AJCN. First published ahead of print August 12, 2015 as doi: 10.3945/ajcn.114.100750.

Effects of a behavioral intervention that emphasizes spices and herbs on adherence to recommended sodium intake: results of the SPICE randomized clinical trial[1,2]

Cheryl AM Anderson,[3,4] Laura K Cobb,[4] Edgar R Miller III,[4,5,10] Mark Woodward,[6,7] Annette Hottenstein,[8] Alex R Chang,[9] Morgana Mongraw-Chaffin,[3] Karen White,[10] Jeanne Charleston,[4,10] Toshiko Tanaka,[11] Letitia Thomas,[10] and Lawrence J Appel[4,5,10]*

[3]Division of Preventive Medicine, University of California San Diego School of Medicine, San Diego, CA; [4]Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD; [5]Welch Center for Prevention, Epidemiology and Clinical Research, Johns Hopkins University, Baltimore, MD; [6]The George Institute for Global Health, University of Sydney, Sydney, Australia; [7]The George Institute for Global Health, Nuffield Department of Population Health, University of Oxford, Oxford, United Kingdom; [8]Sensational Sustenance Inc., Baltimore, MD; [9]Division of Nephrology, Geisinger Health System, Danville, PA; [10]Division of General Internal Medicine, Johns Hopkins School of Medicine, Baltimore, MD; and [11]National Institute of Aging, Translational Gerontology Branch, Baltimore, MD

ABSTRACT

Background: For decades, dietary sodium intake in the United States has remained high, and few studies have examined strategies for maintaining recommended intakes.

Objective: We examined the effects of a behavioral intervention, which emphasized spices and herbs, on the maintenance of sodium intake at the recommended intake of 1500 mg/d in individuals to whom the US *Dietary Guidelines for Americans* apply.

Design: We conducted a 2-phase study that included adults ≥18 y of age for whom *Dietary Guidelines for Americans* recommends 1500 mg Na/d. The study was conducted in Baltimore, Maryland, from 2012 to 2014. In phase 1, 55 individuals consumed a low-sodium diet for 4 wk. Participants were provided all foods, snacks, and calorie-containing drinks. In phase 2, 40 participants from phase 1 were randomly assigned to either a behavioral intervention to reduce sodium intake (n = 20) or a self-directed control group (n = 20) for 20 wk. The primary study outcome was the change in mean 24-h urinary sodium excretion during phase 2. Linear regression analyses were used to determine intervention effects on urinary sodium excretion.

Results: Participant characteristics were as follows: women: 65%; African American: 88%; hypertension: 63%; diabetes: 18%; mean age: 61 y; and mean body mass index (in kg/m^2): 30. At the end of phase 2, mean 24-h sodium excretion was lower in the behavioral intervention than in the self-directed group (mean difference: −956.8 mg/d; 95% CI: −1538.7, −374.9 mg/d) after sodium intake at screening was controlled for (P = 0.002). These findings persisted in sensitivity analyses that excluded potentially incomplete urine collections [Mage's equation mean difference: −1090 mg/d (P = 0.001); Joosens' equation mean difference: −796 mg/d (P = 0.04)].

Conclusions: A multifactorial behavioral intervention emphasizing spices and herbs significantly reduced sodium intake. Because of the ubiquity of sodium in the US food supply, multilevel strategies addressing individual behaviors and the food supply are needed to improve adherence to recommendations. This trial was registered at clinicaltrials.gov as NCT01615159. *Am J Clin Nutr* doi: 10.3945/ajcn.114.100750.

Keywords: adherence, behavioral intervention, clinical trial, diet, sodium

INTRODUCTION

For decades, dietary sodium consumption in the United States has exceeded recommendations (1). Excessive sodium intake has been shown, in a substantial body of clinical research, to increase blood pressure (2–5), and high blood pressure is the leading cause of preventable morbidity and mortality (6). Furthermore, excessive sodium intake is a substantial public health problem because of the relation, shown in general population studies, of high blood pressure to increased risks of heart disease (7–9) and stroke (10, 11). Data have suggested that reducing the population sodium intake from current to recommended intakes will reduce cases of hypertension by 11 million, save $18 billion in health care dollars, and gain 312,000 quality-adjusted life-years (12–14).

The sodium intake recommended in the US *Dietary Guidelines for Americans* is <2300 mg/d for the general population (15); for certain population subgroups (i.e., individuals with hypertension, prehypertension, diabetes, heart failure, or chronic kidney disease), the recommendation is ≤1500 mg/d. The American Heart Association also recommends that Americans consume ≤1500 mg Na/d for a greater reduction in blood pressure (16). The adherence to recommended sodium intake is extremely low in the United States, with <10% of the population meeting the recommendation for <2300 mg/d and<2% of the population meeting the recommendation for <1500 mg/d (17).

Because of the ubiquity of sodium in the US food supply, attaining the recommended sodium intake is challenging.

[1] Supported by a grant from the McCormick Science Institute and in part by a grant from the National Heart, Lung, and Blood Institute (K01 HL092595; to CAMA).

[2] Supplemental Tables 1–5 are available from the "Supplemental data" link in the online posting of the article and from the same link in the online table of contents at http://ajcn.nutrition.org.

*To whom correspondence should be addressed. E-mail: c1anderson@ucsd.edu.

Received October 7, 2014. Accepted for publication June 29, 2015.
doi: 10.3945/ajcn.114.100750.

Furthermore, most dietary sodium comes from commercially processed and restaurant foods (18–20), making it challenging for individuals who do not cook most of their meals from scratch at home to meet their intake goals. A few behavioral intervention studies with blood pressure reduction as a primary endpoint have been effective in helping individuals reduce sodium intake (21, 22). In addition, data from the Trials of Hypertension Prevention suggested that sodium reduction has long-term benefits for cardiovascular health (23). However, to our knowledge, randomized clinical trials that explicitly tested strategies for adherence to recommended sodium intake have not been conducted.

In this randomized clinical trial, we examined the effects of a behavioral intervention, which emphasized spices and herbs, on the maintenance of sodium intake at the recommended intake of 1500 mg/d in individuals to whom US *Dietary Guidelines for Americans* apply. We hypothesized that the intervention would facilitate adherence to the current sodium recommendation.

METHODS

This study was approved by the institutional review board at Johns Hopkins medical institutions. All study participants provided written informed consent. This trial was registered at clinicaltrials.gov as NCT01615159.

Setting and study population

The study was conducted in Baltimore, Maryland, from 2012 to 2014. The study population consisted of men and women aged ≥18 y for whom the *Dietary Guidelines for Americans* recommends 1500 mg Na/d (i.e., individuals with hypertension, prehypertension, or diabetes). Participants were primarily recruited through a mass mailing of brochures with the supplemental use of flyers and advertisements on a local radio station. We excluded individuals with weight >350 lb because of our inability to obtain a measurement on the scale, with medical conditions such as congestive heart failure and ischemic heart disease that would require medical management beyond the scope of the study, or who were using medications or warfarin therapy that may require changes in dosing because of lower sodium intake.

Study design

We conducted a 2-phase study. In phase 1, 55 individuals were given an isocaloric, low-sodium diet for 4 wk for acclimatization to lower sodium intake. Participants were provided all food, snacks, and calorie-containing drinks. In phase 2, 40 participants from phase 1 were randomly assigned to either a behavioral intervention to reduce sodium intake ($n = 20$) or a self-directed control group ($n = 20$) for 20 wk. Our predetermined sample size of 40 provided ≥80% power to investigate the effects of our low sodium behavioral intervention on 24-h urinary sodium excretion. With an estimated SD of 975 mg Na/d and a minimum detectable difference in 24-h urinary sodium excretion between study groups of 1800 mg/d at $\alpha = 0.05$ and power of >80%, a total sample size of 34 (17/arm) was needed. We intentionally overrecruited to account for possible attrition.

Controlled consumption and study diet in phase 1

During controlled consumption, study participants were required to eat 1 meal/d at the research center 3 d/wk. We monitored meal attendance and consumption of on-site meals, and participants completed a daily food diary.

Sodium and nutritional contents of diets consumed in phase 1 were determined by using nutrient composition analysis (Silliker Inc.) (**Tables 1** and **2**). Diets were isocaloric to maintain participants' initial body weights, and participants consumed one of 4 possible kilocalorie amounts. The recommended sodium intake was set at 1500 mg/d; however, there is a high correlation between kilocalories and sodium ($r = 0.80$) (24). As such, from a practical point of view, we calorie-adjusted sodium intake; hence, mean sodium amounts varied by kilocalorie amounts during phase 1 (1119 mg at 1600 kcal, 1413 mg at 2000 kcal, 1740 mg at 2500 kcal, and 2033 mg at 3000 kcal) that were used during consumption. Throughout the 4 wk of phase 1, we rotated through 7 d of meals with the same meal provided on each day of the week. Two sample menus from phase 1 of the study are provided in **Supplemental Table 1**.

Random assignment and masking

Participants were randomly assigned to the intervention or control, and random assignments were generated in blocks of 4. Random assignments were kept in a sealed envelope and in a locked cabinet to conceal the sequence until interventions were assigned. The random allocation sequence was generated by 2 study investigators (CAMA and ERM), a study staff member enrolled participants (LT), and a study investigator (JC) assigned participants to interventions. Data collectors for outcome measurements were masked to the random assignment.

Intervention group

The intervention group was asked to continue to eat a lower-sodium diet by getting guidance from study counselors. Participants in the behavioral intervention group completed ≤18 contacts with the study interventionist either through individual in-person visits at the ProHealth research center, group sessions, or individual contacts by telephone, text, or e-mail. One-on-one counseling sessions ranged from 15 to 60 min depending on whether they were done in person or by telephone.

Intervention goals included adherence to a lower sodium intake at the recommended intake of 1500 mg/d per 2000-kcal intake. To reinforce intervention goals, participants monitored sodium intake by using a sodium-specific tracking tool. This tracking tool was in the form of a booklet and allowed

TABLE 1
Sodium content of meals fed in phase 1 by kilocalorie amount

Kilocalories	Sodium range,[1] mg	Mean sodium, mg
1600	1011–1290	1119
2000	1304–1533	1413
2500	1643–1838	1740
3000	1921–2238	2033

[1]Seven meals were consumed throughout the study. The range reflects the lowest to highest amounts of sodium across the 7 d of meals in the weekly cycle.

TABLE 2
Nutritional contents of meals consumed in phase 1 at a 2000-kcal amount

Nutrient	Range[1]	Mean
Sodium, mg	1304–1533	1413
Potassium, mg	3083–3974	3352
Kilocalories	1837–2034	1968
Protein, % of kilocalories	16–19	17
Carbohydrate, % of kilocalories	47–52	49
Fat, % of kilocalories	31–37	34
Total fat, g	66–81	76
Saturated fat, % of kilocalories	4–8	6
Monounsaturated fat, % of kilocalories	11–19	15
Polyunsaturated fat, % of kilocalories	6–9	7
Other fat, % of kilocalories	3–11	6
Grains, servings	1–2	2
Legumes, servings	0.5–1	0.2
Fruit, servings	2–4	3
Vegetables, servings	2–5	3
Added salt, mg	0–780	380
Added sugar, g	4–37	18
Total sugar, g	71–107	98.4

[1]Seven meals were consumed throughout the study. The range reflects the lowest to highest amounts of the nutrient across the 7 d of meals in the weekly cycle.

participants to record the food item, brand name and description, and amount of sodium being consumed. The booklet was accompanied by a small book designed to inform individuals about sodium and nutrient contents of a wide variety of foods.

Group counseling sessions were 90 min long. Standardized materials and procedures were used in each session. Group sessions covered topics such as goal setting, problem solving, time management, the use of familiar and unfamiliar spices and herbs in recipes, cultural influences on spice choices, self-monitoring of sodium intake, overcoming barriers to making dietary changes, how to choose and order foods when eating out, strategies for eating with family and friends, how to make low sodium intake permanent, and the prevention of a relapse. We also provided small gifts as incentives at group sessions such as spices and a cookbook. Group sessions included cooking demonstrations and provided an opportunity for participants to share how they were changing personal recipes to lower the salt content and include spices and herbs.

Control group

Participants in the control group received standard sodium education materials. Participants were asked to continue to eat a lower-sodium diet by following advice that was given by the US CDC in 2 handouts (25, 26).

Measurements

Trained data collectors conducted visits for study eligibility and baseline and follow-up measures at Johns Hopkins ProHealth, which is a community-based clinical research unit. Measurements were conducted at screening (before phase 1) and again at baseline (end of phase 1 and start of phase 2) and weeks 14 and 24.

The primary study outcome was the change in mean 24-h sodium from random assignment (i.e., week 4) to the final study visit (i.e., week 24). Two complete 24-h urine samples were collected at both weeks 4 and 24 for all participants. The 24-h urine values at weeks 4 and 24 represents the mean of the 2 measurements. To ensure high-quality collections, participants were provided detailed instructions. To be considered complete, 24-h urine samples had to be $\geq$500 mL in volume and had to be reported to be complete by participants. Participants recorded both start and stop times for each collection; all collections were between 22 and 26 h long. To correct for the possibility that the slight variation in collection times influenced sodium values, we standardized each urinary sodium excretion value to what it would be if collected for 24 h by first dividing by the number of hours of collection and multiplying by 24. Two complete 24-h urine collections were also collected at screening (before phase 1). The unit used for standard laboratory results for urine sodium was the millimole. The molecular mass of sodium is 22.99 g/mol, and we converted millimoles to milligrams by multiplying the laboratory value in millimoles by 23. We present study findings in millimoles per day in **Supplemental Tables 2–4**. In keeping with convention, we used 24-h urinary sodium excretion as a proxy for dietary sodium intake. It has been reported that the normal human kidney filters $\sim$25,000 mmol Na/d and reabsorbs 98–99% of the filtered load (27–29). Thus, in individuals at steady state conditions of fluid and sodium balance and who also have minimal sweat losses, the mean urinary sodium excreted is roughly equivalent (90–95% of total intake is excreted in urine) to the ingested sodium.

A sensory test to measure the perception of saltiness was administered at weeks 0 and 4. A series of 8 blind-coded solutions of chicken broth (Pacific Natural Foods Organic Free Range Low Sodium) with added sodium chloride were randomly presented in a sequential monadic fashion. Sodium amounts of the samples were as follows (%wt/wtNaCl/broth): 0.0%, 0.15%, 0.35%, 0.35% (repeated measure), 0.6%, 0.85%, 1.2%, and 1.5%. Participants were asked to mark along a 15-cm line anchored at 0, 7.5, and 15 cm with the words "not at all," "moderately," and "extremely salty." To minimize taste fatigue, participants were given room-temperature bottled water and a 2-min break between each sample with a longer 5-min break halfway through the test. Their mark was measured, which resulted in a potential range of values from 0 to 15.

A symptom questionnaire was administered during phase 1 at weeks 0 and 4. This self-administered checklist collected information on symptoms, including gastrointestinal problems (diarrhea or loose stools, constipation, bloating or uncomfortably full, and nausea or upset stomach). Each symptom was classified by severity (mild, moderate, and severe).

Statistical analysis

Analyses were conducted under the intention-to-treat principle. The primary study outcome was the change in mean 24-h sodium during phase 2 (i.e., from random assignment to the final study visit or week 24 minus week 4). Secondary study outcomes included the perception of saltiness, the percentage of individuals who consumed $<$2300 mg Na/d, and the percentage of individuals who consumed 1500 mg Na/d (or the percentage of individuals who consumed their kilocalorie-adjusted equivalent of 1500 mg Na).

A linear regression analysis was used to estimate the difference in the primary outcome between randomized groups, which was

adjusted for the 24-h urine value at screening. Paired *t* tests were used to test for the difference in salt perception between weeks 4 and 0. All analyses were performed by using Stata version 12 software (Stata Statistical Software: Release 12; StataCorp LP).

Sensitivity analyses

We examined whether our primary results were robust under 2 additional analytic approaches as follows: a quantile regression analysis and a linear regression analysis with robust SEs. We also performed sensitivity analyses that focused on reducing the impact of potentially incomplete 24-h collections because the completeness of a urine collection is a limitation with the use of 24-h urinary excretion measures. We excluded potentially incomplete urine samples on the basis of the following 2 separate criteria: *1*) the CV and *2*) expected creatinine values. For these sensitivity analyses, participants with excluded urine collections remained in the analysis as long as they had at least one valid urine sample at both time points (i.e., weeks 4 and 24). We also assessed the change in the sodium-to-creatinine ratio of the sample.

Over the course of the study, each participant provided 7 urine samples as follows: 2 samples at screening, 2 samples at week 4, one sample at week 14, and 2 samples at week 24. For each participant, we calculated a CV (i.e., SD divided by the mean) for urinary creatinine excretion. In these sensitivity analyses, participants with a CV >30% were excluded on the premise that they had incomplete collections (n = 7).

With regard to expected creatinine values, we calculated the expected urinary creatinine-excretion amount for each participant on the basis of the following 2 different prediction equations: *1*) Joosens' and *2*) Mage's equations. The equation developed by Joosens et al. (30) takes into account sex only, whereas the equation developed by Mage et al. (31) includes age, weight, height, sex, and BMI. We excluded participants with a ratio of observed to expected creatinine <0.6 because of potentially incomplete collections (32); 9 participants were excluded on the basis of Joosens' equation (5 from the intervention group and 4 from the control group), and 2 participants were excluded on the basis of Mage's equation (1 from the intervention group and 1 from the control group).

RESULTS

As shown in **Figure 1**, 100 individuals were screened for study eligibility, and 55 were enrolled in phase 1. There were 40 individuals recruited into the randomized trial. Of these 40 participants, 65% were women, and 88% were African

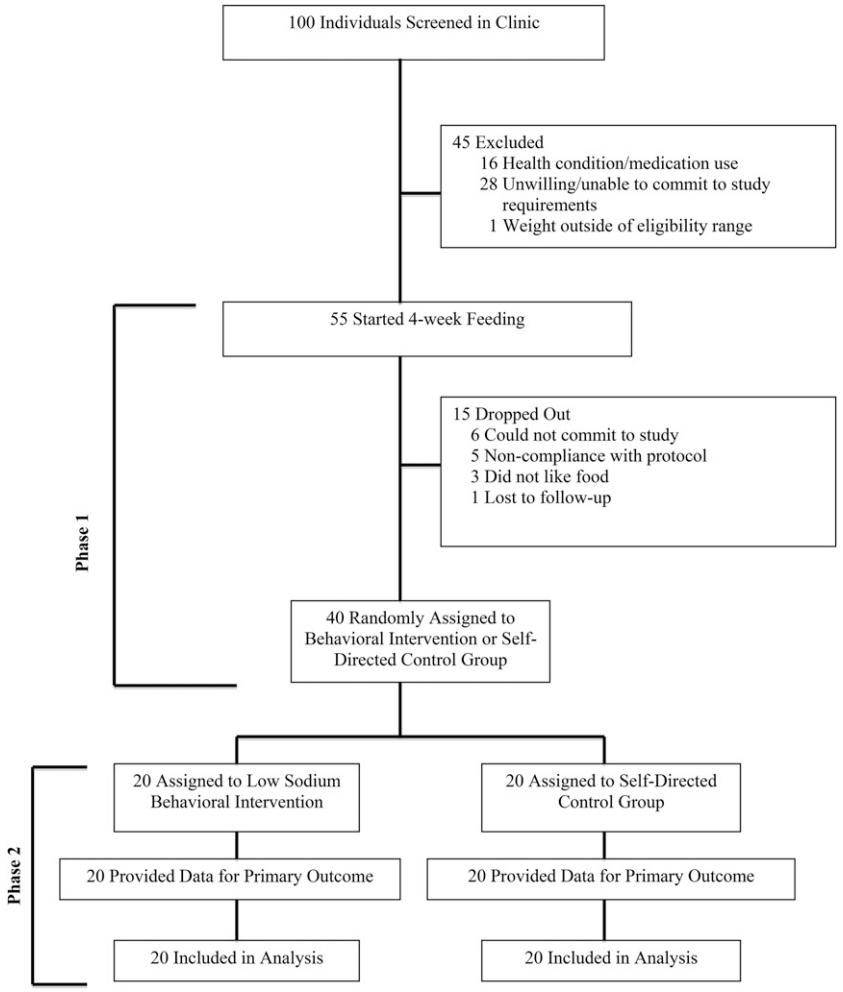

FIGURE 1 Participant flow in the SPICE study.

American; mean ± SD age was 61 ± 9.7 y; mean 24-h urine sodium excretion was 3496 ± 1426 mg/d; and mean BMI (in kg/m^2) was 32.1 ± 6.2 (**Table 3**).

Effects on 24-h urinary sodium excretion

During phase 1 (controlled consumption), the mean 24-h urinary sodium excretion decreased (from 3496 to 1654 mg/d) in the 40 participants who were subsequently randomly assigned to the intervention or control. At the end of the 20-wk behavioral intervention, the behavioral intervention group had lower urinary sodium excretion than that of the self-directed group (**Figure 2**). Specifically, the mean difference in 24 h urine sodium excretion was −956.8 mg/d (95% CI: −1538.7, −374.9 mg/d) after controlling for sodium intake at screening ($P = 0.002$) (**Table 4**). These findings were robust in sensitivity analyses that excluded incomplete urine collections (Mage's equation mean difference: −1090.2 mg/d; 95% CI: −1695.1, −483 mg/d; $P = 0.001$; Joosens' equation mean difference: −795.8 mg/d; 95% CI: −1545.6, −48.3 mg/d; $P = 0.04$). Findings were also robust by using quantile regression and robust SEs and by using the sodium:creatinine ratio of the outcome (Table 4).

Percentage of individuals meeting sodium intake of <2300 or 1500 mg/d

During controlled consumption in phase 1, all participants consumed diets with low sodium amounts. Sodium amounts varied depending on the 3 kilocalorie amounts used (Tables 1 and 2). **Table 5** shows the percentage of study participants who met either a <2300- or 1500-mg/d intake per 2000-kcal diet. Although the 1500-mg/d recommendation applied to all participants enrolled in the study, at the time of entry into the study (screening), the percentage of individuals who consumed <2300 mg/d per 2000 kcal or 1500 mg/d per 2000 kcal was low. For example, the recommendation for 1500 mg/d was met by 0% of subjects in the control group and by 10% of participants in the intervention group.

At the end of phase 1, 55% of individuals in the control group and 75% of individuals in the intervention group consumed 1500 mg/d per 2000 kcal. At the end of phase 2 (week 24), the percentage of individuals who consumed 1500 mg/d per 2000 kcal was lower than at the end of phase 1 (controlled consumption); however, more participants in the intervention group than in the control group met either of these goals. At week 24, 25% of participants in the intervention group consumed 1500 mg/d per 2000 kcal vs. 5% of participants in the control group. However, our estimate of the percentage of individuals who met their goals for sodium intakes may have been unstable, particularly in the tails of the sodium distribution, because of the within-person day-to-day variability in sodium intake, which was not accounted for by using the mean of two 24-h sodium collections.

Effects on perception of saltiness and symptoms

As shown in **Table 6**, after phase 1, participants perceived significantly more saltiness in our lowest-sodium solution (0% added sodium) than they did at the beginning of phase 1 (mean difference: 0.96; $P = 0.04$). For all other sodium concentrations evaluated, there were no statistically significant differences in

TABLE 3
Characteristics of study participants at screening (before phase 1)

	Total (n = 40)	Intervention (n = 20)	Control (n = 20)
Age, y	61.4 ± 9.7[1]	61.2 ± 8.3	61.6 ± 11.2
Women, %	65	65	65
Race			
White	13	15	10
African American	88	85	90
Education, %			
High school graduate	8	13	5
Attended college	42	31	50
College graduate	50	56	45
Hypertension, %	63	60	65
Systolic blood pressure, mm Hg	125.4 ± 14.6	124.9 ± 14.6	125.9 ± 14.9
Diastolic blood pressure, mm Hg	73.1 ± 9.3	72.4 ± 9.6	73.8 ± 9.2
Blood pressure medication use, %	60	60	60
Diabetes, %	18	15	20
Weight, kg	90.6 ± 21.5	94.8 ± 24.1	86.3 ± 18.0
BMI, kg/m^2	32.1 ± 6.2	33.3 ± 7.0	30.9 ± 5.2
Alcohol intake, drinks/wk	1.4 ± 2.7	1.6 ± 3.5	1.3 ± 1.9
Smoking status, %			
Current	17	13	20
Former	25	31	20
Never	58	56	60
24-h sodium excretion,[2] mg/d	3496.0 ± 1426.0	3362.6 ± 1269.6	3627.1 ± 1587.0
24-h creatinine excretion, g/d	1.71 ± 0.65	1.64 ± 0.47	1.77 ± 0.8
24-h sodium:creatinine, mmol/g	92.1 ± 32.4	87.0 ± 24.1	97.3 ± 39.0
Total volume of urine collection, mL	1612.8 ± 532.1	1638.1 ± 511.5	1587.5 ± 564.0

[1]Mean ± SD (all such values).
[2]Adjusted for the number of hours of collection.

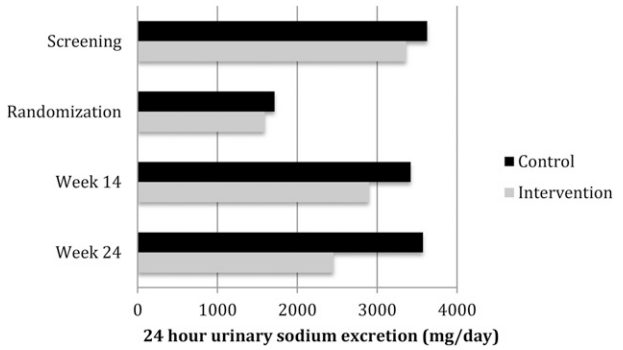

FIGURE 2 Twenty-four–hour urine sodium excretion (adjusted for the number of hours of urine collection) over time by randomly assigned groups (intervention group: $n = 20$; control group: $n = 20$).

the perception of saltiness in the same sample at the end of phase 1 than at the beginning. **Supplemental Table 5** displays reported symptoms on a symptoms checklist. There were no significant between-group differences.

DISCUSSION

In this study, we examined the effects of a behavioral intervention that emphasized spices and herbs on the maintenance of sodium intake at the recommended intake of 1500 mg/d. During phase 1 of the trial, which was a period of isocaloric consumption, the mean 24-h urinary sodium excretion (a proxy for dietary sodium intake) decreased from 3496 to 1654 mg/d (range: 1119–2033 mg/d). During phase 2 of the trial, the mean 24-h urinary sodium excretion increased in both intervention and control groups, but the increase in the mean 24-h sodium excretion during phase 2 was 957 mg/d less in the intervention group than in the control group.

The achieved difference in the change in 24-h urinary sodium excretion between intervention and control groups of −957 mg/d at the end of the behavioral intervention is consistent with large, well-conducted behavioral intervention studies focused on sodium reduction (21–23). In the Trials of Hypertension Prevention, the difference in the change in 24-h urinary sodium reduction between intervention and control groups was −1357 mg/d at the 6-mo follow-up time point and −1012 mg/d at the 18-mo time point (21). Similarly, in the Trial of Nonpharmacologic Interventions in the Elderly study, the difference in the change in 24-h urinary sodium excretion between intervention and control groups was −1081 mg/d at the 9-mo follow-up time point, −1127 mg/d at the 18-mo follow-up time point, and −920 mg/d at the 30-mo time point (22). Our findings complement published data on the efficacy of sodium reduction on health outcomes (21–23) and contribute to the understanding of strategies that may be used to achieve the recommended sodium intake and promote adherence.

Our observations at screening regarding the percentage of individuals who consumed <2300 or 1500 mg/d are consistent with national data suggesting that very few Americans meet recommendations for sodium intake (17). The guideline of 1500 mg/d applied to everyone we enrolled in the study, and as would be expected from our study design, we showed that participants accomplished this intake while being fed in phase 1 of the study. These findings are relevant to clinical settings where counseling for sodium reduction occurs. Various components of our intervention may be helpful to dietitians and other clinicians in their counseling efforts; specifically, individuals may benefit from adopting behaviors such as goal setting, problem solving, time management, and self-monitoring of sodium intake. In addition, the use of spices and herbs in recipes may be a strategy for maintaining flavor when cooking (34).

Adherence to recommended dietary sodium intake requires extraordinary individual effort, and it has been documented as being low in the American population (17). During phase 2 (the 20-wk intervention period after controlled consumption), we observed an increase in sodium intake in both intervention and control groups over time; however, the increase was lower in the intervention group. These findings are relevant to public health efforts to reduce sodium intake in that they highlight the enormous influence of the food environment, even for individuals who have a heightened awareness about their sodium intake and who are trying to meet recommendations. Although individuals made efforts to modify their recipes for sodium reduction, their inability to maintain a previously accomplished low 24-h urinary sodium-excretion concentration was likely because the amount of salt added to foods at the table and during cooking contributes

TABLE 4
Differences in 24-h sodium excretion between intervention and control groups by using different approaches to account for potential inaccuracies in urine collection

Analytic approach	n	Difference in 24-h sodium excretion,[1] mg/d	P
Linear regression	40	−956.8 (−1538.7, −374.9)	0.002
Linear regression with robust SEs	40	−956.8 (−1524.9, −388.7)	0.002
Quantile regression	40	−1221.3 (−2086.1, −356.5)	0.007
Drop CV >30[2]	33	−1030.4 (−1612.3, −448.5)	0.001
Drop on the basis of Joosens' equation[3]	31	−795.8 (−1545.6, −48.3)	0.04
Drop on the basis of Mage's equation[4]	38	−1090.2 (−1695.1, −483.0)	0.001
24-h sodium:creatinine[5]	40	−740.6 (−1209.8, −273.7)	0.003

[1]Values are means; 95% CIs in parentheses.
[2]Participant was removed from the analysis if the CV for creatinine excretion was >30%
[3]Urine collection was removed from the analysis if the ratio of the observed-to-expected creatinine excretion value was <0.6 on the basis of Joosens' equation, which accounted for sex.
[4]Urine collection was removed from the analysis if the ratio of the observed-to-expected creatinine excretion value was <0.6 on the basis of Mage's equation, which accounted for age, weight, height, sex, and BMI.
[5]Not indexed to 24 h of collection.

TABLE 5
Study participants meeting sodium goals per 2000-kcal diet[1]

	Screening	Random assignment	Week 14	Week 24
<2300 mg/d, %				
Control	20	85	20	25
Intervention	35	85	40	55
1500 mg/d, %				
Control	0	55	10	5
Intervention	10	75	25	25

[1]Sodium values were adjusted for the number of hours of urine collection.

only minor amounts to the American diet with the mean sodium-intake density being lower in foods cooked at home and highest in commercially prepared foods (18–20, 35).

Although very little sodium is added at the dining table, contemporary guidelines advocate individual efforts for the modification of sodium (15, 16, 36). In acknowledgment of the significant influence of the food supply on sodium intake, a 2010 report by the Institute of Medicine recommended a regulatory approach that supports the food industry in the reformulation of foods (35). If these efforts were implemented, they should provide greater flexibility for meeting recommendations when individuals consume commercially prepared foods. Spices and herbs may be one option for maintaining flavor when reformulating commercially prepared foods.

There are implications of this study for blood pressure and cardiovascular disease reduction in that effective strategies for dietary sodium reduction would likely affect cardiovascular health. There has been convincing evidence from studies across populations (37–39) and within populations (40–44) that sodium intake is associated with blood pressure. Further, meta-analyses of randomized clinical trials showed that persons with hypertension had a greater response to a reduced sodium intake than do persons with normal blood pressure (40, 43, 44). With a few notable exceptions (45, 46), excess sodium consumption has also been related to cardiovascular disease (8–11, 47). It has been projected that even modest decreases in sodium would reduce annual new cases of coronary heart disease by 60,000 to 120,000 (12).

Our findings about the perception of saltiness suggest that individuals may begin to become sensitized to the taste of a lower sodium diet after 4 wk of controlled consumption. These results are similar to findings from other studies in which a reduced preference for salt after reducing salt in the diet was observed (48–51). However, it has been suggested that a shift in the sensory response to salty taste occurs after 8–12 wk of consumption of a low-sodium diet (49). As such, the 4 wk of controlled consumption used in this study may have been too short to truly affect participants' perceptions of saltiness.

TABLE 6
Difference in perception of the intensity of saltiness before and after phase 1 (i.e., controlled consumption from weeks 0 to 4)

Sample (%wt/wtNaCl/broth)	Week 0	Week 4	Difference[1]
A (0% Na)	1.1 ± 1.4[2]	2.0 ± 2.5	0.96 (0.04)
B (0.15% Na)	2.2 ± 2.5	2.8 ± 3.0	0.64 (0.25)
C (0.35% Na)	3.9 ± 3.2	4.8 ± 2.6	0.92 (0.11)
C2 (0.35% Na)[3]	4.3 ± 3.0	4.8 ± 2.6	0.25 (0.26)
D (0.6% Na)	6.1 ± 3.3	6.9 ± 3.0	0.78 (0.20)
E (0.85% Na)	7.7 ± 3.8	7.8 ± 3.2	0.15 (0.85)
F (1.2% Na)	9.6 ± 3.0	10.0 ± 3.4	0.39 (0.79)
G (1.5% Na)	10.7 ± 3.3	11.4 ± 3.1	0.71 (0.49)
Perceived intensity	5.7 ± 2.0	6.3 ± 2.2	0.60 (0.07)

[1]All values are means; *P* values in parentheses. *P* values were significant at <0.05.

[2]Mean ± SD (all such values).

[3]C2 was a replicate of C.

Our study had both strengths and limitations. First, a potential limitation was our inability to isolate any one factor from our multiple-factor behavioral intervention as being more important than another in the intervention's success. We placed particular emphasis on the use of spices and herbs to maintain flavor when sodium was reduced, but we also included other factors. Although single-factor studies would be needed to isolate individual strategies for sodium reduction, the process of changing eating behavior is complex and addressing multiple, interrelated, and supporting factors was previously shown to be effective (21, 22, 33). Second, we assumed that 24-h urinary sodium excretion would reflect dietary intake. However, the utility of urine collections may be affected by the completeness of the collection, variability in dietary intake, variability in excretion, and other factors such as medication use (52–58). Third, 15 of 55 individuals did not get randomly assigned because they decided not to participate, the reasons of which are provided in Figure 1. This absence may have affected the generalizability of our findings. Fourth, the difference in the number of contacts between intervention and control groups may have increased the possibility that the difference in sodium excretion between the 2 groups may have been due to nondietary factors. Other limitations were our small sample size and our inclusion of only one study center, which was located in Baltimore, Maryland. For enhanced generalizability, a larger sample with greater geographic diversity is needed.

Our study had several strengths. First, before initiating the randomized clinical trial, we conducted controlled consumption to acclimatize individuals to lower sodium intake and enhance our ability to study the maintenance of low sodium intake. This design may be applicable to studying other nutrients for which population intake is inconsistent with dietary guidelines. Second, we focused on obtaining high-quality 24-h urinary sodium-excretion collections and used 2 measurements as a proxy for our primary outcome variable (i.e., dietary sodium intake). Our analyses suggested that we obtained high-quality collections on the basis of the total urine volume collected, which was consistent with the sodium-to-creatinine ratio, and on sensitivity analyses that account for potential inaccuracies in the urine collection (30–32, 52–58). Third, study retention was high with 100% follow-up rates achieved.

In conclusion, a multifactorial behavioral intervention emphasizing spices and herbs has the potential to facilitate adherence to lower sodium intakes. Because of the ubiquity of sodium in the US food supply, multilevel strategies that effectively address individual behaviors as well as the food supply are needed to improve the adherence to sodium recommendations.

The authors' responsibilities were as follows—CAMA, LJA, ERM, and JC: designed the research; CAMA, LKC, ERM, AH, ARC, MM-C, KW, JC, TT, LT, and LJA: conducted the research; CAMA, LKC, and MW: analyzed data or performed the statistical analysis; CAMA, LKC, LJA, and AH:

provided major contributions to the writing of the manuscript; CAMA: had primary responsibility for the final content of the manuscript; and CAMA, LKC, ERM, MW, AH, and LJA: interpreted data. The McCormick Science Institute had no direct role in the design of the trial and no role in reviewing the manuscript. None of the authors reported a conflict of interest related to the study.

REFERENCES

1. Centers for Disease Control, Trends in the prevalence of excess dietary sodium intake - United States, 2003-2010. MMWR Morb Mortal Wkly Rep 2013;62:1021–5.
2. Weinberger MH. Salt sensitivity, pulse pressure and death in normal and hypertensive humans. Hypertension 2001;37:429–32.
3. Aburto NJ, Ziolkovska A, Hooper L, Elloitt P, Cappucio FP, Meerpohl J. Effect of lower sodium intake on health: systematic review and meta-analyses. BMJ 2013;346:f1326.
4. Graudal NA, Hubeck-Graudal T, Jurgens G. Effects of low-sodium diet vs. high-sodium diet on blood pressure, renin, aldosterone, catecholamines, cholesterol, and triglyceride (Cochrane Review). Am J Hypertens 2012;25:1–15.
5. He FJ, Li J, MacGregor GA. Effect of longer-term modest salt reduction on blood pressure: Cochrane systematic review and meta-analysis of randomized trials. BMJ 2013;346:f1325.
6. Lawes CM, Vander Hoorn S, Rogers A, International Society of Hypertension. Global burden of blood-pressure-related disease, 2001. Lancet 2008;371:1513–8.
7. Strazzullo P, D'Elia L, Kandala NB, Cappuccio FP. Salt intake, stroke, and cardiovascular disease: meta-analysis of prospective studies. BMJ 2009;339:b4567.
8. Takachi R, Inoue M, Shimazu T, Sasazuki S, Ishihara J, Sawada N, Yamaji T, Iwasaki M, Iso H, Tsubono Y, et al.. Consumption of sodium and salted foods in relation to cancer and cardiovascular disease: the Japan Public Health Center-based Prospective Study. Am J Clin Nutr 2010;91:456–64.
9. Yang Q, Liu T, Kuklina EV, Flanders WD, Hong Y, Gillespie C, Chang MH, Gwinn M, Dowling N, Khoury MJ, et al. Sodium and potassium intake and mortality among US adults: prospective data from the third National Health and Nutrition Examination Survey. Arch Intern Med 2011;171:1183–91.
10. Tomonari T, Fukuda M, Miura T, Mizuno M, Wakamatsu TY, Ichikawa T, Miyagi S, Shirasawa Y, Ito A, Yoshida A, et al. Is salt intake an independent risk factor of stroke mortality? Demographic analysis by regions in Jaman. J Am Soc Hypertens 2011;5:456–62.
11. Gardener H, Rundek T, Wright CV, Elkind MS, Sacco RL. Dietary sodium and risk of stroke in the Northern Manhattan Study. Stroke 2012;43:1200–5.
12. Bibbins-Domingo K, Chertow GM, Coxon PG, Moran A, Lightwood JM, Pletcher MJ, Goldman L. Projected effect of dietary salt reductions on future cardiovascular disease. N Engl J Med 2010;362:590–9.
13. Palar K, Sturm R. Potential societal savings from reduced sodium consumption in the US adult population. Am J Health Promot 2009;24:49–57.
14. Smith-Spangler CM, Juusola JL, Enns A, Owens DK, Garber AM. Population strategies to decrease sodium intake and the burden of cardiovascular disease. Ann Intern Med 2010;152:481–7.
15. US Department of Agriculture, US Department of Health and Human Services. Dietary guidelines for Americans, 2010. 7th ed. Washington (DC): US Government Printing Office; 2010.
16. Lloyd-Jones DM, Hong Y, Labarthe D, Mozzaffarian D, Appel LJ, Van Horn L, Greenlund K, Daniels S, Nichol G, Tomaselli GF, et al. Defining and setting national goals for cardiovascular health promotion and disease reduction: the American Heart Association's Strategic Impact Goal through 2020 and beyond. Circulation 2010;121:586–613.
17. Cogswell ME, Zhang Z, Carriquiry AL, Gunn JP, Kuklina EV, Saydah SH, Yang Q, Moshfegh AJ. Sodium and potassium intakes among US adults. NHANES 2003-2008. Am J Clin Nutr 2012;96:647–57.
18. Sources of sodium among the US population, 2005-06 [Internet]. Bethesda (MD): National Cancer Institute. Available from: http://riskfactor.cancer.gov/diet/foodsources/sodium/.
19. Mattes RD, Donnelly D. Relative contributions of dietary sodium sources. J Am Coll Nutr 1991;10:383–93.
20. Anderson CA, Appel LJ, Okuda N, Brown IJ, Chan Q, Zhao L, Ueshima H, Kesteloot H, Miura K, Curb JD, et al. Dietary sources of sodium in China, Japan, the United Kingdom, and the United States, women and men aged 40 to 59 years: the INTERMAP study. J Am Diet Assoc 2010;110:736–45.
21. The effects of nonpharmacologic interventions on blood pressure of persons with high normal levels. Results of the Trials of Hypertension Prevention, phase I. JAMA 1992;267:1213–20.
22. Whelton PK, Appel LJ, Espeland MA, Applegate WB, Ettinger WH Jr., Kostis JB, Kumanyika S, Lacy CR, Johnson KC, Folmar S, et al. Sodium reduction and weight loss in the treatment of hypertension in older persons: a randomized controlled trial of nonpharmacologic interventions in the elderly (TONE). TONE Collaborative Research Group. JAMA 1998;279:839–46.
23. Cook NR, Cutler JA, Obarzanek E, Buring JE, Rexrode KM, Kumanyika SK, Appel LJ, Whelton PK. Long term effects of dietary sodium reduction on cardiovascular disease outcomes-observational follow-up of the Trials of Hypertension Prevention (TOHP). BMJ 2007;334:885–8.
24. USDA, Agricultural Research Service, Food Surveys Research Group. Correlations: energy & sodium and energy & potassium [Internet]. 2010 [cited 2011 Jun 29]. Available from: http://www.cnpp.usda.gov/Publications/DietaryGuidelines/2010/Meeting5/Correlations-SodiumAndPotassium-2005-2006.pdf.
25. [cited 2014 Aug 19]. Available from: www.cdc.gov/vitalsigns/pdf/2012-02-vitalsigns.pdf).
26. [cited 2014 Aug 19]. Available from: www.cdc.gov/salt/pdfs/Sodium_Tip_Sheet.pdf.
27. Holbrook JT, Patterson KY, Bodner JE, Douglas LW, Veillon C, Kelsay JL, Mertz W, Smith JC Jr. Sodium and potassium intake and balance in adults consuming self-selected diets. Am J Clin Nutr 1984;40:786–93.
28. Pietinen P. Estimating sodium intake from food consumption data. Ann Nutr Metab 1982;26:90–9.
29. Allsopp AJ, Sutherland R, Wood P, Wooton SA. The effect of sodium balance on sweat sodium secretion and plasma aldosterone concentration. Eur J Appl Physiol Occup Physiol 1998;78:516–21.
30. Joossens JV, Geboers J. Monitoring salt intake of the population: methodological considerations. In: De Backer GG, Pedoe HT, Ducimetiere P, editors. Surveillance of the dietary habits of the population with regard to cardiovascular diseases, EURONUT Report 2. Wageningen (Netherlands): Department of Human Nutrition, Agricultural University; 1984. p. 61–73.
31. Mage DT, Allen RH, Kdali A. Creatinine corrections for estimating children's and adult's pesticide intake doses in equilibrium with urinary pesticide and creatinine concentrations. J Expo Sci Environ Epidemiol 2008;18:360–8.
32. Wang CY, Cogswell ME, Loria CM, Chen TC, Pfeiffer CM, Swanson CA, Caldwell KL, Perrine CG, Carriquiry AL, Liu K, et al. Urinary excretion of sodium, potassium, and chloride, but not iodine, varies by timing of collection in a 24-hour calibration study. J Nutr 2013;143:1276–82.
33. Tapsell LC. Dietary guidelines for health - where do herbs and spices fit? Nutr Today 2008;43:132–7.
34. Elmer PJ, Obarzanek E, Vollmer WM, Simons-Morton D, Stevens VJ, Rohm Young D, Lin P, Champagne C, Harsha DW, Svetkey LP, et al. Effects of comprehensive lifestyle modification on diet, weight, physical fitness, and blood pressure control: 18-month results of a randomized trial. Ann Intern Med 2006;144:485–95.
35. Institute of Medicine. Strategies to reduce sodium intake in the United States. Washington (DC): The National Academies Press; 2010.
36. Whelton PK, Appel LJ, Sacco RL, Anderson CA, Antman EM, Campbell N, Dunbar SB, Frohlich ED, Hall JE, Jessup M, et al. Sodium, blood pressure and cardiovascular disease: further evidence supporting the American Heart Association sodium reduction recommendations. Circulation 2012;126:2880–9.
37. Law MR, Frost CD, Wald NJ. By how much does dietary salt reduction lower blood pressure? Analysis of observational data among populations. BMJ 1991;302:811–5.
38. Intersalt Cooperative Research Group. Intersalt: an international study of electrolyte excretion and blood pressure: results of 24-hour urinary sodium and potassium. BMJ 1988;297:319–28.
39. Elliot P, Stamler J, Nichols R, Dyer AR, Stamler R, Kesteloot H, Marmot M. Intersalt revisited: further analyses of 24 hour sodium excretion and blood pressure within and across populations. BMJ 1997;315:458.

40. Midgley JP, Matthew AG, Greenwood CM, Logan AG. Effect of reduced dietary sodium on blood pressure: a meta-analysis of randomized controlled trials. JAMA 1996;275:1590–7.
41. Cutler JA, Follman D, Allender PS. Randomized trials of sodium reduction: an overview. Am J Clin Nutr 1997;65(Suppl):643S–51S.
42. Mente A, O'Donell MJ, Rangarajan S, McQueen MJ, Poirier P, Wielgosz A, Morrison H, Li W, Wang X, Di C, et al. Association of urinary sodium and potassium excretion with blood pressure. N Engl J Med 2014;371:601–11.
43. He FJ, MacGregor GA. Effect of modest salt reduction on blood pressure: a meta-analysis of randomized trials. Implications for public health. J Hum Hypertens 2002;16:761–70.
44. Graudal NA, Galloe AM, Garred P. Effects of sodium restriction on blood pressure, renin, aldosterone, catecholamines, cholesterols, and triglyceride: a meta-analysis. JAMA 1998;279:1383–91.
45. Stolarz-Skrzypek K, Kuznetsova T, Thijs L, Tikhonoff V, Seidlerová J, Richart T, Jin Y, Olszanecka A, Malyutina S, Casiglia E, et al. Fatal and nonfatal outcomes, incidence of hypertension, and blood changes in relation to urinary sodium excretion. JAMA 2011;305:1777–85.
46. O'Donnell MJ, Yusuf S, Mente A, Gao P, Mann JF, Teo K, McQueen M, Sleight P, Sharma AM, Dans A, et al. Urinary sodium and potassium excretion and risk of cardiovascular events. JAMA 2011;306: 2229–38.
47. Mozaffarian D, Fahimi S, Singh GM, Micha R, Khatibzadeh S, Engell RE, Lim S, Danaei G, Ezzati M, Powles J. N Engl J Med 2014;371:624–34.
48. Beauchamp GK, Engelman K. High salt intake. Sensory and behavioral factors. Hypertension 1991;17:I176–81.
49. Mattes RD. The taste for salt in humans. Am J Clin Nutr 1997;65 (Suppl):692S–7S.
50. Bertino M, Beauchamp GK, Engelman K. Long-term reduction in dietary sodium alters the taste of salt. Am J Clin Nutr 1982;36:1134–44.
51. Blais CA, Pangborn RM, Borhani NO, Ferrel MF, Prineas RJ, Laing B. Effect of dietary sodium restriction on taste responses to sodium chloride. A longitudinal study. Am J Clin Nutr 1986;44:232–43.
52. Rakova N, Jüttner K, Dahlmann A, Schröder A, Linz P, Kopp C, Rauh M, Goller U, Beck L, Agureev A, et al. Long-term space flight simulation reveals infradian rhythmicity in humans Na^+ balance. Cell Metab 2013;17:125–31.
53. Clark AJ, Mossholder S. Sodium and potassium intake measurements: dietary methodology problems. Am J Clin Nutr 1986;43:470–6.
54. Luft FC, Fineberg NS, Sloan RS. Overnight urine collections to estimate sodium intake. Hypertension 1982;4:494–8.
55. McCullough ML, Swain JF, Malarick C, Moore TJ. Feasibility of outpatient electrolyte balance studies. J Am Coll Nutr 1991;10:140–8.
56. Ovesen L, Boeing H. The use of biomarkers in multicentric studies with particular consideration of iodine, sodium, iron, folate, and vitamin D. Eur J Clin Nutr 2002;56(Suppl 2):S12–7.
57. Reinivuo H, Valsta LM, Laatikainen T, Tuomilehto J, Pietinen P. Sodium in the Finnish diet: II trends in dietary sodium intake and comparison between intake and 24-h excretion of sodium. Eur J Clin Nutr 2006;60:1160–7.
58. Schachter J, Harper PH, Radin ME. Comparison of sodium and potassium intake with excretion. Hypertension 1980;2:695–9.