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Effects of Diet and Sodium Intake on Blood Pressure: Subgroup Analysis of the DASH-Sodium Trial

William M. Vollmer, PhD; Frank M. Sacks, MD; Jamy Ard, MD; Lawrence J. Appel, MD; George A. Bray, MD; Denise G. Simons-Morton, MD, PhD; Paul R. Conlin, MD; Laura P. Svetkey, MD; Thomas P. Erlinger, MD; Thomas J. Moore, MD; and Njeri Karanja, PhD, for the DASH-Sodium Trial Collaborative Research Group*

Background: **Initial findings from the Dietary Approaches to Stop Hypertension (DASH)-Sodium Trial demonstrated that reduction of sodium intake in two different diets decreased blood pressure in participants with and without hypertension.**

Objective: **To determine effects on blood pressure of reduced sodium intake and the DASH diet in additional subgroups.**

Design: **Randomized feeding study.**

Setting: **Four clinical centers and a coordinating center.**

Participants: **412 adults with untreated systolic blood pressure of 120 to 160 mm Hg and diastolic blood pressure of 80 to 95 mm Hg.**

Intervention: **Participants followed the DASH diet or a control (typical U.S.) diet for three consecutive 30-day feeding periods, during which sodium intake (50, 100, and 150 mmol/d at 2100 kcal) varied according to a randomly assigned sequence. Body weight was maintained.**

Measurements: **Systolic and diastolic blood pressure.**

Results: **In all subgroups, the DASH diet and reduced sodium intake were each associated with significant decreases in blood pressure; these two factors combined produced the greatest reductions. Among nonhypertensive participants who received the control diet, lower (vs. higher) sodium intake decreased blood pressure by 7.0/3.8 mm Hg in those older than 45 years of age ($P < 0.001$) and by 3.7/1.5 mm Hg in those 45 years of age or younger ($P < 0.05$).**

Conclusion: **The DASH diet plus reduced sodium intake is recommended to control blood pressure in diverse subgroups.**

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For author affiliations, current addresses, and contributions, see end of text.
*For participants in the DASH-Sodium Trial Collaborative Research Group, see the Appendix.
See editorial comment on pp 1084-1086.

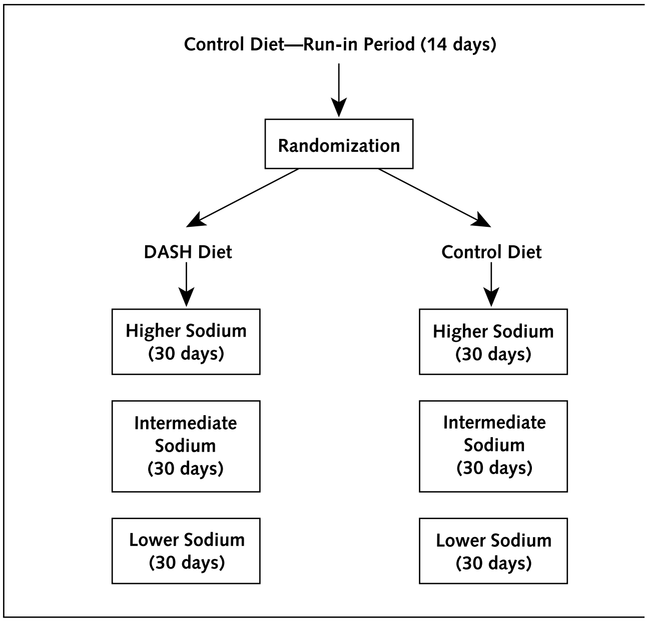
Although epidemiologic data show a direct relation between dietary sodium intake and blood pressure at the population level (1, 2), some experts question the universality of the findings and oppose public health recommendations to decrease sodium intake in the general population (3). Certainly, results from reports on the relationship between sodium and blood pressure among major subgroups vary considerably. Several studies suggest that African Americans and older adults have heightened salt sensitivity (greater blood pressure response to sodium intake) (4–6). Some evidence also indicates increased salt sensitivity in women (7), although other studies do not support this claim (4, 5). The association of sodium intake with cardiovascular morbidity and mortality varies by overweight status (8), perhaps reflecting a differential effect of sodium on blood pressure in overweight persons. Finally, higher dietary intakes of potassium and calcium have been shown to blunt the pressor effects of dietary sodium (9, 10).

Dietary factors other than sodium also directly affect blood pressure, and these effects also appear to vary across subgroups. In the Dietary Approaches to Stop Hypertension (DASH) Trial, for example, a diet that had reduced total and saturated fat and was rich in fruits, vegetables, and low-fat dairy foods (the DASH diet) substantially decreased blood pressure compared with a more typical U.S. diet, in the absence of weight change and at sodium intakes approximating current U.S. consumption (11, 12). These effects persisted across all subgroups and were especially pronounced among hypertensive persons, African Americans, and persons who did not drink alcohol (13).

The DASH-Sodium Trial examined the effects of reduced sodium intake in the context of the DASH diet and a more typical U.S. diet (14). In that study, highly significant decreases in blood pressure were observed with decreased sodium intake in participants following either diet, and the DASH diet decreased blood pressure at sodium intakes well below the current U.S. average. These results were observed overall and in subgroups defined by ethnicity, sex, and hypertension status (15).

We report on more detailed subgroup analyses from

Figure. **Design of the Dietary Approaches to Stop Hypertension (*DASH*)-Sodium Trial.**



During the run-in phase, the higher sodium level was used. During the intervention period, the three 30-day segments were offered in random order.

the DASH-Sodium Trial, including results for subgroups defined by age, obesity, waist circumference, alcohol intake, and baseline sodium intake. We also report the results of multivariate analyses that demonstrate how these effects vary across subgroups defined jointly by age, ethnicity, sex, and hypertension status.

METHODS

Study Design

The DASH-Sodium Trial was a multicenter, randomized feeding trial comparing the effects on blood pressure of three levels of sodium intake and two dietary patterns. The 412 participants were 22 years of age or older and had systolic blood pressures of 120 to 159 mm Hg and diastolic blood pressures of 80 to 95 mm Hg (15). The three levels of sodium intake (lower, intermediate, and higher) varied according to energy intake in a ratio of 1:2:3; target intakes were 50, 100, and 150 mmol/d, respectively, for a 2100-kcal diet. The dietary patterns were a control diet, typical of what many Americans eat, and the DASH diet, which emphasizes fruits, vegetables, and low-fat dairy foods; includes whole grains, poultry, fish, and nuts; and is reduced in fats, red meat, sweets, and sugar-containing beverages (11, 14).

Participants were recruited in four separate feeding cohorts and were randomly assigned to one of the two dietary patterns by using a parallel-group design. They then ate their assigned diet for three consecutive 30-day intervention feeding periods, during which sodium intake varied among the three levels by a randomly assigned sequence (**Figure**). Participants ate the control diet at the higher sodium intake during a 2-week run-in period. During the three intervention periods, participants received all their food in the context of the study and were asked not to eat any nonstudy food. Individual energy intake was adjusted to keep body weight stable.

Exclusion criteria were heart disease, renal insufficiency, poorly controlled hyperlipidemia or diabetes mellitus, diabetes requiring insulin, special dietary requirements, intake of more than 14 alcoholic drinks/wk, or use of antihypertensive drugs or other medications that would affect blood pressure or nutrient metabolism.

The study was approved by the human subjects committees of the clinical centers and coordinating center, and participants gave informed consent.

Measurement Protocol

Trained staff measured blood pressure at each of three screening visits, on 2 days during the run-in period, and on 5 of the last 9 days of each intervention feeding period. Interim blood pressures were assessed once during each of the first 3 weeks of each intervention feeding period.

During screening and the last week of each intervention feeding period, a 24-hour urine collection was obtained. Height and weight were measured, and body mass index was calculated. Baseline physical activity was measured by using a 7-day physical activity recall interview (16). Information on education level, income, alcohol consumption, and family history was obtained by using a questionnaire.

Baseline blood pressure was defined as the average of the five preintervention blood pressures. End-of-feeding blood pressures were defined as the average of the five blood pressures at the end of each 30-day intervention feeding period. If no end-of-feeding blood pressure values were available (49 of 1236 possible cases), interim (n = 9) or screening (n = 40) blood pressures were used to impute end-of-feeding blood pressures.

Definitions of Subgroups

Ethnicity was categorized as African American versus other (primarily non-Hispanic white). Participants were considered hypertensive if their untreated baseline systolic blood pressure was 140 mm Hg or greater and their diastolic blood pressure was 90 mm Hg or greater. (Use of antihypertensive agents was an exclusion criterion [17].) Obesity was defined as body mass index of 30 kg/m^2 or greater, and high-risk waist circumference was defined as greater than 102 cm in men and greater than 88 cm in women (18). Age, physical activity, baseline alcohol intake, baseline 24-hour urinary sodium level, and family income were dichotomized at the approximate median. Level of education was dichotomized as high school or less versus more than high school.

Statistical Analysis

The data were analyzed on an intention-to-treat basis. Given the differential effects of sodium on blood pressure observed in previous analyses among participants eating the DASH diet versus the control diet (15) and because power for subgroup analyses is more limited than for overall analysis, we focused our comparisons on the maximum contrasts (higher versus lower sodium intake with the control diet, DASH diet versus control diet at the higher sodium intake, and the combined effect of DASH diet and lower sodium intake versus control diet and higher sodium intake).

We used generalized estimating equations (19) to fit linear models that predicted baseline and end-of-feeding blood pressures as a function of diet (DASH vs. control), sodium level, and subgroup indicators. Different ways of modeling the diet–sodium effects and their interactions with the subgroup indicators were used to test specific hypotheses. In particular, two-way interactions of the various diet–sodium effects with ethnicity, sex, hypertension status, and age were analyzed to determine the incremental effect on blood pressure in each of these subgroups while controlling for the main and incremental effects of the other subgroups. This model allowed us to estimate various diet–sodium contrasts for each of the 16 subgroups defined by hypertension status, ethnicity, sex, and age. A second set of models examined subgroup variables in a bivariate manner and did not assume simple additivity of subgroup effects. Finally, unadjusted subgroup analyses included main effects and interactions for a single subgroup indicator.

All analyses were performed by using the *xtgee* procedure in Stata software, version 5 (Stata Corp., College Station, Texas) (20) and included adjustment for baseline blood pressure, site, feeding cohort, and carryover effects. An exchangeable covariance matrix was assumed for the repeated measurements for each participant. Unless otherwise stated, a *P* value less than 0.05 was significant, and all confidence intervals are 95% confidence intervals. Because subgroup analyses were planned to interpret and elucidate the overall study results, they are not adjusted for multiple comparisons.

RESULTS

Of the 412 participants who underwent randomization, 390 (95%) completed the 12-week intervention feeding period. Adherence to the study diets seemed excellent, and body weight remained stable over time (15).

Table 1 shows baseline characteristics of the 412 participants. Mean urinary sodium excretion at screening was 155 mmol/d, a value higher than that found while participants ate higher-sodium diets (142 mmol/d).

Several key subgroups were highly interrelated. Women made up 70% of African-American participants but only 39% of non–African-American participants. Women were more likely to be hypertensive than were men. The percentage of both men and women with hypertension increased sharply with age among non–African-American participants (21% of those ≤45 years of age vs. 47% of those >45 years of age) but was equally high among older and younger African Americans (43% of those ≤45 years of age vs. 45% of those >45 years of age). These correlations highlight the potential for confounding in our results and, hence, the importance of the multivariate-adjusted analyses.

Effects of the DASH Diet

Table 2 shows the effect on systolic blood pressure of the DASH diet compared with the control diet during higher sodium intake. The previously reported overall effect (15) persisted in all subgroups that we examined and did not differ among subgroups. The same was true for the effects of the DASH diet on diastolic blood pressure (**Table 3**). The diminished effects of the DASH diet at the intermediate and lower sodium levels also persisted in the subgroup analyses (data not shown).

Table 1. **Characteristics of Study Sample**

Characteristic*	Nonhypertensive Participants (n = 244)	Hypertensive Participants (n = 168)	African-American Participants (n = 234)	Non–African-American Participants (n = 178)	All Participants (n = 412)
Blood pressure					
Hypertensive, *n (%)*	–	–	103 (44)	65 (37)	168 (41)
Mean systolic blood pressure, *mm Hg*	129.1 ± 5.6	143.0 ± 7.8	135.3 ± 9.3	134.1 ± 9.8	134.8 ± 9.5
Mean diastolic blood pressure, *mm Hg*	83.7 ± 3.3	88.5 ± 4.5	86.1 ± 4.5	85.1 ± 4.4	85.7 ± 4.5
Ethnicity, *n (%)*					
African American	131 (54)	103 (61)	–	–	234 (57)
White	103 (42)	59 (35)	–	–	162 (39)
Other	10 (4)	6 (4)	–	–	16 (4)
Women, *n (%)*	128 (52)	106 (63)	164 (70)	70 (39)	234 (57)
Age					
>45 y, *n (%)*	130 (53)	110 (65)	133 (57)	107 (60)	240 (58)
Mean age, *y*	46.7 ± 9.3	50.3 ± 10.6	47.5 ± 9.2	49.1 ± 10.9	48.2 ± 10.0
Annual family income ≥ $45 000, *n (%)*†	107 (44)	66 (41)	78 (34)	95 (55)	173 (43)
Positive family history of hypertension, *n (%)*	165 (68)	118 (70)	163 (70)	120 (67)	283 (69)
Body mass index					
Obese (≥30 kg/m²), *n (%)*	94 (39)	66 (39)	96 (41)	64 (36)	160 (39)
Mean body mass index, *kg/m²*	29.4 ± 4.7	28.9 ± 5.0	29.7 ± 4.9	28.5 ± 4.7	29.2 ± 4.8
Post–high school education, *n (%)*‡	210 (86)	130 (78)	185 (79)	155 (88)	340 (83)
Physical activity					
Energy expenditure ≥ 36 kcal/kg per day	125 (51)	94 (56)	134 (57)	85 (48)	219 (53)
Mean energy expenditure, *kcal/kg per day*	38.5 ± 7.1	39.1 ± 7.2	39.3 ± 7.3	38.1 ± 6.9	38.8 ± 7.1
Consumption of ≥1 alcoholic drinks/wk, *n (%)*	116 (48)	64 (38)	79 (34)	101 (57)	180 (44)
High-risk waist circumference, *n (%)*§	142 (58)	95 (57)	141 (60)	96 (54)	237 (58)
Urinary sodium excretion‖					
≥140 mmol/d, *n (%)*	125 (52)	83 (50)	107 (46)	101 (57)	208 (51)
Mean urinary sodium excretion, *mmol/d*	156.0 ± 75.9	153.4 ± 74.8	150.7 ± 77.8	160.6 ± 71.8	155.0 ± 75.3

* Values with a plus/minus sign are the mean ± SD.
† Data are missing for 10 participants.
‡ Data are missing for 2 participants.
§ Defined as greater than 102 cm in men and greater than 88 cm in women.
‖ Data are missing for 4 participants.

Effects of Sodium

Table 2 shows systolic blood pressure with higher versus lower sodium intake among participants eating the control and DASH diets, respectively. Effects were significant in all of the subgroups and were greater for participants who ate the control diet. The effects of sodium were especially pronounced in hypertensive persons, African Americans, women, and persons older than 45 years of age. The results for diastolic blood pressure were qualitatively similar (**Table 3**), although the absolute effect sizes were smaller and not all of the same subgroup differences were statistically significant.

The increased salt sensitivity observed in older compared with younger participants was limited to those without hypertension. Among nonhypertensive participants eating the control diet, for example, the blood pressure effect of lower (vs. higher) sodium intake was −7.0/−3.8 mm Hg in those older than 45 years of age compared with −3.7/−1.5 mm Hg (95% CI, −5.8/−2.9 to −1.6/− 0.1 mm Hg) in those 45 years of age or younger ($P < 0.05$ for each systolic blood pressure and diastolic blood pressure comparison). Nonetheless, the reductions were statistically significant even in younger participants, as the CI indicates. Among participants with hypertension, the decrease in blood pressure associated with decreased sodium intake was greater in those who were younger, although the differences were not statistically significant (−8.0/−3.8 mm Hg in those >45 years of age vs. −9.0/−6.0 mm Hg in those ≤45 years of age).

Table 4 shows the results of multivariate regression analyses that adjusted simultaneously for age, ethnicity, sex, and hypertension status. The regression estimates can be used to predict the effect of lower sodium intake on systolic and diastolic blood pressure for persons eating the DASH or control diet. Regression equations are also shown for the combined effects of the DASH diet and lower sodium intake. The models suggest a wide variation in response to the effects of sodium reduction.

For example, among persons eating the control diet, the estimated effect of the lower versus higher sodium intakes ranged from a 2.8–mm Hg decrease in systolic blood pressure in the reference group (nonhypertensive, non–African-American men 45 years of age or younger) to a 10.1–mm Hg decrease in hypertensive African-American women older than 45 years of age (the value was obtained by summing all coefficients).

Combined Effect of DASH Diet and Lower Sodium Intake

The combination of the DASH diet plus lower sodium intake consistently produced the greatest mean

Table 2. **Unadjusted Analyses of the Effects of DASH-Sodium Trial Interventions on Systolic Blood Pressure in Selected Subgroups***

Subgroup	DASH Diet Recipients/Control Diet Recipients	Mean Change in Systolic Blood Pressure (95% CI)			
		DASH Diet − Control Diet, Higher Sodium Intake	Lower − Higher Sodium Intake, Control Diet	Lower − Higher Sodium Intake, DASH Diet	DASH Diet with Lower Sodium Intake − Control Diet with Higher Sodium Intake
	n/n	←——— *mm Hg*			———→
Hypertension status					
Hypertensive	85/83	−6.6 (−9.1 to −4.0)	−8.3 (−10.0 to −6.6)†	−4.9 (−6.6 to −3.3)‡	−11.5 (−14.1 to −8.9)‡
Nonhypertensive	123/121	−5.4 (−7.7 to −3.2)	−5.6 (−7.0 to −4.1)	−1.7 (−3.1 to −0.3)	−7.1 (−9.4 to −4.9)
Ethnicity					
African American	119/115	−5.9 (−8.2 to −3.6)	−8.0 (−9.4 to −6.5)‡	−3.6 (−5.1 to −2.2)	−9.6 (−11.8 to −7.3)
Non–African American	89/89	−5.6 (−8.1 to −3.0)	−5.1 (−6.7 to −3.4)	−2.2 (−3.8 to −0.5)	−7.8 (−10.3 to −5.2)
Sex					
Female	123/111	−6.6 (−8.8 to −4.3)	−7.5 (−9.0 to −6.0)	−4.0 (−5.4 to −2.5)†	−10.5 (−12.8 to −8.2)†
Male	85/93	−5.1 (−7.7 to −2.6)	−5.7 (−7.3 to −4.1)	−1.7 (−3.4 to 0.0)	−6.8 (−9.3 to −4.3)
Age					
>45 y	111/129	−7.1 (−9.4 to −4.9)	−7.5 (−8.9 to −6.1)†	−4.5 (−6.0 to −3.0)‡	−11.6 (−13.9 to −9.4)‡
≤45 y	97/75	−4.3 (−6.9 to −1.7)	−5.3 (−7.0 to −3.5)	−1.4 (−2.9 to +0.2)	−5.6 (−8.2 to −3.1)
Annual family income					
<$45 000	111/118	−6.7 (−9.0 to −4.4)	−7.0 (−8.5 to −5.6)	−2.8 (−4.3 to −1.3)	−9.5 (−11.8 to −7.1)
≥$45 000	93/80	−4.2 (−6.8 to −1.5)	−5.9 (−7.7 to −4.2)	−3.4 (−5.1 to −1.8)	−7.6 (−10.2 to −5.0)
Family history of hypertension					
Yes	150/133	−6.6 (−8.8 to −4.5)	−6.5 (−7.9 to −5.1)	−2.6 (−3.9 to −1.3)	−9.2 (−11.4 to −7.1)
No	58/71	−4.2 (−7.1 to −1.3)	−7.0 (−8.9 to −5.2)	−4.1 (−6.1 to −2.1)	−8.3 (−11.2 to −5.4)
Body mass index					
Obese (≥30 kg/m²)	78/82	−6.0 (−8.7 to −3.3)	−6.9 (−8.6 to −5.1)	−1.8 (−3.6 to 0.0)	−7.8 (−10.5 to −5.1)
Nonobese (<30 kg/m²)	130/122	−5.8 (−8.0 to −3.5)	−6.6 (−8.0 to −5.1)	−3.7 (−5.1 to −2.3)	−9.5 (−11.7 to −7.3)
Education level					
High school or less	28/42	−5.6 (−9.4 to −1.7)	−8.0 (−10.4 to −5.6)	−2.9 (−5.8 to 0.0)	−8.5 (−12.3 to −4.6)
More than high school	179/161	−5.7 (−7.7 to −3.7)	−6.3 (−7.6 to −5.0)	−3.0 (−4.2 to −1.8)	−8.7 (−10.7 to −6.6)
Physical activity					
Energy expenditure < 36 kcal/kg per day	93/100	−6.2 (−8.7 to −3.7)	−7.1 (−8.7 to −5.5)	−3.2 (−4.9 to −1.6)	−9.4 (−11.9 to −6.9)
Energy expenditure ≥ 36 kcal/kg per day	115/104	−5.6 (−8.0 to −3.3)	−6.3 (−7.8 to −4.8)	−2.9 (−4.3 to −1.4)	−8.5 (−10.9 to −6.2)
Alcohol use					
<1 drink/week	116/116	−6.5 (−8.7 to −4.2)	−7.5 (−9.0 to −6.1)	−3.5 (−4.9 to −2.0)	−9.9 (−12.2 to −7.6)
≥1 drinks/week	92/88	−5.1 (−7.6 to −2.6)	−5.6 (−7.3 to −3.9)	−2.4 (−4.1 to −0.8)	−7.5 (−10.1 to −5.0)
Waist circumference					
≤102 cm (men) or ≤88 cm (women)	95/80	−6.0 (−8.5 to −3.4)	−6.5 (−8.2 to −4.7)	−2.9 (−4.5 to −1.3)	−8.9 (−11.4 to −6.4)
>102 cm (men) or >88 cm (women)	113/124	−5.9 (−8.2 to −3.5)	−6.8 (−8.2 to −5.4)	−3.1 (−4.6 to −1.6)	−9.0 (−11.3 to −6.6)
Urinary sodium excretion					
<140 mmol/d	104/96	−6.0 (−8.5 to −3.5)	−7.1 (−8.7 to −5.5)	−2.8 (−4.3 to −1.2)	−8.8 (−11.3 to −6.3)
≥140 mmol/d	100/108	−6.0 (−8.3 to −3.6)	−6.3 (−7.8 to −4.8)	−3.3 (−4.9 to −1.7)	−9.3 (−11.6 to −6.9)

* Analyses are unadjusted for other subgroups. All models included adjustment for baseline systolic blood pressure, study site, feeding cohort, and carryover effects. DASH = Dietary Approaches to Stop Hypertension.
† $P < 0.05$ for subgroup differences.
‡ $P < 0.01$ for subgroup differences.

Table 3. **Unadjusted Analyses of the Effects of DASH-Sodium Trial Interventions on Diastolic Blood Pressure in Selected Subgroups***

Subgroup	DASH Diet Recipients/Control Diet Recipients	Mean Change in Diastolic Blood Pressure (95% CI)			
		DASH Diet − Control Diet, Higher Sodium Intake	Lower − Higher Sodium Intake, Control Diet	Lower − Higher Sodium Intake, DASH Diet	DASH Diet with Lower Sodium Intake − Control Diet with Higher Sodium Intake
	n/n	←—— *mm Hg* ——→			
Hypertension status					
Hypertensive	85/83	−3.2 (−4.8 to −1.5)	−4.4 (−5.5 to −3.3)†	−2.5 (−3.6 to −1.4)†	−5.7 (−7.4 to −4.0)
Nonhypertensive	123/121	−2.7 (−4.1 to −1.2)	−2.8 (−3.8 to −1.9)	−1.1 (−2.0 to −0.1)	−3.7 (−5.2 to −2.3)
Ethnicity					
African American	119/115	−3.1 (−4.6 to −1.6)	−4.5 (−5.5 to −3.6)‡	−1.9 (−2.9 to −1.0)	−5.0 (−6.5 to −3.6)
Non–African American	89/89	−2.4 (−4.1 to −0.8)	−2.2 (−3.2 to −1.1)	−1.3 (−2.4 to −0.2)	−3.7 (−5.4 to −2.0)
Sex					
Female	123/111	−3.0 (−4.5 to −1.5)	−3.7 (−4.7 to −2.7)	−1.7 (−2.6 to −0.8)	−4.7 (−6.2 to −3.2)
Male	85/93	−2.7 (−4.4 to −1.0)	−3.2 (−4.3 to −2.2)	−1.6 (−2.7 to −0.5)	−4.2 (−5.9 to −2.6)
Age					
>45 y	111/129	−3.4 (−4.8 to −1.9)	−3.8 (−4.8 to −2.9)	−2.2 (−3.1 to −1.2)	−5.5 (−7.0 to −4.0)†
≤45 y	97/75	−2.2 (−3.9 to −0.6)	−2.8 (−4.0 to −1.7)	−1.1 (−2.1 to 0.0)	−3.3 (−5.0 to −1.6)

* Analyses are unadjusted for other subgroups. All models included adjustment for baseline systolic blood pressure, study site, feeding cohort, and carryover effects. DASH = Dietary Approaches to Stop Hypertension.
† $P < 0.05$ for subgroup differences.
‡ $P < 0.01$ for subgroup differences.

reductions in blood pressure (**Tables 2** and **3**). For systolic blood pressure, these reductions generally ranged from 7 to 12 mm Hg, and the CIs suggest a decrease in systolic blood pressure of at least 5 mm Hg. The combined effects tended to be greatest in hypertensive persons, those older than 45 years of age, and (for systolic blood pressure) women. Differences by ethnicity were similar to those with sodium intake but were not statistically significant.

These trends persisted after multivariate adjustment, although the only significant differences in the multivariate models were in the age and hypertension subgroups (**Table 4**). For systolic blood pressure, differences by sex approached statistical significance (two-tailed $P =$ 0.074). As in the models for the effects of lower sodium intake alone, the models for the combined effects of the DASH diet plus lower sodium intake suggest a wide variation in response to these joint interventions across subgroups. For systolic blood pressure, these effects range from a 2.2–mm Hg decrease in nonhypertensive, non–African-American men 45 years of age or younger to a 15.1–mm Hg decrease in hypertensive African-American women older than 45 years of age.

DISCUSSION

Our findings extend those of initial reports from the DASH-Sodium Trial (15), showing that lower sodium intake and the DASH diet decreased blood pressure in diverse subgroups. Of note is the apparent increased sodium sensitivity of older (>45 years of age) nonhypertensive persons compared with nonhypertensive participants age 45 years or younger. A similar age differential was not seen for hypertensive participants. We also found no evidence of differential salt sensitivity according to body mass index. Multivariate analysis suggests a wide range of response across subgroups defined jointly by age, sex, ethnicity, and hypertensive status.

In the original DASH Trial, we observed that the DASH diet compared with control diet decreased blood pressure by 11.4/5.5 mm Hg in hypertensive participants and by 3.5/2.1 mm Hg in those without hypertension (12). Analogous results from the current trial are decreases of 6.6/3.2 mm Hg and 5.4/2.7 mm Hg, respectively. These differences presumably result from sampling variability rather than variation in measurement techniques or entry criteria, because these latter factors were very similar in both studies. The best estimate of the effect of the DASH diet at sodium intake between 134 mmol/d (DASH Trial urinary excretion levels) and 142 mmol/d (DASH-Sodium Trial urinary excretion levels) is a weighted average from the two studies (−8.0/−3.9 mm Hg for hypertensive persons and −4.1/−2.4 mm Hg for nonhypertensive persons).

Comparable pooled estimates for African Americans and non–African Americans are −6.4/−3.4 mm Hg and −4.5/−2.2 mm Hg.

The decreases in blood pressure associated with reduced sodium intake were present in all subgroups and were clinically relevant (**Tables 2** and **3**). For example, the difference in systolic blood pressure between lower and higher sodium intakes in participants eating the control diet generally ranged from 5 to 8 mm Hg across all subgroups. Of particular importance are the results in nonhypertensive participants in the study, because some investigators have questioned the benefits of sodium reduction in such persons (3). We noted statistically significant and clinically relevant reductions in blood pressure in our nonhypertensive participants, especially those eating a typical U.S. diet. These effects were more pronounced in participants older than 45 years of age and, as previously reported (15), in nonhypertensive African Americans. These findings, together with the lack of significant differences in salt sensitivity by sex, are generally consistent with those in the literature (21–24).

One prospective study from the United States and one from Finland found that sodium intake (8) or excretion (25) predicted cardiovascular disease significantly more in persons with a body mass index greater than 27 kg/m^2 than in those with a body mass index of 27 kg/m^2 or less. An obvious explanation would be that sodium intake has a greater effect on blood pressure in obese patients. However, we found no evidence that blood pressure responses were heightened among obese

Table 4. **Multivariate Regression Analyses of the Effects of the DASH-Sodium Trial Interventions on Blood Pressure in Selected Subgroups***

Outcome	Model Term	Regression Coefficient ± SE, *mm Hg*†	Two-Tailed *P* Value
Lower minus higher sodium intake, control diet			
Systolic blood pressure	Referent	−2.8 ± 1.2	0.015
	Hypertensive	−2.2 ± 1.1	0.048
	African American	−2.6 ± 1.1	0.02
	Female	−0.6 ± 1.1	>0.2
	Age > 45 y	−1.8 ± 1.1	0.10
Diastolic blood pressure	Referent	−1.3 ± 0.8	0.094
	Hypertensive	−1.3 ± 0.7	0.066
	African American	−2.5 ± 0.7	0.001
	Female	0.5 ± 0.7	>0.2
	Age > 45 y	−0.8 ± 0.7	>0.2
Lower minus higher sodium intake, DASH diet			
Systolic blood pressure	Referent	1.1 ± 1.1	>0.2
	Hypertensive	−2.8 ± 1.1	0.009
	African American	−0.8 ± 1.1	>0.2
	Female	−1.7 ± 1.1	0.14
	Age > 45 y	−2.9 ± 1.1	0.006
Diastolic blood pressure	Referent	−0.3 ± 0.8	>0.2
	Hypertensive	−1.3 ± 0.7	0.06
	African American	−0.7 ± 0.7	>0.2
	Female	0.2 ± 0.8	>0.2
	Age > 45 y	−1.0 ± 0.7	0.14
DASH diet with lower sodium intake minus control diet with higher sodium intake			
Systolic blood pressure	Referent	−2.2 ± 1.7	0.19
	Hypertensive	−3.5 ± 1.5	0.022
	African American	−0.8 ± 1.6	>0.2
	Female	−2.8 ± 1.6	0.074
	Age > 45 y	−5.7 ± 1.5	<0.001
Diastolic blood pressure	Referent	−1.9 ± 1.1	0.088
	Hypertensive	−1.7 ± 1.0	0.11
	African American	−1.4 ± 1.1	0.19
	Female	0.2 ± 1.1	>0.2
	Age > 45 y	−2.1 ± 1.0	0.038

* DASH = Dietary Approaches to Stop Hypertension.
† Referent values are the estimated effect in nonhypertensive, non–African-American men 45 years of age or younger. All other coefficients represent incremental effects associated with a specific subgroup after adjustment for other terms in the model. For example, the effect on diastolic blood pressure of the DASH diet with lower sodium intake versus the control diet with higher sodium intake among nonhypertensive African-American men older than 45 years of age is (−1.9) + (−1.4) + (−2.1) = −5.4.

participants compared with nonobese participants. We reached the same conclusion when we categorized body mass index as 27 kg/m^2 or greater versus 27 kg/m^2 or less and as 25 kg/m^2 or greater versus 25 kg/m^2 or less (data not shown). This pattern suggests that increased dietary sodium intake has adverse effects beyond increased blood pressure on processes that cause a cardiovascular event.

In practice, many people find it difficult to implement the dietary or sodium reduction intervention to its fullest extent, both because of the nature of the U.S. food supply and because of the inherent difficulty in making lifestyle changes. Recommending both interventions provides the public with two proven nonpharmacologic dietary strategies for controlling blood pressure, thus increasing the chance that a given person will find at least one that he or she can adopt. Furthermore, the fact that both interventions decreased blood pressure in all subgroups studied suggests that the beneficial effects of the DASH diet and reduction of dietary sodium intake are broadly generalizable across groups.

Although the findings from the DASH-Sodium Trial are compelling, the study has limitations. Support for the relatively short (30-day) duration of the feeding periods came from individual trials (12, 26, 27) and meta-analyses (21, 28) suggesting that the effects on blood pressure of the DASH diet and of changes in sodium intake are largely achieved by 4 weeks. The best available evidence suggests that the blood pressure–decreasing effects of reduced sodium intake persist over time if adherence is maintained, and that these benefits are achieved without apparent adverse effects (23, 26, 29). Although some researchers have suggested that reduced sodium intake may be detrimental in some persons (30–32), the studies supporting this claim have been based on very low sodium intake (10 to 20 mmol/d) or have had methodologic shortcomings (8, 33, 34).

Our study group was limited to participants with baseline blood pressures of at least 120/80 mm Hg; however, this describes approximately 50% of the U.S. adult population, including 80% of persons 50 years of age or older (35). Even if the immediate effect of these dietary changes in persons with lower blood pressures is minimal, adopting these changes on a long-term basis may help to blunt the increase in blood pressure that occurs with increasing age (36).

In conclusion, our results highlight the potential for decreased sodium intake, coupled with the DASH diet, to reduce blood pressure in diverse subgroups, including nonhypertensive and older persons. Given the overwhelming evidence that increased blood pressure increases the risk for cardiovascular morbidity throughout a wide range of hypertensive and nonhypertensive blood pressures (37), the DASH diet plus decreased sodium intake should be broadly recommended for prevention and treatment of hypertension and its sequelae.

APPENDIX: THE DIETARY APPROACHES TO STOP HYPERTENSION (DASH)-SODIUM COLLABORATIVE RESEARCH GROUP

Clinical Centers

Brigham and Women's Hospital and Harvard Medical School, Boston, Massachusetts: Natalie Alexander; Jean Belmonte, RDT; Faiza Bodden; Linda Cashman; Paul R. Conlin, MD; Brenda Cox; Joanne Dyer; Anna Ghosh; James Hackett; Eileen Hamilton, RDT; Tarra Holiday; Joanne Karimbakis, MS, RD; Courtney Larson, RD; Marjorie McCullough, MS, RD; Davida McDonald; Paton McVinney; Dianne Moeller, RD; Thomas J. Moore, MD; Pamela Morris; Michelle Myrie; Kathy Osborn; Elaine Penachio; Susan Redican, MS, RD; Frank M. Sacks, MD; Janice Sales; Janis Swain, MS, RD; Zaw Than; Kelly Weed.

Duke University Medical Center, Durham, North Carolina: John Abbott; Kathleen Aicher; Jamy Ard, MD; Jannie Baughman; Michelle Baughman; Blondeaner Brown; Arline Bohannon, MD; Brenda Graves; Kimberly Hoben, MPH, RD, LDN; Julie Huang, MBA; LaVerne Johnson-Pruden; Pao-Hwa Lin, PhD; Tori Phelps; Claudia Plaisted, MS, RD, LDN; LaChanda Reams; Patrice Reams; Taryn Ross; Fran Rukenbrod, RD, MEd; Laura P. Svetkey, MD; Erin Ward.

Johns Hopkins University, Baltimore, Maryland: James Abshere; Lawrence J. Appel, MD; Donna Bengough; Lindsay Bohlman; Jeanne Charleston, RN, MSN; Lily Clement; Cindy Dahne; Fatimah Dennis; Sandra Dobry; Karen Eldridge; Thomas Erlinger, MD; MPH; Ann Fouts, RN; Charles Harris; Barbara Horseman; Magan Jehn; Shirley Kritt; Joyce Lambert; Estelle Levitas; Phyllis McCarron, MS, RD; Edgar R. Miller III, MD, PhD; Nadiyah Muhammad; Melissa Nagy; Bonnie Peterson; Donna Rhodes, MS, RD; Victoria Shank; Thomas Shields; Tina Stanger; Avra Thomas; Ebony Thomas; Letitia Thomas; Roberta Weiss; Essie Wilke; Winny Wong.

Pennington Biomedical Research Center, Baton Rouge, Louisiana: George A. Bray, MD; Catherine Champagne, PhD, RD; Staci Crawford, RD; Frank L. Greenway, MD; David Harsha, PhD; Jana Ihrig, RN; Betty Kennedy, MPA; Jennifer Perault; Debbie Sanford, LPN; Anita Sawyer; Steven Smith, MD;

Richard Tulley, PhD; Janaki Vaidyanathan, MS, RT; Marlene M. Most-Windhauser, PhD.

Coordinating Center

Kaiser Permanente Center for Health Research, Portland, Oregon: Mikel Aickin, PhD; Michael Allison; Shelly Baxter, PhD; Nancy Becker, MS, RD; Shirley Craddick, MHA, RD; Bryce Doster; Chris Eddy; Denise Ernst, MS; Arlene Garrison; Suzanne Gillespie, MA; Rebecca Gould; Teri Haswell; Lauren Haworth, MA; Fran Heinith; Matthew Hornbrook; Njeri Karanja, PhD; Kelly Kirk; Pierre A. LaChance; Reesa Laws, BS; Mike Leitch; Wan-Ru Li, MBA; Lisa Massinger; Martha McMurray, MS, RD; Gayle Meltesen, MS; Gary Miranda; Steve R. Mitchell, PhD; Nadia Redmond; Jeanne Reinhardt; Jessie Rice; Paula Runk; Roberleigh Schuler, MS; Carrie Souvanlasy; Martie Sucec; Thomas M. Vogt, MD, MPH; William M. Vollmer, PhD.

Food Analysis Coordinating Center

Virginia Polytechnic Institute, Blacksburg, Virginia: Katherine Phillips, PhD.

Sponsor

National Heart, Lung, and Blood Institute, Bethesda, Maryland: Colleen M. Brown; Jeffrey A. Cutler, MD; Marguerite A. Evans, MS, RD; Eva Obarzanek, PhD; Michael A. Proschan, PhD; Denise G. Simons-Morton, MD, PhD.

Laboratory

Washington University School of Medicine, Core Laboratory for Clinical Studies, St. Louis, Missouri: Thomas Cole, PhD (*Director*).

From the Center for Health Research, Portland, Oregon; Brigham and Women's Hospital and Boston University Medical Center, Boston, Massachusetts; Duke University Medical Center, Durham, North Carolina; Johns Hopkins University, Baltimore, and National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, Maryland; and Pennington Biomedical Research Center, Baton Rouge, Louisiana.

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Requests for Single Reprints: William M. Vollmer, PhD, Center for Health Research, 3800 North Interstate Avenue, Portland, OR 97227-1110; e-mail, william.vollmer@kpchr.org.

Current Author Addresses: Drs. Vollmer and Karanja: Center for Health Research, 3800 North Interstate Avenue, Portland, OR 97227.
Drs. Sacks and Conlin: Brigham and Women's Hospital, 221 Longwood Avenue, Boston, MA 02115.
Drs. Ard and Svetkey: Duke University Medical Center, 3020 Pickett Road, Durham. NC 27705.
Drs. Appel and Erlinger: Johns Hopkins University, 2024 East Monument Street, Suite 2-602, Baltimore, MD 21205.
Dr. Bray: Pennington Biomedical Research Center, 6400 Perkins Road, Baton Rouge, LA 70808.
Dr. Simons-Morton: National Heart, Lung, and Blood Institute, National Institutes of Health, 6701 Rockledge Drive, Bethesda, MD 20892.
Dr. Moore: Boston University School of Medicine, 715 Albany Street, Boston, MA 02118.

Author Contributions: Conception and design: W.M. Vollmer, F.M. Sacks, L.J. Appel, G.A. Bray, D.G. Simons-Morton, P.R. Conlin, L.P. Svetkey, T.J. Moore, N. Karanja.
Analysis and interpretation of the data: W.M. Vollmer, J. Ard, L.J. Appel, D.G. Simons-Morton, P.R. Conlin, L.P. Svetkey, T.J. Moore, N. Karanja.
Drafting of the article: W.M. Vollmer, F.M. Sacks, J. Ard, G.A. Bray, P.R. Conlin, L.P. Svetkey, T.J. Moore, N. Karanja.
Critical revision of the article for important intellectual content: W.M. Vollmer, F.M. Sacks, J. Ard, L.J. Appel, G.A. Bray, D.G. Simons-Morton, P.R. Conlin, L.P. Svetkey, T.P. Erlinger, T.J. Moore.
Final approval of the article: W.M. Vollmer, F.M. Sacks, L.J. Appel, G.A. Bray, P.R. Conlin, L.P. Svetkey, T.P. Erlinger, T.J. Moore.
Provision of study materials or patients: F.M. Sacks, L.J. Appel, P.R. Conlin, L.P. Svetkey.
Statistical expertise: W.M. Vollmer.
Obtaining of funding: W.M. Vollmer, F.M. Sacks, L.J. Appel, G.A. Bray, L.P. Svetkey, T.J. Moore, N. Karanja.
Administrative, technical, or logistic support: W.M. Vollmer, D.G. Simons-Morton, P.R. Conlin, L.P. Svetkey, T.J. Moore, N. Karanja
Collection and assembly of data: W.M. Vollmer, L.J. Appel, G.A. Bray, P.R. Conlin, L.P. Svetkey, T.J. Moore, N. Karanja.

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