Modeled changes in US sodium intake from reducing sodium concentrations of commercially processed and prepared foods to meet voluntary standards established in North America: NHANES

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ABSTRACT

Background: Approximately 2 in 3 US adults have prehypertension or hypertension that increases their risk of cardiovascular disease. Reducing sodium intake can decrease blood pressure and prevent hypertension. Approximately 9 in 10 Americans consume excess sodium (≥2300 mg/d). Voluntary sodium standards for commercially processed and prepared foods were established in North America, but their impact on sodium intake is unclear.

Objective: We modelled the potential impact on US sodium intake of applying voluntary sodium standards for foods.

Design: We used NHANES 2007–2010 data for 17,933 participants aged ≥1 y to model predicted US daily mean sodium intake and the prevalence of excess sodium intake with the use of the standards of the New York City's National Salt Reduction Initiative (NSRI) and Health Canada for commercially processed and prepared foods. The Food and Nutrient Database for Dietary Studies food codes corresponding to foods reported by NHANES participants were matched to NSRI and Health Canada food categories, and the published sales-weighted mean percent reductions were applied.

Results: The US population aged ≥1 y could have reduced their usual daily mean sodium intake of 3417 mg by 698 mg (95% CI: 683, 714 mg) by applying NSRI 2014 targets and by 615 mg (95% CI: 597, 634 mg) by applying Health Canada's 2016 benchmarks. Significant reductions could have occurred, regardless of age, sex, race/ethnicity, income, education, or hypertension status, up to a mean reduction in sodium intake of 850 mg/d in men aged ≥19 y by applying NSRI targets. The proportion of adults aged ≥19 y who consume ≥2300 mg/d would decline from 88% (95% CI: 86%, 91%) to 71% (95% CI: 68%, 73%) by applying NSRI targets and to 74% (95% CI: 71%, 76%) by applying Health Canada benchmarks.

Conclusion: If established sodium standards are applied to commercially processed and prepared foods, a significant reduction of US sodium intake could occur. *Am J Clin Nutr* 2017;106:530–40.

Keywords: intake, modeling, national, sodium, food, United States

INTRODUCTION

Approximately 9 in 10 people in the United States consume more dietary sodium than the maximum amount recommended by the 2015–2020 Dietary Guidelines for Americans (Dietary Guidelines), thereby increasing their risk of high blood pressure (1–3). High blood pressure (i.e., hypertension) is a major risk factor for heart disease and stroke, which are the first and fifth causes of death, respectively, in the United States (4–6). Strong evidence has indicated that reducing blood pressure reduces the risks of heart disease and stroke, and reducing sodium intake decreases blood pressure, with a greater sodium effect in persons at higher cardiovascular disease risk (e.g., older adults, African Americans, and people with elevated blood pressure) (7–10). Consistent with the Dietary Guidelines and US and Canadian Dietary Reference Intakes, a national health objective in Healthy People 2020 is to reduce the mean US population sodium intake to 2300 mg/d by the year 2020, which would be an ∼37% reduction from current amounts (1, 3, 11). Most (>70%) of our sodium intake comes from processed and restaurant foods rather

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Supplemental Methods, Supplemental Tables 1 and 2, and Supplemental Figures 1 and 2 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://ajcn.nutrition.org.

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Abbreviations used: AI, Adequate Intake; FDA, Food and Drug Administration; FNDDS, Food and Nutrient Database for Dietary Studies; IOM, Institute of Medicine; NSRI, National Salt Reduction Initiative; PIR, poverty index ratio; SR, National Nutrient Database for Standard Reference.

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than from salt that is added by the consumer at the table or during home preparation and cooking, which prompted the Institute of Medicine (IOM) to recommend mandatory national standards for the sodium content of these foods (12–14). Voluntary food standards were recommended as an interim strategy (12). Voluntary standards to decrease the sodium content of commercially processed foods by 25–30% over 4–5 y were published by New York City's National Salt Reduction Initiative (NSRI) for the United States in 2009 and by Health Canada in 2012 (15–18). Both standards were based on the sodium content of foods that are produced by major food manufacturers. Although declines occurred in the sodium content of some US and Canadian commercially processed foods after the publication of these standards, sodium standards were not met for all food categories, and the potential impact on the change in sodium intake has been unclear (2, 19–21).

In 2016, the US Food and Drug Administration (FDA) published a draft guidance of voluntary sodium-reduction goals for public comment with an aim to reduce US daily sodium intake from 3400 to 3000 mg within 2 y (short-term goals) and to 2300 mg within 10 y (long-term goals) (22). The methodology that was used to arrive at the FDA draft voluntary standards was informed by both the sodium standards of New York City's NSRI and Health Canada (15–18). Although sources of sodium intake and the sodium content of foods in Canada and the United States are similar (23–25), the standards applied in this study, which are called targets in the NSRI or benchmarks in Health Canada, differed in the types and numbers of food categories. The objective of the current study was to model the potential impact on US sodium intake of applying published voluntary sodium standards for foods overall and by sociodemographic and health subgroups. An understanding of potential changes in US sodium intake through the application of standards could help inform the FDA draft guidance on voluntary sodium-reduction goals.

METHODS

NHANES 2007–2010

The NHANES was used for this analysis and included a multistage, national probability sample of the US noninstitutionalized population for each 2-y phase starting in 1999–2000. For this analysis, we combined data from the NHANES 2007–2008 and 2009–2010 to reflect the sodium concentrations (milligrams of sodium per 100 g food) in the food supply and sodium intake at baseline before and after the voluntary implementation of standards. Detailed descriptions of the survey design and data-collection procedures are available elsewhere (26). Respondents participated in household interviews, physical examinations, dietary interviews, and postexamination components. The survey was approved by National Center for Health Statistic's Ethical Review Board, and all participants provided written informed consent.

The unweighted response rate for the examined sample was 75% in 2007–2008 and 77% in 2009–2010. We included respondents aged ≥1 y (n = 19,142) and excluded individuals who were pregnant (n = 195) or whose dietary recall did not meet the minimum required standards for data quality (n = 1014) for a final sample of 17,933 subjects. Although the Dietary Guidelines for sodium do not differ for pregnant women, their dietary habits may differ from those of nonpregnant women, thereby potentially skewing the results in some population subgroups.

Sodium intake

Two 24-h dietary recalls were collected and coded in the NHANES as part of the USDA's What We Eat in America diet component by trained interviewers with the use of USDA's Automated Multiple-Pass Method with food models (27–29). An initial dietary recall was collected in the mobile examination center, and a second recall was collected 3–10 d later via telephone. For participants aged 0–5 y, a proxy (such as the mother) was asked to recall intake; for participants aged 6–11 y, the participant was assisted by a proxy. The nutrient contents of each reported food were assigned with the use of the USDA Food and Nutrient Database for Dietary Studies (FNDDS), which corresponded to each NHANES 2-y phase (30). The sodium concentrations (milligrams of sodium per 100 g) of foods in the FNDDS are derived from the USDA National Nutrient Database for Standard Reference (SR) (31). The calculation of dietary sodium intake excludes salt added at the table because the amount of salt added is not quantified (32). For these analyses, we used data files that did not adjust the sodium concentrations of foods for the frequency of salt added in home cooking or preparation. (32). Excess sodium intake was defined as usual sodium intake greater than the IOM age-specific Tolerable Upper Intake Level, which is the basis for the limits for sodium intake that was set by the Dietary Guidelines (1, 3). Although the Dietary Guidelines focus on the population aged ≥2 y, in the current study, we focused on the population aged ≥1 y to correspond with the IOM Tolerable Upper Intake Levels (3). The Dietary Guidelines also state that, for people with hypertension and prehypertension, a "further reduction to 1500 mg/d can result in even greater blood pressure reduction." Thus, we also examined the proportion of adults with hypertension and prehypertension (see definitions in the Covariates section) with sodium intake greater than this threshold. As specified in the Dietary Reference Intakes (3), "mean usual intake at or above the Adequate Intake (AI), implies a low prevalence of inadequate intakes." In addition, we examined the prevalence of individual estimated usual intakes greater than the AI (3).

Covariates

Age, sex, race/ethnicity, education, and income were self-reported. Race or ethnicity was categorized as non-Hispanic white, non-Hispanic black, or Hispanic. Poverty index ratios (PIRs) were defined as household income relative to national poverty thresholds for a household of a similar size, composition, and location. PIR categories correspond with those that were used in Healthy People 2020; a PIR <100% corresponds to a household with an income that is below the poverty level (11). BMI (in kg/m^2) was calculated as measured weight divided by measured height squared. BMI was categorized according to current NIH guidelines as not overweight or obese (≤25), overweight (>25–29.9), and obese (≥30) (33). Hypertension was defined as a mean systolic blood pressure ≥140 mm Hg, a mean diastolic blood pressure ≥90 mm Hg, or the self-reported use of an antihypertensive medication as in previous studies (34–36). In individuals without hypertension, prehypertension was defined as a mean systolic blood pressure of 120–139 mm Hg or a mean diastolic pressure of 80–89 mm Hg (35, 36). Normal blood pressure was defined as a mean systolic blood pressure <120 mm Hg and a mean diastolic blood pressure <80 mm Hg.

Sodium standards

The analyses in this study were based on *1*) the NSRI 2009 baselines and 2014 targets (15) and *2*) Health Canada's Guidance for the Food Industry on Reducing Sodium in Processed Foods (Health Canada) 2009–2010 baselines and 2016 benchmarks (18). The methods that were used to develop these standards are described in detail in **Supplemental Methods**. Briefly, both standards based their baselines and target and benchmark nutrient data on sales-weighted mean sodium concentrations (milligrams per 100 g). A sales-weighted mean sodium concentration was calculated as the mean of the sodium concentrations for all food products within the category weighted by the sales volume [i.e., the number of equivalent units sold in a standardized unit such as ounces (1 oz = 28.35 g)] of each of those food products. In 2010, the NSRI published targets for a total of 87 food categories including 62 packaged food and 25 restaurant food categories that were purchased by consumers. In 2012, Health Canada published benchmarks for 94 processed food categories that were meant to be applied to packaged foods that were purchased by consumers or that were used by the industry as ingredients in food manufacturing or preparation of restaurant, food service, or cafeteria foods. With each standard, food manufacturers and preparers were encouraged to reformulate their product portfolios within the food category to meet the sales-weighted mean target or benchmark sodium concentration for that category. For the NSRI, restaurant food manufacturers also were encouraged to meet maximum sodium concentrations for all products within their portfolios for that food category. For Health Canada, all processed food manufacturers and preparers were encouraged to reformulate their products to not exceed maximum sodium concentrations.

Predicted sodium concentrations of foods

Reductions in US sodium intake were predicted on the basis of sales-weighted mean sodium targets or benchmarks. Most nutrient values that were used for the FNDDS food codes were not manufacturer (brand) specific but were based on data from the SR and represent sales-weighted mean composites of top selling foods. Some, but not all, of the foods that were included in the manufacturers' portfolios are part of the SR food composites (37). Because of the lack of brand-specific values, the maximum target or benchmark could not be applied within a category. The predicted sodium concentration of a food code was modeled on the basis of the predicted percentage of reduction in the sodium concentration for the applicable food category for 2 major reasons. First, the application of the percentage of reduction to the FNDDS food code approximates how the targets will be applied by manufacturers (i.e., foods with different baseline sodium concentrations can be lowered to a concentration that is greater than or less than the target or benchmark as long as the sales-weighted mean of the sodium concentrations of all the foods in the specified food category meets the target or benchmark. Second, the application of the percentage of reduction accounts for moisture losses and additions in cooking or food preparation. For some foods, such as cooked instant oatmeal or soup that is made from a dry mix, the matching food category could be an unprepared version. Here, the absolute target or benchmark sodium concentration would be wrongly applied to the prepared version, but the percentage pf reduction would be the equivalent or nearly so. Similarly, the application of the percentage of reduction to estimate the predicted sodium concentrations can account for the addition of other food components in the preparation of the food as long as the added food components contain very little sodium.

In general, estimating the predicted sodium concentrations of a food occurred in 3 steps. First, the ratio of the target or benchmark to the baseline was estimated for each food category for each sodium standard as follows:

$$\begin{aligned}\text{Ratio} &= \text{target (benchmark) sodium concentration} \div \\ &\quad \text{baseline sodium concentration} \\ &= \text{sodium (mg/100 g)}_{\text{target (benchmark)}} \div \\ &\quad \text{sodium (mg/100 g)}_{\text{baseline}}\end{aligned} \tag{1}$$

For example, for the NSRI category bread and rolls, the baseline sodium concentration was 485 mg/100 g, and the 2014 target was 360 mg/100 g; therefore, the ratio of the target to the baseline sodium concentration was 0.7423, which represented a percentage of reduction of 25.8% as the predicted sodium-concentration reduction for the bread and rolls category of the NSRI. For Health Canada, the percentage of reduction for white bread was 29.6% [(1 − 0.7036) × 100] (**Supplemental Table 1**). Second, each FNDDS food-code description was reviewed by 2 independent reviewers and matched to the applicable food category with the use of a stepwise approach (**Supplemental Figures 1** and **2**). Third, the predicted reductions were applied to the FNDDS food codes or to one more of its components with the use of the recipe approach with the FNDDS-SR linked files (30). Overall, for 4177 and 3752 FNDDS food codes, sodium reductions were applied to the sodium concentration for the food code with the use of the ratio of the applicable NSRI target and Health Canada benchmark, respectively, to its baseline. Of these, the number of FNDDS food codes with sodium reductions that were applied on the basis of the recipe approach was n = 57 for the NSRI and n = 1010 for Health Canada. For the remainder of the unique FNDDS food codes (such as for fresh fruit and vegetables without added salt or sauces), no sodium reduction was applied to the sodium concentration. Then, predicted sodium concentrations were calculated for each FNDDS food code that was used in the analysis by multiplying the ratio of the target (benchmark) to the baseline sodium concentrations by the sodium concentration for the applicable FNDDS food code. See Supplemental Table 1 for sample calculations.

Modeling sodium intake

For each individual for each day, the predicted sodium intakes (milligrams per day) were modeled separately on the basis of NSRI 2014 targets and Health Canada 2016 benchmarks with the use of the individual food files in the NHANES. The predicted sodium intake from each food that was consumed on the dietary recall day was calculated by multiplying the amount of each food consumed on the dietary recall day (grams) times the predicted sodium concentration (milligrams per 100 g). Total predicted sodium intake for the dietary recall day for each individual was calculated from the sum of predicted sodium intake from each food that was consumed on that day. Eight-two percent of the total dietary sodium that was consumed from foods (excluding salt added at the table) by NHANES participants ≥1 y old came from those foods that were matched to an NSRI 2014 target, whereas 74% of total sodium intake came from those foods that were matched to a Health Canada 2016 benchmark.

Statistical analysis

For the mean and prevalence of excess usual sodium intake on the basis of the NHANES 2007–2010, NSRI 2014, and Health Canada 2016 as well as absolute differences of predicted intake (NSRI 2014 and Health Canada 2016) from NHANES 2007–2010 population intakes, the National Cancer Institute's SAS (SAS Institute Inc.) macro (version 1.1) was used to account for between- and within-person variations in intake with adjustment for the day of the week, age, sex, and race/ethnicity (38). Mean usual intakes were estimated for the total population aged ≥1 y and by population subgroups and separately in adults aged ≥19 y for demographic and health (e.g., by hypertensive status) subgroups. The prevalence of individuals with excess sodium intake was estimated both overall and by subgroups. The proportion of individuals with estimated usual intake greater than the AI was calculated by age group. We used R statistical software (version 3.2.4; The R Foundation) to plot the estimated distribution (probability functions in milligrams of sodium) of usual daily sodium intakes for the total population aged ≥1 y from 1000 representative intakes (38, 39). The distribution represents the probability of an individual's usual sodium intake falling within a particular region that is given by the integral of individual usual sodium intakes over the region. The integral over the entire space of the distribution is equal to 1.

Survey sample weights were applied in all analyses to produce nationally representative estimates. Analyses included participants of all race/ethnic groups except when reported by categories of race/ethnic groups. Estimates that were presented by race/ethnic categories were restricted to non-Hispanic white, non-Hispanic black, and Hispanic participants, the latter of whom were oversampled as part of the survey design. We used combined 4-y, 2-d dietary sampling weights to account for a differential nonresponse and noncoverage and to adjust for oversampling. We estimated SEs and 95% CIs for usual intakes with the use of balanced repeated-replication weights on the basis

TABLE 1
Modeled usual sodium intakes with sodium reduction (NSRI 2014; Health Canada 2016) and without sodium reduction (NHANES 2007–2010) in commercially processed foods in the US population aged ≥1 y[1]

	Usual population sodium intake,[2] mg/d				
	NHANES 2007–2010	NSRI 2014[3]	Difference[4]	Health Canada 2016[5]	Difference[6]
Total (*n* = 17,933)[7]	3417 (3348, 3485)	2719 (2663, 2775)	698 (683, 714)	2801 (2746, 2857)	615 (597, 634)
Sex					
M (*n* = 9054)	3894 (3800, 3988)	3097 (3023, 3171)	799 (777, 822)	3198 (3125, 3272)	694 (670, 719)
F (*n* = 8879)	2958 (2906, 3009)	2358 (2317, 2399)	602 (591, 613)	2421 (2381, 2460)	540 (525, 555)
Race/ethnic group[8]					
Hispanic (*n* = 5796)	3143 (3052, 3235)	2500 (2431, 2570)	643 (618, 668)	2630 (2555, 2705)	512 (490, 535)
Non-Hispanic white (*n* = 7543)	3502 (3419, 3585)	2782 (2715, 2849)	719 (702, 736)	2855 (2787, 2923)	652 (634, 670)
Non-Hispanic black (*n* = 3672)	3199 (3102, 3295)	2529 (2455, 2603)	669 (649, 690)	2629 (2554, 2704)	567 (546, 588)
Age group,[9] y					
1–3 (*n* = 1484)	2110 (2021, 2199)	1701 (1632, 1770)	411 (388, 434)	1757 (1687, 1827)	362 (337, 388)
4–8 (*n* = 1895)	2799 (2710, 2887)	2224 (2156, 2292)	579 (559, 599)	2276 (2207, 2344)	531 (510, 551)
9–13 (*n* = 1717)	3243 (3103, 3382)	2569 (2457, 2681)	676 (638, 715)	2633 (2521, 2745)	614 (579, 649)
19–30 (*n* = 2164)	3717 (3565, 3869)	2944 (2820, 3067)	776 (743, 808)	3061 (2943, 3180)	664 (630, 698)
31–50 (*n* = 3719)	3719 (3614, 3825)	2958 (2873, 3043)	760 (738, 783)	3061 (2978, 3144)	659 (632, 686)
51–70 (*n* = 3457)	3457 (3332, 3582)	2766 (2667, 2864)	688 (663, 714)	2841 (2748, 2934)	618 (589, 648)
≥71 (*n* = 2930)	2930 (2812, 3047)	2345 (2256, 2434)	583 (555, 611)	2403 (2314, 2493)	531 (503, 559)

[1] All values are means (95% CIs). NSRI, National Salt Reduction Initiative.

[2] Intakes account for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.

[3] Predicted intakes account for the percentage of reduction in the sodium content of applicable reported foods to correspond with the percentage of reduction as indicated by New York City's NSRI 2014 targets by category of packaged and restaurant food (15).

[4] Absolute differences between sodium intakes on the basis of the NHANES 2007–2010 and NSRI 2014 accounting for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.

[5] Predicted intakes account for the percentage of reduction in the sodium content of applicable reported foods to correspond with the percentage of reduction as indicated by Health Canada's 2016 mean sodium-reduction benchmarks by category of processed food (18).

[6] Absolute differences between sodium intakes on the basis of the NHANES 2007–2010 and Health Canada 2016 accounting for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.

[7] Sample sizes across some subgroups (family income, weight status, and hypertensive status) do not add up to the total number of adults because of missing data or nonresponses for some variables and questions.

[8] Subgroup analyses were restricted to Hispanics, non-Hispanic whites, and non-Hispanic blacks.

[9] Institute of Medicine Adequate Intakes are 1000 mg/d for children aged 1–3 y, 1200 mg/d for children aged 4–8 y, 1500 mg/d for persons aged 9–50 y, 1300 mg/d for adults aged 51–70 y, and 1200 mg/d for adults ≥71 y (3).

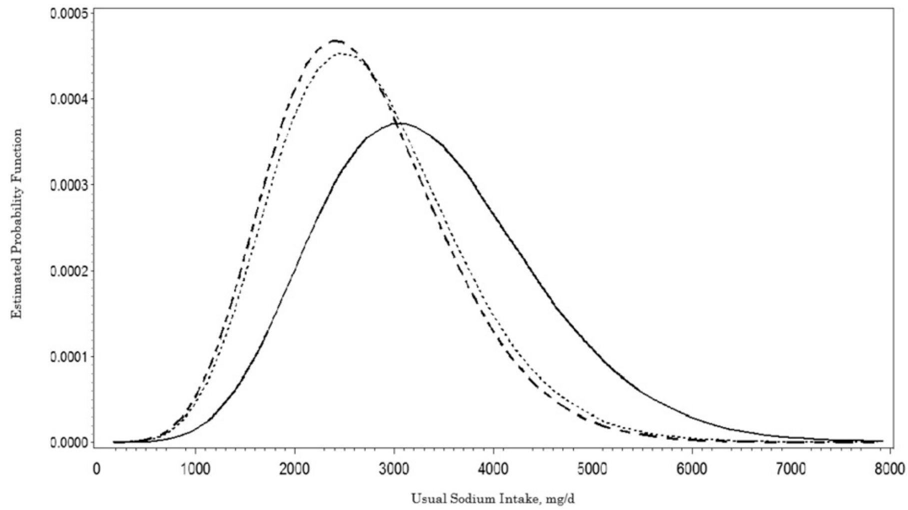

FIGURE 1 Estimated distribution of usual daily intakes of sodium (milligrams per day) in the US population aged ≥1 y according to the NHANES 2007–2010 (solid line) or as predicted via sodium reduction on the basis of New York City's National Salt Reduction Initiative 2014 targets (long dash) (15) or Health Canada 2016 benchmarks (dotted line) (18) (*n* = 17,933 participants aged ≥1 y). Usual sodium intake accounts for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.

of 4-y combined sampling weights. When 95% CIs did not overlap, differences between independent population subgroups in percentiles of usual nutrient intake were considered statistically significant.

RESULTS

The total mean estimated usual daily dietary sodium intake for the US population aged ≥1 y in 2007–2010 was 3417 mg/d (NHANES 2007–2010). On the basis of the model of reducing sodium concentrations with the use of NSRI 2014 sodium targets, mean predicted usual daily sodium intake was 2719 mg/d, which was a significant 698-mg difference from intake in NHANES 2007–2010 (**Table 1**). On the basis of the model with the use of Health Canada's 2016 benchmarks, average daily predicted sodium intake was 2801 mg/d, which was significant 615-mg difference from intake in NHANES 2007–2010 (Table 1). With both models, the overall distribution of predicted sodium intake was narrowed and shifted toward lower amounts compared with the distribution of sodium intake in NHANES 2007–2010 (**Figure 1**).

On the basis of modeling, significant differences from NHANES 2007–2010 sodium intake would occur within each sex, race/ethnic, and age groups in the total US population aged ≥1 y (Table 1) and in adults within each sex, race/ethnic, socioeconomic, obesity-status, and hypertensive-status groups

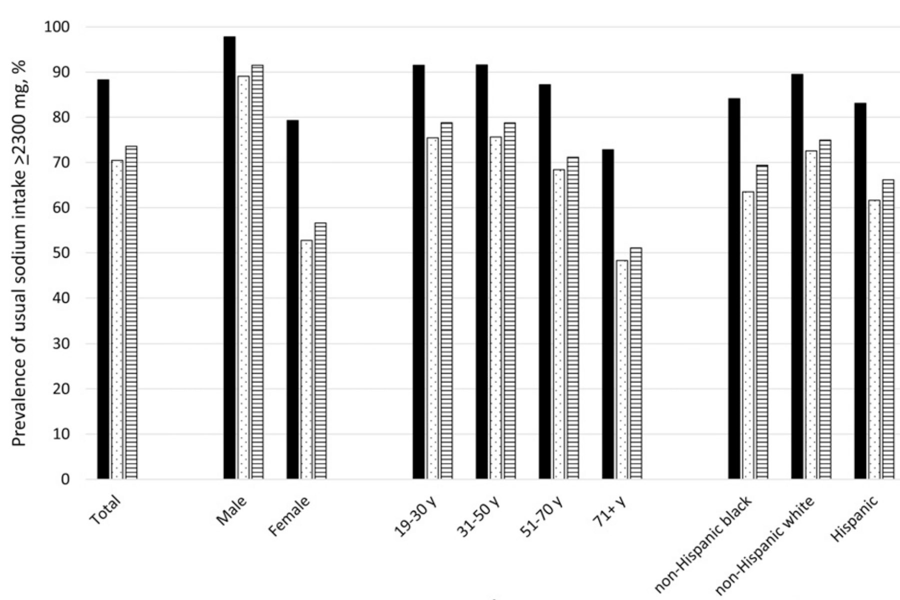

FIGURE 2 Prevalence (percentage) of usual sodium intake ≥2300 mg in the NHANES 2007–2010 (solid bars) and with sodium reductions that are based on New York City's National Salt Reduction Initiative 2014 targets (bars with dots) (15) or Health Canada's 2016 benchmarks (bars with horizontal lines) (18) (total and by sex, age, and race/ethnicity) in US adults aged ≥19 y. Usual sodium intake accounts for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.

TABLE 2
Modeled usual sodium intakes with sodium reduction (NSRI 2014; Health Canada 2016) and without sodium reduction (NHANES 2007–2010) in commercially processed foods in US adults aged ≥19 y[1]

	Usual population sodium intake,[2] mg/d				
	NHANES 2007–2010	NSRI 2014[3]	Difference[4]	Health Canada 2016[5]	Difference[6]
Total (*n* = 11,302)[7]	3570 (3488, 3652)	2847 (2781, 2912)	727 (708, 746)	2938 (2875, 3001)	638 (616, 661)
Sex					
M (*n* = 5623)	4155 (4044, 4266)	3305 (3216, 3394)	850 (822, 878)	3424 (3337, 3512)	733 (704, 763)
F (*n* = 5679)	3017 (2953, 3080)	2413 (2364, 2462)	611 (599, 624)	2479 (2432, 2526)	549 (531, 567)
Race/ethnic group[8]					
Hispanic (*n* = 3216)	3344 (3238, 3450)	2664 (2587, 2742)	679 (650, 708)	2814 (2727, 2900)	530 (501, 559)
Non-Hispanic white (*n* = 5362)	3636 (3546, 3725)	2896 (2825, 2967)	746 (728, 765)	2974 (2905, 3044)	674 (653, 695)
Non-Hispanic black (*n* = 2207)	3304 (3176, 3432)	2630 (2532, 2728)	686 (660, 712)	2739 (2637, 2841)	567 (538, 596)
Education					
Less than high school (*n* = 3341)	3426 (3339, 3514)	2736 (2668, 2804)	695 (674, 716)	2841 (2773, 2909)	594 (567, 621)
High school or greater (*n* = 7945)	3604 (3516, 3693)	2873 (2802, 2943)	735 (715, 754)	2961 (2894, 3029)	649 (626, 672)
Household income, % of poverty					
<100 (*n* = 2227)	3482 (3384, 3580)	2781 (2704, 2857)	714 (692, 736)	2880 (2808, 2952)	608 (581, 634)
100–199 (*n* = 2836)	3470 (3375, 3565)	2771 (2700, 2842)	706 (685, 728)	2866 (2795, 2937)	612 (587, 638)
200–299 (*n* = 1596)	3527 (3426, 3629)	2818 (2740, 2896)	719 (697, 742)	2900 (2823, 2977)	633 (608, 658)
300–399 (*n* = 1081)	3604 (3521, 3687)	2870 (2799, 2941)	737 (715, 759)	2955 (2882, 3028)	652 (628, 676)
≥400 (*n* = 2539)	3675 (3582, 3769)	2926 (2852, 3000)	749 (729, 769)	3009 (2937, 3082)	667 (645, 689)
Obesity status					
Not overweight or obese (*n* = 3243)	3554 (3460, 3647)	2832 (2755, 2909)	723 (703, 742)	2917 (2841, 2993)	637 (614, 660)
Overweight (*n* = 3790)	3630 (3545, 3716)	2893 (2827, 2959)	739 (719, 759)	2987 (2921, 3052)	647 (626, 669)
Obese (*n* = 4141)	3530 (3432, 3628)	2813 (2736, 2891)	720 (697, 743)	2910 (2833, 2987)	630 (604, 656)
Hypertensive status					
Not hypertensive (*n* = 4153)	3571 (3488, 3654)	2841 (2775, 2908)	733 (715, 752)	2937 (2873, 3002)	640 (618, 662)
Prehypertensive (*n* = 2714)	3748 (3650, 3847)	2984 (2905, 3062)	766 (745, 787)	3086 (3010, 3163)	668 (643, 692)
Hypertensive (*n* = 4160)	3411 (3315, 3507)	2727 (2653, 2800)	688 (666, 710)	2806 (2735, 2877)	612 (586, 638)

[1] All values are means (95% CIs). NSRI, National Salt Reduction Initiative.
[2] Intakes account for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.
[3] Predicted intakes account for the percentage of reduction in the sodium content of applicable reported foods to correspond with the percentage of reduction as indicated by New York City's NSRI 2014 targets by category of packaged and restaurant food (15).
[4] Absolute differences between sodium intakes on the basis of the NHANES 2007–2010 and NSRI 2014 accounting for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.
[5] Predicted intakes account for the percentage of reduction in the sodium content of applicable reported foods to correspond with the percentage of reduction as indicated by Health Canada's 2016 mean sodium-reduction benchmarks by category of processed food (18).
[6] Absolute differences between sodium intakes on the basis of NHANES 2007–2010 and Health Canada 2016 accounting for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.
[7] Sample sizes across some subgroups (family income, weight status, and hypertensive status) do not add to the total number of adults because of missing data or nonresponses for some variables and questions.
[8] Subgroup analyses were restricted to Hispanics, non-Hispanic whites, and non-Hispanic blacks.

(**Table 2**). Estimated decreases in usual population sodium intake ranged from 362 mg/d (children aged 1–3 y on the basis of Health Canada benchmarks) (Table 1) to 850 mg/d (men aged ≥19 y on the basis of NSRI targets) (Table 2). Greater estimated absolute decreases in usual population sodium intake occurred within population subgroups with higher mean NHANES 2007–2010 sodium intakes (Tables 1 and 2).

The prevalence of excess sodium intake (≥2300 mg/d) in US adults was 88% compared with a predicted 70% with NSRI 2014 targets and 74% with Health Canada 2016 benchmarks (**Figure 2**), thereby resulting in a decrease of 14–18 percentage points. Percentage point decreases in the prevalence of excess sodium intake with modeled reductions varied in population subgroups (Figure 2, **Figure 3**). On the basis of modeling, men had the smallest percentage point decrease (6–9 percentage points) in excess sodium intake (from 98% in NHANES 2007–2010 to 89% as predicted on the basis of NSRI targets and to 92% as predicted on the basis of Health Canada benchmarks). In contrast, women, adults aged ≥71 y, non-Hispanic blacks, and Hispanics had greater than a 20–percentage point decrease in the prevalence of excess sodium intake on the basis of NSRI targets. For example, 79% of US women consumed excess sodium intake on the basis of NHANES 2007–2010 values compared with a predicted 53% of US women with modeled sodium reductions on the basis of NSRI targets, i.e., a 26–percentage point reduction.

In adults without hypertension, with prehypertension, and with hypertension, predicted decreases in the prevalence of excess sodium intake were significant. In adults with hypertension, the prevalence of excess sodium intake was 84% on the basis of NHANES 2007–2010 values compared with a predicted 65–68% with modeling (Figure 3). When considering the impact of

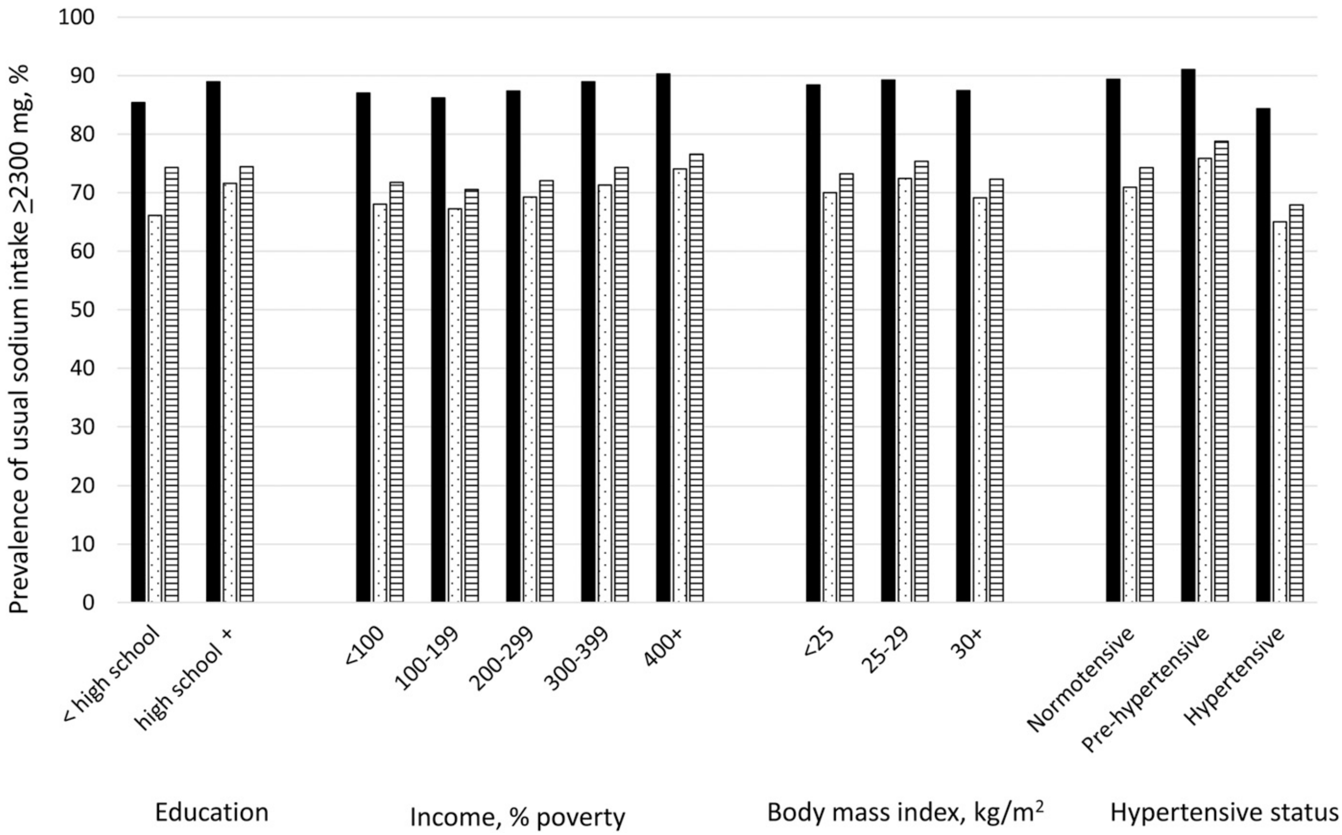

FIGURE 3 Prevalence (percentage) of usual sodium intake ≥2300 mg in the NHANES 2007–2010 (solid bars) and with sodium reductions that are based on the mean sodium concentrations of packaged and restaurant foods according to New York City's National Salt Reduction Initiative 2014 targets (bars with dots) (15) or Health Canada's 2016 benchmarks (bars with horizontal lines) (18) by educational level, household income, BMI, and hypertension status in US adults aged ≥19 y. Usual sodium intake accounts for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.

achieving these targets on people who are prehypertensive or hypertensive and aiming for intake ≤1500 mg/d, the prevalence of sodium intake ≥1500 mg/d was 99% on the basis of NHANES 2007–2010 values in prehypertensive or hypertensive adults (**Supplemental Table 2**). In prehypertensive adults, the prevalence of sodium intake ≥1500 mg/d was reduced to a predicted 97–98% with modeling on the basis of standards. In hypertensive adults, the prevalence was reduced to a predicted 94–95% with modeling (Supplemental Table 2).

Similar to adults, in US children, significant percentage point decreases occurred in the prevalence of excess sodium intake with modeled reductions in the sodium content of foods (**Table 3**). The NHANES 2007–2010 prevalence of excess sodium intake was 82% in children aged 1–3 y, 91% in children aged 4–8 y, 94% in children aged 9–13 y, and 88% in children aged 14–18 y. In comparison, the modeled predicted prevalence of excess sodium intake on the basis of NSRI targets decreased to 58% in children aged 1–3 y, 65% in children aged 4–8 y, 71% in children aged 9–13 y, and 68% in children aged 14–18 y, which were decreases of 20–26 percentage points. The greatest predicted percentage point declines in the prevalence of excess sodium intake occurred in Hispanic and non-Hispanic black children aged 9–13 y (31% and 29%, respectively) and females aged 14–18 y (29%). Similar decreases were seen on the basis of Health Canada benchmarks.

The NHANES 2007–2010 and predicted mean usual sodium intakes were greater than the AI for all groups examined (Table 1, **Table 4**). The NHANES 2007–2010 proportion of individuals with intake greater than the AI was 97% for US children aged 1–3 y and 99% for children aged 4–18 y and for adults (Table 4). In addition, the prevalence of predicted intake greater than the AI was ∼91–93% in US children aged 1–3 y, ∼94–95% in US children aged 9–13 y with the reduction of the sodium concentration to NRSI targets, and >95% for all other age groups (Table 4).

DISCUSSION

Modeling suggests that the reduction of sodium concentrations of commercially processed and prepared foods to be consistent with established North American standards could substantially decrease mean US sodium intake and the prevalence of the excess sodium intake in the population. In addition, the probability of inadequate sodium intake would remain low. Even with these substantive reductions, mean sodium intake for the US population aged ≥1 y and all subgroups of adults would remain greater than the Healthy People 2020 objective of 2300 mg/d (11).

To our knowledge, this is the first published analysis of the potential impact on US sodium intake from reductions in the sodium concentrations of commercially processed and prepared foods on the basis of NSRI targets and Health Canada benchmarks (15, 18). Our analyses confirm NSRI

TABLE 3
Modeled prevalence of excess usual sodium intakes with sodium reduction (NSRI 2014; Health Canada 2016) and without sodium reduction (NHANES 2007–2010) in commercially processed foods in US children and adolescents aged 1–18 y[1]

		Prevalence of population sodium intake greater than the UL[2]		
	IOM UL,[3] mg/d	NHANES 2007–2010	NSRI 2014[4]	Health Canada 2016[5]
Aged 1–3 y	1500			
Total (n = 1484)		82.0 (74.2, 89.7)	57.9 (50.9, 65.0)	62.3 (55.4, 69.3)
Sex				
M (n = 772)		83.0 (74.3, 91.8)	60.5 (50.9, 70.0)	64.8 (55.7, 73.8)
F (n = 712)		80.5 (72.6, 88.4)	56.1 (48.4, 63.8)	60.1 (52.4, 67.8)
Race/ethnic group[6]				
Hispanic (n = 589)		75.0 (63.1, 86.8)	49.3 (36.8, 61.7)	56.3 (42.7, 69.9)
Non-Hispanic white (n = 498)		82.1 (71.1, 93.2)	58.1 (46.4, 69.8)	61.4 (49.9, 72.9)
Non-Hispanic black (n = 293)		87.6 (80.8, 94.3)	64.7 (53.9, 75.5)	69.4 (59.1, 79.7)
Aged 4–8 y	1900			
Total (n = 1895)		90.8 (86.8, 94.8)	65.4 (59.8, 71.0)	69.6 (64.1, 75.1)
Sex				
M (n = 1001)		93.2 (89.3, 97.1)	71.7 (65.1, 78.3)	75.2 (68.6, 81.8)
F (n = 894)		87.7 (82.3, 93.2)	59.4 (52.2, 66.7)	63.3 (55.7, 70.8)
Race/ethnic group[6]				
Hispanic (n = 751)		87.2 (80.7, 93.8)	57.4 (48.6, 66.3)	63.5 (54.6, 72.4)
Non-Hispanic white (n = 626)		90.8 (85.9, 95.7)	65.2 (56.6, 73.7)	68.1 (60.3, 76.0)
Non-Hispanic black (n = 400)		94.7 (90.6, 98.9)	73.8 (63.4, 84.2)	77.1 (67.1, 87.2)
Aged 9–13 y	2200			
Total (n = 1717)		93.7 (89.4, 98.1)	70.9 (63.9, 77.8)	74.4 (66.8, 81.9)
Sex				
M (n = 850)		96.7 (93.6, 99.8)	79.7 (73.0, 86.5)	82.7 (75.6, 89.8)
F (n = 867)		90.9 (84.9, 96.9)	62.1 (52.6, 71.7)	65.9 (55.5, 76.4)
Race/ethnic group[6]				
Hispanic (n = 665)		89.0 (81.3, 96.7)	58.5 (46.6, 70.4)	65.4 (52.9, 77.9)
Non-Hispanic white (n = 539)		—*	76.2 (66.3, 86.0)	78.8 (68.9, 88.8)
Non-Hispanic black (n = 408)		91.3 (84.5, 98.1)	62.0 (49.7, 74.3)	65.3 (52.3, 78.2)
Aged 14–18 y	2300			
Total (n = 1535)		87.9 (81.9, 94.0)	68.2 (60.4, 76.0)	70.8 (63.1, 78.5)
Sex				
M (n = 808)		—*	87.4 (79.0, 95.8)	88.8 (81.1, 96.4)
F (n = 727)		79.3 (68.8, 89.7)	50.2 (40.1, 60.3)	53.2 (42.4, 64.0)
Race/ethnic group[6]				
Hispanic (n = 575)		85.7 (77.6, 93.8)	63.3 (53.1, 73.5)	67.6 (57.3, 77.9)
Non-Hispanic white (n = 518)		89.3 (81.5, 97.2)	71.0 (59.3, 82.7)	72.6 (60.9, 84.3)
Non-Hispanic black (n = 364)		81.5 (73.8, 89.1)	56.7 (47.7, 65.7)	59.3 (49.7, 68.9)

[1] UL is nutrient intake above which there is a high probability of adverse outcomes. *Estimates were statistically unreliable with an SEE >30% of the mean. IOM, Institute of Medicine; NSRI, National Salt Reduction Initiative; UL, Tolerable Upper Intake Level.

[2] All values are percentages (95% CIs). The prevalence of usual sodium intake in excess of the IOM UL accounts for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.

[3] IOM-set age-specific UL for sodium for children adjusted for mean energy intake by age group (3). The IOM is now the Health and Medicine Division of the National Academy of Sciences, Engineering, and Medicine.

[4] Modeled usual sodium intake accounts for the percentage of reduction in the sodium content of applicable reported foods to correspond with the percentage of reduction as indicated by New York City's NSRI 2014 targets by category of packaged and restaurant food (15).

[5] Modeled usual sodium intake accounts for the percentage of reduction in the sodium content of applicable reported foods to correspond with the percentage of reduction as indicated by Health Canada's 2016 mean sodium-reduction benchmarks by category of processed food (18).

[6] Subgroup analyses were restricted to Hispanics, non-Hispanic whites, and non-Hispanic blacks.

predictions that an average 25% reduction in the sodium concentration of these foods would result in an ∼20% reduction in US intake (16). The decreases in mean sodium intake on the basis of Health Canada benchmarks were slightly less, but on average, these differences were relatively small (<150 mg Na/d).

Without compliance by all food manufacturers, smaller overall reductions may occur. In the United Kingdom, a comprehensive strategy including the publication of voluntary targets on the basis of an average 20–40% reduction in many packaged foods (not including prepared, restaurant, or take-away foods) was associated with an 11–15% reduction in sodium intake as

TABLE 4
Modeled prevalence of usual sodium intake meeting or exceeding the AI with sodium reduction (NSRI 2014; Health Canada 2016) and without sodium reduction (NHANES 2007–2010) in commercially processed foods in the US population aged ≥1 y[1]

		Prevalence of population sodium intake greater than the AI[2]		
	IOM AI,[3] mg/d	NHANES 2007–2010	NSRI 2014[4]	Health Canada 2016[5]
Age group, y				
1–3 (*n* = 1484)	1000	96.8 (95.2, 98.4)	91.1 (88.3, 93.8)	92.5 (90.0, 95.0)
4–8 (*n* = 1895)	1200	98.9 (98.1, 99.7)	95.5 (93.3, 97.6)	96.1 (94.1, 98.0)
9–13 (*n* = 1717)	1500	98.7 (97.8, 99.5)	93.8 (91.5, 96.0)	94.7 (92.4, 98.0)
14–18 (*n* = 1535)	1500	99.3 (98.7, 99.8)	96.3 (94.3, 98.2)	97.0 (95.2, 98.0)
19–50 (*n* = 5913)	1500	99.7 (99.4, 99.9)	97.9 (96.9, 98.8)	98.4 (97.6, 98.0)
51–70 (*n* = 3513)	1300	99.8 (99.6, 100.0)	98.8 (98.0, 99.5)	98.9 (98.4, 98.0)
≥71 (*n* = 1876)	1200	99.4 (98.9, 99.9)	97.2 (95.7, 98.7)	97.6 (96.2, 98.0)

[1] AI is nutrient intake approximating intake assumed to be adequate for a group of apparently healthy people when a Recommended Dietary Allowance [meeting the needs of nearly (97–98%) all healthy individuals] cannot be established. AI, Adequate Intake; IOM, Institute of Medicine; NSRI, National Salt Reduction Initiative.

[2] All values are percentages (95% CIs). Prevalence of usual sodium intake in excess of the IOM AI accounts for between- and within-person variances in daily consumption and the survey sampling design adjusting for the day of the week, age, sex, and race/ethnicity.

[3] IOM-set age-specific AI for sodium by age group adjusted for mean energy intake by age group (3). The IOM is now the Health and Medicine Division of the National Academy of Sciences, Engineering, and Medicine.

[4] Predicted usual sodium intake accounts for the percentage of reduction in the sodium content of applicable reported foods to correspond with the percentage of reduction as indicated by New York City's NSRI 2014 targets by category of packaged and restaurant food (16).

[5] Predicted usual sodium intake accounts for the percentage of reduction in the sodium content of applicable reported foods to correspond with the percentage of reduction as indicated by Health Canada's 2016 mean sodium-reduction benchmarks by category of processed food (19).

measured via 24-h sodium excretion (40, 41). In relation to the NSRI, by 2014, data from US packaged foods showed that 43% of food categories had significantly reduced sodium, but most categories did not meet 2014 NSRI targets, and US dietary data suggest that sodium intake has not substantially declined (2, 20). With implementation of Health Canada benchmarks, significant sodium reductions were observed in ∼16% of processed food categories by 2013, and further data on sodium intake reduction are not available to our knowledge (21). A 2017 Cochrane review provided evidence to suggest that voluntary national food standards may have a greater potential to reduce sodium intake when they are part of a multicomponent strategy including monitoring (42).

The reformulation of food products to contain less salt and other sodium compounds has been promoted as an effective, feasible, and safe public health strategy that affects the majority of the population without requiring specific behavioral changes. Results have suggested that the application of standards to commercially processed and prepared foods could significantly reduce sodium and would not result in socioeconomic inequities in dietary sodium consumption (43). The current study results suggest that groups with higher overall sodium consumption and potentially higher risk of high blood pressure might experience slightly larger absolute reductions. Concern about altering the taste and consumer acceptance of foods led the IOM to suggest gradual stepwise targets rather than a single, large change at one point in time (12). A recent systematic review and meta-analyses of 50 studies of "salt reduction, replacement or compensation" indicated that substantial changes in the sodium content of foods might be made without decreasing consumer acceptability (44). The sodium content of bread, for example, could be reduced by 25–37% and that of processed meat could be reduced by 16–67% without changing consumer liking or acceptability (44). Mean usual sodium intake and prevalence greater than the AI (91–99%) in the current study "implies a low prevalence of inadequate intake" after applying sodium standards to commercially processed and prepared foods (3). It is likely that the probability of inadequacy is even lower because dietary sodium intake in this study excluded salt that was added at the table (45).

Our modeling is subject to several potential limitations. The 24-h dietary recall data used to estimate sodium intake are subject to reporting bias and exclude salt added at the table which could affect estimates of overall sodium intake (46). The USDA FNDDS do not include brand-specific manufacturer food codes for most foods. Target or benchmark reductions are meant to be applied against manufacturer portfolios. Instead, in the current study, they are applied against FNDDS food codes. The nutrient values for these codes come from SR nutrient composites representing sales-weighted mean composites of foods rather than brand-specific nutrient information. Some, but not all, of the foods included in manufacturers' portfolios are part of the SR food composites (37). The estimated percentage of reduction (on the basis of baseline and sodium standard amounts from published NSRI targets and Health Canada benchmarks) as applied to the FNDDS food code moves the mean sodium concentration of the food composites of brands by the same percentage of reduction regardless of whether the brands that are used as part of the composites are greater or less than the target or benchmark after the sodium reduction is applied. We did not model maximum amounts, thereby likely underestimating the overall sodium reduction. Reducing sodium concentrations below the maximums likely does not affect the lower end of the distribution of intake because the maximums are higher than the sales-weighted means. For foods that were obtained from schools, we did not model separate reductions, which might have affected reductions for school-age children if sodium targets for school foods differ. Matches to food categories generally assume that the food is manufactured and prepackaged or prepared at a restaurant rather than prepared at home. This assumption likely overestimates reductions. Analyses were based on foods being categorized according to FNDDS food codes and did not account for possible combination codes, which might have affected some of the predicted percentages of reductions. Our data assume no change in the patterns of foods consumed or salt added at the table; however, sodium intake did not change substantially from NHANES 2007–2010 to 2013–2014 (2) nor did the use of salt that was added at the table (45), thereby suggesting that the modeled reductions still apply.

In conclusion, the data in this study potentially can inform projections of the health impact and cost of setting sodium targets or benchmarks for commercially processed and prepared foods because of the potential differences in the modeled reduction in sodium intake across population subgroups whom may have differing baseline cardiovascular disease risks. In addition, these data suggest that setting targets for foods as prepared by the manufacturer (Health Canada) or as purchased by the consumer (NSRI) may be equally effective if implemented. The FDA draft guidance includes more food categories than does the NSRI or Health Canada (i.e., 150 food categories for the FDA draft guidance compared with ∼90 food categories for Health Canada and NSRI) with some categories having targets for >1 form (e.g., dry-mix mashed potatoes and ready-to-eat or -heat mashed potatoes) or storage method (frozen or shelf stable). As with the Health Canada benchmarks, the FDA targets are applicable to "all products commercially processed, packaged, and prepared by industry (including food service establishments), regardless of whether they are sold directly to consumers, other manufacturers, or to food service establishments (restaurants and other food service establishments)." The FDA draft guidance baseline sodium amounts are based on 2010 data. Targets are set for 2 and 10 y with 2-y targets aimed at a 400-mg reduction in US sodium intake. It is reasonable to assume that the potential for reducing sodium intake with 2-y targets may be comparable or less than the mean sodium reduction modeled in this study if adoption is widespread. These data on the potential and expected changes in intake coupled with data on actual changes in food concentrations and intake suggest publishing long-term standards complemented by comprehensive supporting strategies, such as those implemented in the United Kingdom and as recommended by the IOM, are needed to move beyond minimal sodium reduction and toward Healthy People 2020 goals.

The authors' responsibilities were as follows—MEC: had full access to all of the data in the study and primary responsibility for the integrity of the data, the accuracy of the data analysis, drafting of the manuscript, and the final content of the manuscript; KY, CG, MEC, and SMP: performed the statistical analysis; CG, SMP, KY, WJ, CJC, MV, JC, PR, AM, JA, PP, LB, and RM: critically revised the manuscript for important intellectual content; and all authors: created the study concept and design and read and approved the final manuscript. None of the authors reported a conflict of interest related to the study.

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