant or relatively small in magnitude. Sustained, comparably high intakes across ethnic groups at this upper end of the distribution are consistent with the persistent disproportionate burden of overweight among minorities (3).

This study used several strategies in an effort to address concerns about the utility of a limited number of self-reported 24-h recalls to evaluate trends in energy intake. Rather than a single day of energy intake as in most previous studies that used NHANES data (15), this analysis estimated usual intakes using up to 2 d of recalls, accounting for intraindividual variation and incorporating covariates that predict under- and overestimation of habitual intake (16,17). Other studies with multiple recalls (44) found that incorporating a second day and accounting for covariates such as weekend days can substantially improve

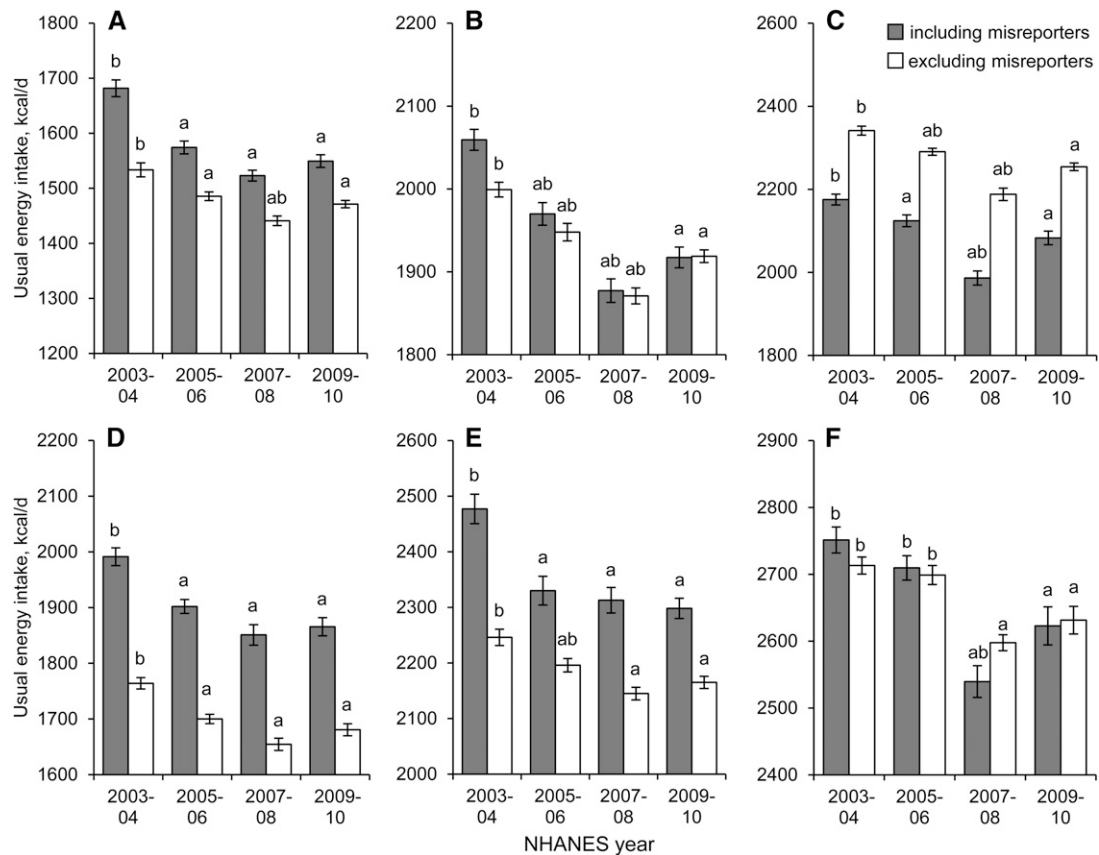


FIGURE 3 Adjusted predictions (with SEs) of usual energy intakes with and without misreporters from NHANES 2003–2004 to 2009–2010 at the 50th percentile for ages 2–5 y (A), 6–11 y (B), and 12–18 y (C) and at the 90th percentile for ages 2–5 y (D), 6–11 y (E), and 12–18 y (F). Misreporters were defined on the basis of a disparity in reported energy intake vs. estimated energy requirements exceeding ± 1.5 SDs, where estimated energy requirement was estimated for each participant on the basis of doubly labeled water predictions and SDs were estimated on the basis of CVs in daily energy intake, predicted energy requirements, and measured energy expenditure as prescribed by Huang et al. (32). Results were consistent whether or not misreporters were included in the analysis. ^aDifferent from 2003–2004, $P < 0.05$; ^bdifferent from 2009–2010, $P < 0.05$.

estimation of usual energy intake. The NCI method used to estimate usual energy intake was shown to provide reliable estimates of the intake distribution (16). Our extension to apply quantile regressions enabled us to assess the significance of trends in intake at extremes of the distribution, as well as the significance of differences associated with factors such as age and race/ethnicity.

As in adults, studies that used doubly labeled water indicate that energy intakes in children may be substantially under- or over-reported (32,45,46). Another recent study identified substantial energy intake misreporting in NHANES adults (14). In that study, under-reporting estimates may have been elevated by applying basal metabolic rate equations that perform poorly in populations with high rates of obesity (46,47). Importantly, our analysis, which estimated misreporting on the basis of doubly labeled water equations (32,46), suggests that misreporting in children did not influence trends in intake. Neither analysis took into account weight loss from dieting, which may increase estimates of under-reporting that assume weight stability (48). Although both children (49) and adults (50) in NHANES reported such diets, the proportion of children who successfully achieve meaningful weight loss is uncertain, and, in contrast to adults, it was not possible to take this issue into account. The focus on recent intake trends in this article also reduced the likelihood of bias related to methodologic changes.

Although misreporting did not influence trends over time, it did modify estimates of intake, which were lower in younger

children and higher in older children when misreporters were excluded. These changes reflect the higher proportion of over-reporting at younger ages (45). Under- and over-reporting prevalence estimates were 4% and 14% among children 2–5 y, 5% and 5% among children 6–11 y, and 13% and 2% among children 12–18 y in 2003–2004. In 2009–2010, the corresponding prevalence rates were 6% and 10% among children 2–5 y, 6% and 2% among children 6–11 y, and 14% and 1% among children 12–18 y. These estimates suggest that the prevalence of misreporting among children did not appreciably increase during this short time span. Under-reporting estimates were comparable to those derived on the basis of doubly labeled water (51,52). Nonetheless, despite efforts to maximize the validity of the data used, it is not possible to ascertain to what extent error or bias in reported intakes may have influenced the trends observed (13).

Another limitation of this analysis is uncertainty with regard to the extent to which recent increases in energy intake among adolescents may be attributable to increases in physical activity. Although accelerometry data for part of this period suggest small increases in active time among younger children, there was no evidence of such increases among adolescents (53). It is unclear whether small increases in adolescent self-reports of active time on the basis of crude measures such as days per week being active reflect meaningful changes, and whether any increases in active time may have been offset by simultaneous increases in video game and computer use (54). Moreover, current

knowledge is limited on the extent to which physical activity promotes higher energy intake, and whether it may do so more than sedentary activities such as television watching (55–57).

In summary, this study, which used nationally representative dietary data and accounted for variability in usual intake and misreporting, found evidence that short-term declines in the distribution of U.S. children's energy intakes between 2003–2004 and 2007–2008 may have halted in 2009–2010 among younger children, with increases in intake among older children. Despite the limitation of relying on self-reported data, intake trends are consistent with temporal patterns in child obesity. This recent shift in energy intake trends, if real, may pose a threat to the positive changes in child overweight achieved just before this period.

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