Reducing salt intake: a systematic review and meta-analysis of behavior change interventions in adults

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Context: Prolonged high salt (sodium) intake can increase the risk of hypertension and cardiovascular disease. Behavioral interventions may help reduce sodium intake at the population level. Objective: The effectiveness of behavior change interventions to reduce sodium intake in adults was investigated in this systematic review and meta-analysis. Data source: The PubMed, Cochrane Library, Cumulative Index to Nursing and Allied Health Literature, and EMBASE databases were searched. Data extraction: Narrative synthesis and random-effects meta-analyses were used to determine intervention efficacy. A total of 61 trials (46 controlled trials and 15 quasi-experimental studies) were included. Results: Behavior change interventions resulted in significant improvements in salt consumption behavior (e.g., decrease in purchase of salty foods; increase in use of salt substitutes), leading to reductions in sodium intake as measured by urinary sodium in 32 trials (N = 7840 participants; mean difference, –486.19 mg/d [95%CI, –669.44 to –302.95]; P < 0.001; I² = 92%) and dietary sodium in 19 trials (N = 3750 participants; mean difference –399.86 mg/d [95%CI, –581.51 to –218.20]; P < 0.001; I² = 96%), equivalent to a reduction of >1 g of salt intake daily. Effects were not significantly different based on baseline sodium intakes, blood pressure status, disease status, the use of behavior change theories, or the main method of intervention delivery (i.e., online vs face-to-face). Conclusion: Behavior change interventions are effective at improving salt consumption practices and appear to reduce salt intake by >1 g/d.

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Salt (sodium chloride) is one of the oldest ingredients for preserving food. Despite the introduction of refrigeration and other preservation techniques, the food industry continues to use salt to reduce pathogen growth, to maintain color, and to enhance the taste and sensory attributes of foods. Every 100 g of dietary salt contains ~40 g of sodium. Sodium is a micronutrient with essential roles in human physiology. It is a major electrolyte of extracellular fluid and, along with potassium, is necessary for our normal biological functions. The daily sodium requirement to maintain these functions is very low (<500 mg) and can easily be met through a balanced diet of animal- and plant-based foods. However, the global average sodium intake is ~3,950 mg/day, almost twice the World Health Organization recommended limit of 2000 mg (2 g sodium or 5 g salt) per day.

Prolonged high sodium intake has the potential to alter the fluid regulatory system and the functions of the kidney, cardiac, and central nervous systems, leading to the development of hypertension (or high blood pressure [BP]). Hypertension is the greatest contributor to the burden of cardiovascular disease (CVD), the leading cause of death globally at approximately 17.9 million lives each year. Thus, high sodium intake is a product of multiple factors, including lifestyle and genetic predisposition, it is a major contributor to hypertension and CVD. In fact, approximately 10% of all CVD-related deaths worldwide annually (~1.8 million lives) can be attributed to excess sodium consumption.

Different behavioral strategies, including face-to-face and online (app or internet-based) interventions have been developed to reduce salt intake. Findings of a previous review, which included studies published up to 2015, suggested that population-level education and awareness-raising interventions were effective to reduce salt intake but were not likely to be sustained over time. However, the overall impact of behavior change interventions on salt intake was not quantified in this review, and the authors did not differentiate between face-to-face and online-driven interventions. Thus, the aim of this study was to update the previous systematic review of behavior change interventions to reduce salt intake and quantify their effectiveness on the basis of different delivery methods (ie, face-to-face vs online) and characteristics, using meta-analytic procedures. Findings from this study will inform future interventions and policies aiming to develop and implement salt-reduction strategies.

**INTRODUCTION**

**MATERIALS AND METHODS**

**Literature search strategy**

PubMed (MEDLINE) Cochrane Library (Central), Cumulative Index to Nursing and Allied Health Literature, and Embase online databases were searched from January 1, 2000, to May 1, 2021, for eligible studies. One of our aims for this systematic review was to differentiate the effectiveness of behavior change interventions on the basis of the main method of intervention delivery (face-to-face vs online) in the included studies. Interventions prior to 2000 were unlikely to use online technology as their main method of intervention delivery. To allow comparisons between similar standards of design and technology, studies published before 2000 were excluded. A combination of keywords and Medical Subject Heading terms was used for the online literature search following the PICOS (population, intervention, comparison, outcome, setting/design) approach (Table 1). An example of the search strategy used is presented in Table S1 in the Supporting Information online. The database search was limited to articles on human trials and reported in English. The PRISMA guidelines were followed during the literature search and the preparation and presentation of this systematic review. Methodology for this systematic review was registered with the International Prospective Register for Systematic Reviews (registration no. CRD42020185639).

**Study eligibility**

Controlled trials and quasi-experimental studies investigating the effects of behavior change interventions on salt intake in adults (≥18 years of age), regardless of their health status, were included. Studies were eligible if (1) they reported changes in salt or sodium intake or behavior after an intervention; and (2) the intervention itself was behavioral in nature (eg, educational or informational interventions, consultations, feedback-based interventions, goal setting, dietary behavior change, self-monitoring of salt intake) and delivered face-to-face and/or online (internet or app based). Studies were excluded if they (1) used modified salt (eg, sodium chloride plus chitosan, or low-sodium salt), a specific diet or food modification or reformulation to reduce sodium intake (instead of a behavior change intervention)—this included studies that used a combined behavior change and dietary intervention (unless a behavior change–only arm was included); (2) reported changes in knowledge or awareness of salt, without reporting changes in behavior or intake of salt; and/or (3) did not have an
English, full-text format available. Studies in which general salt-intake behaviors (e.g., intake of salty foods, changes in food choices) or salt (sodium) intake specifically (e.g., estimated dietary sodium intake, urinary sodium excretion) were measured were included in the qualitative synthesis. Only controlled trials reporting changes in salt (sodium) intake specifically were included in the quantitative analysis (i.e., the meta-analysis).

A 2-step screening process was used. First, the titles and abstracts of the searched literature were screened; those not meeting the eligibility criteria were excluded. Next, the full text of the remaining studies was reviewed to identify the eligible studies. The reference lists of all included studies were also hand-searched to ensure all relevant articles were captured. Two researchers were involved in all steps of the screening process. The final decision regarding the eligibility of studies was made by these 2 researchers and a third reviewer was involved to resolve any disagreements.

**Outcome measured**

Salt-related behavior and salt intake were the primary outcomes of this study. Salt-related behavior was defined as choosing lower-salt foods, adding less salt while preparing or serving food, using salt alternatives, and other measured behaviors relevant to choosing less-salty food options. Salt intake was defined as the quantity of salt consumed reported as dietary sodium (measured subjectively using dietary questionnaires and records) or urinary sodium concentration (measured objectively using a 24-hour or spot urine sample). Literature suggests that approximately 90% of dietary sodium intake is excreted as urinary sodium.\(^\text{12}\) Given the biological variability in urinary sodium excretion\(^\text{12}\) and bias in self-reporting dietary sodium intake,\(^\text{13}\) information on dietary sodium and urinary sodium was collected and reported separately in this study. All units of sodium measurement (millimoles, milliequivalents, grams) were converted to milligrams for consistency. Sodium intake in milligrams was also reported as grams of salt intake for ease of interpretation (1 g salt = 390 mg sodium).\(^\text{14}\)

**Data extraction and quality assessment**

Study characteristics, including author; publication year; country; participants’ age and health status; intervention and control characteristics; study design; main delivery method of intervention (face-to-face or online); reported compliance; outcomes (salt-related behavior and salt intake); and outcome measurement methods were extracted from included studies. For studies to be classified as online, the main method of intervention delivery had to use online technologies (i.e., websites or smartphone apps). Studies that used telephone, messaging, email, or websites to deliver only part of the intervention (e.g., to follow up, as an intervention reminder, or to send quick tips) were not classified as using online interventions unless this was the only behavior change intervention offered. For studies with multiple follow-up points, only those measurements reported immediately at the end of the intervention period were included (as the postintervention measurement) to ensure consistency. For studies with multiple eligible intervention arms and 1 control group (no intervention or usual care), each intervention was treated as a separate trial and the participant number for the control group was divided evenly between the intervention groups.\(^\text{15}\) Methodological quality of included studies was examined using the Rosendal scale\(^\text{16}\) and the Cochrane risk-of-bias assessment tool\(^\text{17}\) (quality assessment method is discussed in detail in the Supporting Information online).

**Data analysis**

The effect of lifestyle behavior change interventions on salt intake was defined as the mean difference (MD) of salt intake observed between the intervention and control groups. The means and SDs of change for studies that did not report the absolute change values were calculated following the Cochrane Handbook for Systematic Review of Interventions guidelines.\(^\text{15}\) Mean change was calculated on the basis of the difference between dietary and urinary sodium measures at baseline and postintervention. To calculate the SD of change, a
correlation coefficient was first derived using data from trials that reported mean and SD of baseline, postintervention, and absolute change, using the following formula:15:

$$ r = \frac{SD_{Baseline}^2 + SD_{Final}^2 - SD_{Change}^2}{2 \times SD_{Baseline} \times SD_{Final}}. $$

The calculated correlation coefficient was then used to calculate the SD of change in studies with no reported absolute change, using the following formula:

$$ SD_{Change} = \sqrt{SD_{Baseline}^2 + SD_{Final}^2 - (2 \times r \times SD_{Baseline} \times SD_{Final})}. $$

Separate weighted mean intervention effects were derived for dietary sodium and urinary sodium using 2 random-effects meta-analyses. Heterogeneity was assessed using Cochran’s Q and the I² index. Values < 40%, 40%–75%, and > 75% corresponded to low, moderate, and high heterogeneity, respectively.15

Effect sizes were considered extreme outliers if their confidence interval did not overlap the confidence interval for the pooled effect size. The sensitivity of the overall meta-analyses to outliers was investigated by excluding the identified studies. Sensitivity analyses were also performed by excluding individual trials (a leave-1-out method), with changes in overall results and heterogeneity explored.

Subgroup analyses were performed to investigate differences in dietary and urinary sodium changes from interventions that used a face-to-face (in-person) approach as their main method of intervention delivery and those that used online delivery systems. We also compared a subgroup of studies in which using behavior change theories or frameworks to guide the intervention was reported with studies that did not report this information. Trials with the majority of the participants diagnosed as having elevated or high BP were also compared with those not including this population. Elevated or high BP was defined as mean baseline BP of ≥ 130/85 mmHg, hypertension diagnosis, or taking medication to reduce BP (as reported by the original studies). The subgroup of studies involving healthy participants was compared with those involving participants with underlying medical conditions (other than overweight and obesity). Mixed-effects-models meta-regression analyses were performed to determine if the effectiveness of the behavior change intervention was influenced by: (1) the quality of included studies and (2) baseline dietary and urinary sodium levels.

All statistical analyses were performed using RStudio software, version 1.3.1073.18 The packages “meta”19 and “dmetar”20 were used for the analysis (R codes used in this study are available in the Appendix S1 in the Supporting Information online). All data are presented as mean ± SD. Statistical significance was accepted at P < 0.05.

## RESULTS

### Overview of included studies

A total of 155 studies were identified from the literature search. Of these, 61 trials (from 56 studies: 5 studies had 2 eligible trials) met the eligibility criteria, including 46 controlled trials (CTs) (intervention group, n = 24 468; control group, n = 13 305), 15 quasi-experimental (experiment group, n = 23 204; control group, n = 14 192). Salt use behavior and salt intake changes were measured in all studies. Eligible CTs were also included in the meta-analysis to quantify the effect of behavior change interventions on salt intake. Figure 1 presents the PRISMA flow diagram of the selection process.

### Systematic review results

#### Controlled trials

A total of 43 CTs (n = 46 trials, of which 3 studies had 2 eligible trials) were included in this systematic review. The characteristics of included CTs are presented in Table 2.21–63 Participants were aged between 25 and 83 years. Interventions had a duration of between 4 weeks and 18 months. Of the 46 trials included, 22 specifically included participants with elevated or high BP.

Twenty-three CTs had good methodologic quality, achieving a Rosendal score ≥60%16 (Table S3 in the Supporting Information online). These studies typically also had a low risk of bias, based on the Cochrane risk-of-bias tool (Table S4 in the Supporting Information online). The study by Appel et al.22 achieved the highest Rosendal score (92%) of the included studies.

Use of a behavior change theory model or framework was reported in 19 CTs (Table 2). No theory or framework was reported for the remaining studies. Theories used in the studies included social cognitive theory (n = 4); social marketing theory (n = 1); theory of planned behavior (n = 1); theory of planned behavior and self-efficacy (n = 1); self-regulation (n = 2); theory of planned behavior and implementation intention strategy (n = 1); precede-proceed model (n = 1); social marketing assessment and response tool model (n = 1); theory of planned behavior and self-regulation (n = 1); continuous care model (n = 1); chronic care model (n = 1); behavior theory and social cognitive theory (n = 2); and self-determination theory (n = 3).
Face-to-face delivery was the main method of intervention delivery in the majority of included CTs. Online interventions were used in 5 CTs. Face-to-face CTs used individual and/or group education sessions and provided a combination of education, counselling, phone or text follow-ups, and distributed information through newsletters, text messages, recipes, handouts, email, and mail. Studies used reinforcement, self-monitoring, recording of food items, and nutritional goal setting to motivate behavior change. Online CTs used smartphone apps, websites, social media, messaging and e-coaching to deliver intervention content and help individuals choose lower-salt foods. The majority of trials used usual care as the control (n = 23), followed by general dietary advice (n = 10), no intervention (n = 5), non-nutritional advice or guidelines (n = 5), and general salt advice (n = 2).

Compliance or adherence to interventions was highly variable. Two CTs reported achieving 100% compliance to the salt-reduction behavior change interventions. Thirty studies reported a high compliance level (>70%), 4 studies reported poor adherence (<70%), and 1 study reported the 82% of participants completed the final assessment (at 12 months) but few completed the 6-month assessment.

Salt-related behavior was measured in 10 of the 46 trials included in this review (Table 2). All trials reported a significant improvement in salt use behavior after the behavior change intervention. Reduced intake of specific foods high in sodium and reduction in the household purchase of salt, use of salt in cooking, self-reported intake, and salt habits; and increase in the purchase and use of salt substitutes and a better attitude toward a low-sodium diet were the

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**Figure 1** Diagram indicating article selection process. CT, controlled trial; Na, sodium.
| Reference               | Location, participants, age, mean ± SD (y) | Intervention/control characteristics (no. of participants) | Duration | Theory-driven, no/yes (method), compliance | Measured: urine, diet, or behavior (method) | Intervention changes from baseline, mean ± SD (mg/d) | Control changes from baseline, mean ± SD (mg/d) |
|------------------------|--------------------------------------------|----------------------------------------------------------|----------|---------------------------------|---------------------------------|------------------------------------------|------------------------------------------|
| Anderson et al21       | United States, adults, 61 ± 9.7            | Salt behavior (20)/standard sodium education (20)       | 20 wk    | N, 100% completed               | U (24 h)                        | 866.2 ± 1269.6                         | 1858.4 ± 1587                           |
| Appel et al22          | United States, elevated BP, 50 ± 8.9       | Lifestyle behavior (212)/advice only (215)              | 6 mo     | Y (SCT), high                   | U (24 h)                        | -726.8 ± 1718.1                       | -473.8 ± 1646.8                       |
| Appel et al22b         | United States, elevated BP, 50 ± 8.9       | Lifestyle behavior + DASH (211)/advice only (215)       | 6 mo     | Y (SCT), high                   | U (24 h)                        | -749.8 ± 1796.3                       | -473.8 ± 1646.8                       |
| Arcand et al23         | Canada, patients with HF, normal BP, 56 ± 3| Nutritional behavior (23)/usual care (24)               | 3 mo     | N, 3 dropouts                   | D (3DFR)                        | -660 ± 242.3                          | -260 ± 212.1                          |
| Assuncao et al24       | Brazil, OW/OB, 41.1 ± 1.2                 | Lifestyle behavior (97)/usual care (95)                 | 6 mo     | N, 19.2% attrition              | D (FFQ)                         | -371.5 ± 112.7                        | 33.0 ± 109.1                          |
| Brown et al25          | United States, HTN/pre-HTN, (66%), 53 (44–65) | Culturally sensitive lifestyle behavior (411)/skin cancer awareness material or sunblock (229) | 12 mo | Y (SD), 82% completed at 12 m | D (FFQ) | -278 ± 790.2 | -155 ± 681.3 |
| Cappuccio et al26      | Ghana, Africa, Adults, 54 ± 11            | Salt behavior + diabetes, HTN, and infective diseases (399)/diabetes, HTN, and infective diseases (402) | 6 mo     | N, 80% completed                | U (24 h)                        | -204.7 ± 1012.7                       | -328.9 ± 990.7                       |
| Choi and Lee27         | Korea, CKD, 53.93 ± 13.47                | Diet and CKD self-management program (31)/not parallel, control group with general maintenance. | 2 mo     | N, all completed                | U (not specified)               | 22.31 ± 41.63                         | -5.29 ± 55.2                          |
| Cooper et al28         | United States, OW/OB, 38.4 ± 5.8          | Lifestyle + salt behavior intervention (79)/lifestyle intervention (79) | 12 mo | N, 117 dropped out              | U (24 h)                        | -805 ± 1851.5                         | -471.5 ± 1950.4                       |
| Comelio et al29        | Brazil, HTN women, 60.5 ± 11.2            | Salt behavior intervention (43)/usual care with general lifestyle intervention (49) | 3 mo     | Y (TPB and SE), 30.6% dropped out | U (24 h)                        | -624 ± 1189.5                         | -429 ± 1189.5                         |
| de Freitas Agondi et al30 | Brazil, HTN women, 59 ± 8                | Salt behavior intervention (49)/usual care, medical and nursing consultation (49) | 40 d     | Y (TPB & IS) 13 dropped out     | D (self-estimate)                | -1800 ± 3800                          | -400 ± 3756                           |
| Donner Alves et al31   | Brazil, HF (65% HTN), 58 ± 10             | Diet behavior + usual care (23)/usual care (23)         | 6 wk     | N, 1 dropout                    | D (FFQ)                         | -316 ± 23.7                           | -74 ± 86.5                            |
| Dorsch et al32         | United States, HTN, 56.6 ± 10             | Online diet and salt behavior app (24)/no app (26)      | 8 wk     | Y (TPB), SR and MDM             | D (FFQ)                         | -954 ± 2295.8                         | -123 ± 1854.4                         |
| Dunbar et al33a        | United States, HF (73.5% HTN), 56.7 ± 11.1| Patient-family lifestyle behavior (30)/informational brochure and usual care (29) | 8 mo     | Y (SD), 81.8% adherence         | U (24 h)                        | -433 ± 2095.7                         | -359 ± 2113.3                         |

(continued)
| Reference | Location, participants, age, mean ± SD (y) | Intervention/control characteristics (no. of participants) | Duration | Theory-driven, no/yes (method), compliance | Measured: urine, diet, or behavior (method) | Intervention changes from baseline, mean ± SD (mg/d) | Control changes from baseline, mean ± SD (mg/d) |
|-----------|------------------------------------------|------------------------------------------------|----------|------------------------------------------|----------------------------------|------------------------------------------------|----------------------------------|
| Dunbar et al 33b | United States, HF (73.5% HTN), 55.1 ± 10.2 | Patient-family lifestyle behavior + family partnership (30)/informational brochure and usual care (29) | 8 mo | Y (SD), 87.9% adherence | D (3DFR) U (24 h) | -508 ± 1225.7 (n = 25) -893 ± 1714.3 | -23 ± 696 (n = 14.5) -359 ± 2131.3 (n = 14.5) |
| Espeland et al 34 | United States, HTN, 60–79 | Lifestyle and sodium reduction behavior (127)/usual care (273) | 4 mo | N | D (24 h recall) U (24 h) | -1042.2 ± 1040.1 -844.1 ± 1541.7 | -163.3 ± 1826.7 62.1 ± 1317.3 |
| Eyles et al 35 | New Zealand, CVD (elevated BP), 67 ± 7 | Online salt behavior app (32)/usual care (32) | 4 wk | N, 1 dropout | U (spot) B | -91 ± 544.9 | 241 ± 544.9 |
| Ferrara et al 36 | Italy, HTN, 56.2 ± 10 | Lifestyle and HTN behavior (94)/usual care (94) | 12 mo | N, 12 dropouts | D (FFQ) | -835 ± 761.4 | -106 ± 541.5 |
| Francis and Taylor 37 | United States, women, aged 54–83 | Dietary behavior (28)/mailed handout, instructions for 3DFR (30) | 3 mo | Y (SMT), 91.4% completion | D (3DFR) | -432 ± 849.4 (n = 25) | -197 ± 726.4 (n = 24) |
| He et al 38 | China, family of schoolchildren, 43.8 ± 12.2 | Salt behavior (278)/no intervention (275) | 3.5 mo | N, 21 lost to follow-up | U (24 h) | -841 ± 1809.8 | 303.6 ± 1829.17 |
| Huang et al 39 | China, hemodialysis and HTN, 55.1 ± 0.1 | Salt, BP, and medication self-management (46)/usual care and routine health education (44) | 5 wk | N, 4 dropouts | D (FFQ) | -1700 ± 1800 | 100 ± 539 |
| Humalda et al 40 | Netherlands, CKD, 58.2 ± 13.2 | Online web-based salt self-management intervention, and usual care (40)/C: usual care (40) | 3 mo | Y (SR), 5 dropouts | U (24 h) | -922.3 ± 1218.052 | -351.9 ± 1301.34 |
| Jahan et al 41 | Bangladesh, HTN, 46.4 ± 8.3 | Online and in-person lifestyle behavior and DASH diet (204)/control: in-person materials (208) | 5 mo | N, 98% | U (24 h) B | -70.2 ± 1173.9 | -245.7 ± 1201.2 Improvement in no. of days with ≤6 g daily salt intake in both groups |
| Kaur et al 42 | India, 35–70 | Online SMART Eating intervention (366)/pamphlets on nutrition education (366) | 6 mo | Y, P-P, 91.3% | D (FFQ) | -404.02 ± 622.25 | -203.06 ± 847.23 |
| Kitaoka et al 43 | Japan, high normal, stage 1 or 2 HTN men, 66.2 ± 5.45 | Diet and salt education and individualized feedback (38)/no education (26) | 5 mo | N, 1 dropout | U (spot) B | -1833 ± 3985.6 | -2400 ± 3997.3 Reducing intake of salty food and preserved vegetables |
| Kumanyika et al 44 | United States, OW adults, 44.2 | Diet and salt education and counseling (582)/usual care (577) | 6 mo | N, 56%–90% attendance | U (24 h) | -1736.5 ± 1874.5 | -563.5 ± 2387.4 |
| Layeghiasl et al 45 | Iran, salt intake ≥5 g/d, 36.4 ± 7.6 | Salt education and counselling (63)/usual care (63) | 4 wk | Y, SMA and RT | U (spot) | -1173.9 ± 928.2 | 70.2 ± 327.6 (continued) |
| Reference | Location, participants, age, mean ± SD (y) | Intervention/control characteristics (no. of participants) | Duration | Theory-driven, no/yes (method), compliance | Measured: urine, diet, or behavior (method) | Intervention changes from baseline, mean ± SD (mg/d) | Control changes from baseline, mean ± SD (mg/d) |
|-----------|---------------------------------------------|-------------------------------------------------------------|----------|------------------------------------------|-------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| Li et al⁴⁶ | China, 56% HTN, 55 ± 15 | Salt and disease community-based education and availability of salt substitutes (975)/usual care (928) | 18 mo | N | U (24 h) 8 | Final: 5451 ± 2231 | Final: 5773 ± 2162 Increase in salt substitute use; more likely to know the salt recommendations and modify intake⁸ |
| Lin et al⁴⁷ | United States, HTN, 60.5 ± 11.1 | Lifestyle behavior and DASH diet (141)/usual care (140) | 6 mo | Y (SCT), 91% completion D (FFQ) | U (24 h) | −234 ± 902 | −217 ± 792 (n = 105) |
| Meuleman et al⁴⁸ | Netherlands, Decreased kidney function and HTN, 55.6 ± 11.7 | Salt education, consultation, self-monitoring and personalized feedback + regular care (67)/usual care (71) | 3 mo | Y (SR), 26% dropout | U (24 h) | −485.3 ± 1681.1 (n = 67) | 211.6 ± 1681.1 (n = 71) |
| Miura et al⁴⁹ a | Japan, HTN, 62 ± 10 | Lifestyle education and personalized counseling (18)/usual care (19) | 24 wk | Y (BT and SCT) | U (spot) | −759 ± 1104 | 414 ± 966 (n = 9.5) |
| Miura et al⁴⁹ b | Japan, HTN, 62 ± 10 | Lifestyle modification action plan (20)/usual care (19) | 24 wk | Y (BT and SCT) | U (Spot) | −598 ± 1472 | 414 ± 966 (n = 9.5) |
| Nakano et al⁵⁰ | Japan, HTN, 58.7 ± 13.4 | Personalized salt education and plan (51)/usual nutrition education (44) | 3 mo | N, 2 dropped out | U (24 h) | −702 ± 1205.5 | 195 ± 1252.1 |
| Ndanuko et al⁵¹ | Australia, OW/ OB 25–54 | Personalized advice based on ADG (62)/usual dietary advice (67) | 3 mo | N | U (24 h) | 2.3 ± 1600.8 | −598 ± 1858.4 |
| Petersen et al⁵² | Australia, T2DM (76% HTN), 62.9 ± 10.8 | Salt and label education (39)/no education (39) | 3 mo | N, high adherence | D (24 h) | −63 ± 249 | −701 ± 190 |
| Philipson et al⁵³ | Sweden, CHF, 74 ± 8 | Salt recommendation and individualized counseling (17)/general dietary advice (13) | 12 wk | N | U (24 h) | 23 ± 345 | 138 ± 322 |
| Pisani et al⁵⁴ | Italy, CKD 58.8 ± 12.06 | Diet education and individualized low-protein dietary tips (27)/control: standard nonindividualized low-protein diet material (27) | 6 mo | N, 3 lost to follow-up | U (24 h) | −418.6 ± 2093.9 | 103.5 ± 2089.1 |
| Sevick et al⁵⁵ | United States, hemodialysis, 51–70 | Hemodialysis diet and salt education and counseling + technology-based sodium tracking (93)/hemodialysis diet education (86) | 16 wk | Y (SCT), 14 withdrawals | D (24 h) | 59 ± 1483 | 131 ± 993 |
| Shahnazari et al⁵⁶ | United States, with or without condition, 49–59 | Individualized nutrition education + diet behavior coaching (28)/individualized nutrition education (22) | 6 mo | N, 9 dropped out; 6 dropped out | D (FFQ) | −1030 ± 1023.8 (n = 28) | −300 ± 810.2 (n = 22) |

(continued)
| Reference     | Location, participants, age, mean ± SD (y) | Intervention/control characteristics (no. of participants) | Duration | Theory-driven, no/yes (method), compliance | Measured: urine, diet, or behavior (method) | Intervention changes from baseline, mean ± SD (mg/d) | Control changes from baseline, mean ± SD (mg/d) |  |
|---------------|-------------------------------------------|-------------------------------------------------------------|----------|---------------------------------------------|---------------------------------------------|------------------------------------------------|------------------------------------------------|---|
| Shamsi et al  | Iran, HTN, 58.28 ± 7.16                   | Lifestyle education and consultation (25)/usual care (25)  | 4 mo     | Y, CCM, no dropouts                         | U (not specified)                           | −810 ± 883.09                                  | −80 ± 870.76                                  |   |
| Takashashi et al | Japan, 56.3 ± 7.7                         | Tailored community-based dietary intervention (231)/observation only (239) | 10 mo    | N, 7 dropped out                             | D (FFQ)                                     | −384 ± 1973.5                                  | 255 ± 1984.2                                  | (n = 96)|
| Towfighi et al | United States, stroke and IA, 57 ± 8.7   | Culturally tailored chronic disease self-management and counselling plus usual care (241)/control: usual care (246) | 12 mo    | Y, CCM, 85% completion                       | B                                           | B                                             | Significant reduction in salted-food intake   |   |
| Veroff et al  | United States, HF, 79.9 ± 8.6             | HF information, fact sheet DVD and booklet (1170)/basic written materials only (1269) | 4 wk     | N                                            | B                                           | Intervention group more likely to follow a low-sodium diet |   |
| Welsh et al   | United States, HF, 59.2 ± 8.3             | Salt education, advice and counseling (27)/usual care (25) | 6 mo     | Y (TPB), 12 did not complete                 | D (3DFR)                                    | −618 ± 1180 (n = 15)                           | 97 ± 834.5 (n = 17)                          | More positive attitude in the intervention group about following a low-sodium diet. |
| Williams et al| Australia, OW/OB men, 39.8 ± 5.0         | Family-based lifestyle intervention (48)/waitlist control (45) | 3 mo     | N, 95% attendance                            | D (FFQ)                                     | −471 ± 890.7                                  | −57 ± 821.4                                  |   |
| Zhang et al   | China, >18                                 | Government-led community lifestyle initiative (17 684)/nonpracticing communities (13 115) | 24 mo    | N                                            | B                                           | Participants were more likely to know the limit of salt consumption and more likely to modify consumption. |   |

*Additional information extracted from a study by Ma et al.64

Abbreviations: 3DFR, 3-day food record; ADG, Australian Dietary Guidelines; B, behavior; BP, blood pressure; BT, behavior theory; CCM, social cognitive theory; CHF, congestive heart failure; CKD, chronic kidney disease; CVD, cardiovascular disease; D, diet; DASH, Dietary Approach to Stop Hypertension; FR, food record; FFQ, food frequency questionnaire; HF, heart failure; HTN, hypertension; IIS, Implementation Intention Strategy; MDM, mindful decision-making; N, no; OB, obesity; OW, overweight; P-P, precede-proceed; RT, randomised trial; SD, self-determination; SE, self-efficacy; SCT, social cognitive theory; SMA, social marketing assessment; SMT, social marketing theory; SR, self-regulation; T2DM, type 2 diabetes mellitus; TPB, theory of planned behavior; U, urine; Y, yes.
behavior changes reported. One study indicated improvement in the self-reported number of days with <6 g salt intake in both the behavior change intervention and control groups.42

Salt intake was measured in 40 of the 46 CTs (Table 2). Urinary sodium changes were reported in 32 trials (11 studies reported both dietary sodium and urinary sodium measurements), and dietary sodium changes were reported in 19 trials. Of the trials in which urinary sodium measurements were recorded, 5 trials reported spot urine, 1 did not specify the urine sodium measurements, and the remainder used 24-hour methods of urinary collection for sodium measurement. Overall, 36 CTs reported a reduction in salt intake after the behavior change intervention. Two studies21,51 reported an increase in salt intake in the intervention group, and another 2 studies52,65 had conflicting results, with a reported reduction in dietary sodium but an increase in urinary sodium after the behavior change intervention.

Quasi-experimental studies

Thirteen quasi-experimental studies (2 of 15 trials had 2 eligible trials) were included in this systematic review. The characteristics of studies are presented in Table 365–77 (in Table S2 in the Supporting Information online). Participants were aged between 18 and 84 years. Interventions had a duration of between 4 weeks and 5 years. The majority of studies (n = 11) included healthy adults as participants or did not recruit participants on the basis of an existing health condition.

Eight quasi-experimental studies had good methodological quality, achieving a Rosendal score of ≥60%16 (Table S3 in the Supporting Information online). These studies generally also had a medium risk of bias, based on the Cochrane risk of bias tool (Table S4 in the Supporting Information online). The highest Rosendal score of 73% was achieved by the Land et al.66 study.

Six studies were theory driven and included theories such as communication for behavioral impact framework (n = 2), behavior change and cognitive theory (n = 1), behavior modification and social learning theory (n = 1), principals of behavior change (n = 1), and the theory of reasoned action (n = 1).

A face-to-face approach was the main method of intervention delivery for 6 studies.66–71 A mixture of individual, group, or combination of both individual and group sessions was used. Four studies used technologies to deliver the intervention, including computer-tailored support72; the MyFitnessPal application to record sodium content and feedback73; weekly web-based educational newsletters and text messages74; and a mass-media campaign to increase salt awareness.75 Three studies use different labelling techniques76–78 to promote and evaluate salt awareness and behavior change (Table 3).

Salt-related behavior was reported in 9 of the 13 included studies (Table 3). Significant improvements in salt-use behavior were reported in all 9 studies after the behavior change intervention compared with baseline. A significant reduction in adding salt to cooking and at the table was reported in 3 studies,67,74,75 a positive change in attitudes toward salt and habits was reported in 2 studies,71,72 and selection of lower-sodium products and meals,63,76–78 and eating-out behaviors as well as an increase in spice intake, salt substitute, and label reading were reported in 2 studies.64,66

Salt intake was reported in 7 studies (n = 9 trials) (Table 3). Dietary sodium changes were reported in 2 trials and urinary sodium changes in 7 trials. Almost all (n = 8 of 9) trials reported a reduction in salt intake after the behavior change intervention compared with baseline. One study23 had 2 trials, with 1 using technology for monitoring salt intake and receiving feedback reporting a reduction in sodium intake. The other trial used a paper tally for estimating salt intake and provided education on using the MyPlate diagram, but the authors observed no reduction in salt intake.

Meta-analysis of controlled trials

Urinary sodium (measured by urinary excretion) Thirty-two CTs reported changes in salt intake via assessment of urinary sodium excretion (n = 7840). Mean baseline urinary sodium excretion was 4317.76 mg/d (95% CI, 320.71–5114.82). Behavior change interventions significantly reduced urinary sodium excretion (MD, −486.19 mg/d; 95% CI, −669.44 to −302.95; P < 0.001; I² = 92%), equivalent to an approximate 12% reduction below baseline urinary sodium levels (Figure 2).21,23,26–35,38 In 9 trials, spot urine was used for measuring sodium excretion. Excluding these trials from the meta-analysis did not alter the magnitude or overall direction of the effect (n = 23; MD, −464.35 mg/d; 95% CI, −692.31 to −236.39; I² = 86.9%).

Nine studies were identified as outliers.36,38,41,44,45,47,51,52 Excluding these studies reduced the heterogeneity of the analysis to 34.4% but did not alter the magnitude or overall direction of the effect (MD, −558.80 mg/d; 95% CI, −702.32 to −415.28; P < 0.001). Results of Baujat plot and influence analyses (Figure S1 and S2 in the Supporting Information online) suggested that the overall meta-analysis was sensitive to the studies by Kumanyika et al.44 and Layeghiash et al.45 Excluding these studies individually reduced the heterogeneity but did not alter the magnitude or direction of the effect (MD, −451.03 [95% CI, −624.48 to
Table 3 Characteristics of included quasi-experimental studies

| Reference          | Location, participants, age, mean ± SD (y) | Intervention/control characteristics (no. of participants) | Duration | Theory-driven no/yes (method), compliance | Measured urine/diet/behavior (method) | Intervention changes from baseline, mean ± SD (mg/d) |
|--------------------|-------------------------------------------|-------------------------------------------------------------|----------|-------------------------------------------|--------------------------------------|---------------------------------------------------|
| Byrd, et al65      | United States, adults, ≥ 21               | Online menu nutrition information experiment: calorie (127); calorie + numeric sodium (139); calorie + sodium warning (115); no labelling (139) | One-off  | N                                        | B                                    | Calorie + numeric sodium was associated with lower-sodium meals selection but only in those believing lower-sodium and lower-calorie foods are tasty. −822.2 ± 2177.5 |
| Do, et al66        | Vietnam, 45.3 ± 11.8                      | Salt, community-based behavioral intervention (88)7          | 12 mo    | Y (COMBI)                                 | U (spot)                            | Improvement in salt reduction behavior (added salt or sauces when cooking or at the table and processed food intake) |
| Fujii, et al67     | Japan, 43.5 ± 10.1                        | Online, web-based, computer-tailored lifestyle and salt intervention (650) | 4 mo     | Y, (PBC), 28.5% completed                 | B                                    | Improvements if low-salt intake in women. Preferable effect on stage of change about low-salt intake and self-efficacy of low-salt intake in men. |
| Goodman, et al68   | Canada, ≥ 18                              | Front of packaging sodium labeling information experiment: basic numeric (99); numeric with high or low sodium (84); detailed (84) or simple traffic light (81)/no label (82) | One-off  | N                                        | B                                    | Front of package labels with high- or low-sodium content descriptors and detailed TL were more effective |
| Ipjian and Johnston69a | United States, 35.5 ± 14.9                | Online app-based salt-reduction intervention (15)            | 4 wk     | N, 92% adherence                          | U (spot)                            | −838 ± 1093                                      |
| Ipjian and Johnston69b | United States, 33.3 ± 16.8               | Hard-copy educational materials on salt reduction and food diary (15) | 4 wk     | N, 82% adherence                         | U (spot)                            | 236 ± 1333                                      |
| Ireland, et al70a  | Australia, 57.2 ± 12.9                    | Salt food list and label (HF tick symbol) education (22)    | 8 wk     | N                                        | U (24 h)                            | −345 ± 1128.1                                   |
| Ireland, et al70b  | Australia, 54.9 ± 11.1                    | Salt food list and FSANZ guideline on choosing low-salt based on label (21) | 8 wk     | N                                        | U (24 h)                            | −782 ± 1098.2                                   |
| Khokhar, et al71   | Australia, 41.0 ± 7.0                     | Online, web-based salt behavior intervention (73)            | 5 wk     | Y (BCT and CT)                           | B                                    | Higher frequency of engaging in salt-reduction behavior, including reduced addition of salt during cooking and at the table |
| Khosravi, et al72  | Iran, 36.34 ± 13.14                       | Healthy lifestyle, community-based trial (374)               | 5 y      | NA                                       | D                                    | −1860                                            |
| Land, et al73      | Australia, ≤ 20                           | Salt reduction, community-based intervention + FoodSwitch app (572) | 18 mo    | Y (COMBI), low response                  | U (24 h)                            | −312 (95%CI, −483.6, −132.6) Reduction in eating out, increase in spice use but also a reduction in label reading. |
Table 3 Continued

| Reference          | Location, participants, age, mean ± SD (y) | Intervention/control characteristics (no. of participants) | Duration       | Theory-driven no/yes (method), compliance | Measured urine/diet/sodium (method) | Intervention changes from baseline, mean ± SD (mg/d) |
|--------------------|--------------------------------------------|-------------------------------------------------------------|----------------|-------------------------------------------|------------------------------------|---------------------------------------------------|
| Robare, et al⁷⁴    | United States, older adults, 75.1 ± 53    | Lifestyle and diet (DASH) intervention and counseling (103) | 10 wk          | Y (BM and SLT)                           | N                                  | −138 (95% CI, −132.0, 186.3)                      |
| Scourboutakos, et al⁷⁵ | Canada, adults 20–69                    | Restaurant menu labeling experiment: calorie; sodium; calorie + sodium + serving size (3080) | One-off | N                                      | U (24 h)                           | Calorie + sodium, ordered meals containing less sodium |
| Wang, et al⁷⁶      | United States, Met-S, 20–52 ± 10         | AHA diet and lifestyle guidelines (92)                      | 12 mo          | N, 27 not completed                     | D (24 h)                           | −648 ± 105.9                                      |
| Wentzel-Viljoen, et al⁷⁷ | South Africa, 18–55                     | Online, mass media awareness campaign on salt intake, blood pressure, and CVD (477) | 6 mo           | Y (TRA)                                 | B                                  | Improvement in salt attitude improvement in salt reduction behavior including reduced addition of salt during cooking and at the table |

Abbreviations: AHA, American Heart Association; B, behavior; BCT, behaviour change theory; BM, behavior modification; COMBI, Communication for Behavioral Impact; CT, cognitive theory; CVD, cardiovascular disease; D, diet; DASH, Dietary Approach to Stop Hypertension; FSANZ, Food Standards Australia New Zealand; N, no; SLT, social learning theory; TRA, theory of reasoned action; Met-S, metabolic syndrome PBC, principles of behavioral change; U, urine; Y, yes.
Meta-regression analysis demonstrated that the effectiveness of the behavior change intervention was not associated with study methodology quality ($Q = 1.36; P = 0.24$) (Figure S7 in the Supporting Information online) or baseline dietary sodium intake ($Q = 2.79; P = 0.09$) (Figure S8 in the Supporting Information online). A subgroup analysis of studies with Rosendal quality scores <60% and a high risk of bias, compared with studies with higher quality and lower risk of bias, also did not reveal a significant difference (between-group $Q = 0.04; P = 0.83$). Subgroup analysis suggested a smaller reduction in dietary sodium intake in trials that reported using a theory to guide their intervention design, compared with those that did not (MD, −187.74 mg/d vs −491.99 mg/d) (Table 3), but the test for subgroup difference was not statistically significant ($Q = 3.71; P = 0.05$) (Table 4). The reduction in dietary sodium intake observed across the subgroup of trials with the majority of participants having high baseline BP did not differ significantly from that of participants in trials not focused on this population. Similarly, the reduction in dietary sodium intake was not different based on disease status (Table 4). Only 1 of the CTs reported using online methods to deliver the intervention. Excluding this study42 did not change the magnitude or direction of the weighted mean effect ($n = 18$; MD, −421.61; 95% CI, −621.66 to −221.56; $I^2 = 95.5\%$) (Table 4).

**DISCUSSION**

The findings of this systematic review and meta-analysis suggest behavior change interventions can be effective in reducing dietary salt intake. A mean reduction of approximately 10%–13% of baseline salt intake can be expected from behavior change interventions focusing on salt reduction. This is an improvement with appreciable public health implications, because reducing salt intake by approximately 2 g/d can lead to a 35% reduction in the incidence of hypertension.79 A 1 g/d reduction in salt intake is estimated to prevent approximately 5000 heart attacks and strokes, saving >1300 lives and >$120 million in health care and societal costs in Australia.80 Reducing salt intake to the
recommended intake of 5 g/d to reduce the risk of hypertension and cardiovascular incidents is estimated to prevent 2.5 million deaths globally each year.5

The behavior change interventions we reviewed were heterogeneous, incorporating a range of different components and behavior change techniques. It was not possible, therefore, to evaluate the effectiveness of individual components and techniques (and specific combinations of these). In general, the methods used included group and/or individual consultation or education sessions delivered in either face-to-face or online, the promotion of self-monitoring and goal setting, reinforcement using a variety of modes (ie, email, phone, text, in-person follow-ups), newsletters and handouts, recipes, and food recording or tracking (paper or application based).

The majority of behavior change interventions reviewed were delivered during face-to-face sessions. Eleven interventions (included in 5 CTs, 4 pre-post interventions, and 2 experimental studies) used online methods of delivering content and were also successful in improving salt-related behavior. The majority of these studies were able to achieve high levels of engagement and compliance through the use of smartphone applications (ie, SaltSwitch, MyFitnessPal), websites, and online communication tools,32,35,40,41,73 in addition to traditional education sessions, materials, goal setting, and follow-ups. Overall, subgroup analysis in the present study revealed no significant difference in the effectiveness of face-to-face and online interventions in reducing urinary sodium excretion. Traditional in-person methods of intervention delivery require the physical presence of participants, have limited reach, and are difficult to implement at the population level. Given the increasing number of internet users and individuals with access to computers and smartphones globally,81 online behavior change interventions may provide an effective, low-cost alternative or supplemental intervention with a wide reach.82,83 Thus, there is a need for research investigating the effectiveness of online interventions to effect salt reduction behavior change at a population level.

We did not find significant differences between subgroups that reported and those that did not report using a behavior change theory to guide their intervention development. However, behavior change interventions that are underpinned by theories or frameworks are generally reported to have a better engagement and adherence, with even small adjustments in health behaviors resulting in considerable improvements in health outcomes.84 They may also be more effective in reducing risky health behaviors.85 It is possible that authors of some of the studies included in this systematic review may have used, but did not report using, behavior change theories or frameworks when designing their interventions (n = 30). Others appear to have “inadvertently” used evidence-based behavior change techniques. Indeed, all studies implemented at least 1 behavior change technique (most commonly self-monitoring, feedback, goal setting, support, and problem solving), and these techniques were typically underpinned by behavior change theories or frameworks.

We also did not find a significant difference in the effectiveness of salt-reduction behavior change interventions focusing on adults with elevated BP and
studies that did not exclusively include participants with elevated BP. High adherence and completion rates were also reported in both groups. Dietary changes and salt reduction are priorities for adults with hypertension who are attempting to manage BP and prevent further CVD. One might anticipate higher motivation and intention to change salt behavior in this population. Conversely, findings from this study suggest that behavior change interventions may be similarly effective in reducing salt intake by adults with hypertension and those who are normotensive. These interventions could have utility, therefore, in the prevention of hypertension and CVD at a broad public health level. Similarly, subgroup analysis conducted in this study did not indicate a significant difference in the effectiveness of salt-reduction behavior change interventions on the basis of the disease status of participants. These findings suggest that behavior change interventions can be effective at reducing salt intake irrespective of participants’ health status and thereby have the potential to make an important contribution to improving public health.

A major strength of this systematic review and meta-analysis was that it included a large number of behavior change interventions and experiments designed to reduce salt intake. As such, findings from this study provide guidance for the design of future public health policies and interventions aimed at reducing salt intake. This study does have some limitations. A high degree of heterogeneity was observed in the meta-analysis outcomes. A few studies were identified as the source of this, and excluding these sources improved heterogeneity slightly. Although a random-effects model was used, the existing heterogeneity may have influenced the magnitude of the effect. Also, there was a limited number of studies in which researchers used online internet or app-based behavior change interventions. This limited our interpretation of findings related to these types of interventions.

CONCLUSION

The findings from this systematic review and meta-analysis suggest that behavior change interventions are effective at improving salt use behavior and reducing salt intake. Reductions in salt purchasing and use of salt in cooking, and improvements in label reading, choosing lower-salt options, and using a salt substitute can be expected from these interventions. A reduction of approximately 10%–13% of the baseline salt intake (>1g/d salt) regardless of individual BP status may be expected from salt behavior change interventions. Online interventions can be as effective as face-to-face interventions, which can offer an innovative way of promoting salt reduction on a larger scale that does not require physical presence of participants. Although a 10%–13% reduction in salt intake is meaningful, future interventions and government policies may need behavior change interventions combined with industry regulations and awareness-raising campaigns to achieve the target salt intake of 5g/d at a population level and reduce the associated morbidity and mortality.

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Supporting Information

The following Supporting Information is available through the online version of this article at the publisher’s website.

Table S1 An example of search strategy for MEDLINE (PubMed)

Table S2 Detailed characteristics of included salt intake studies

Table S3 Methodology quality assessment summary based on the Rosendal scale

Table S4 Cochrane risk-of-bias assessment

Appendix S1 R codes used in this meta-analysis

Figure S1 Baujat plot of the sensitivity of the overall urinary sodium meta-analysis to individual studies

Figure S2 Influence plot of the sensitivity of the overall urinary sodium meta-analysis to individual studies

Figure S3 Meta-regression of the effect of behavior change interventions on urinary sodium associated with the methodology quality of included studies

Figure S4 Meta-regression of the effect of behavior change interventions on urinary sodium associated with the baseline dietary sodium levels

Figure S5 Baujat plot of the sensitivity of the overall dietary sodium meta-analysis to individual studies

Figure S6 Influence plot of the sensitivity of the overall dietary sodium meta-analysis to individual studies

Figure S7 Meta-regression of the effect of behavior change interventions on dietary sodium associated with the methodology quality of included studies

Figure S8 Meta-regression of the effect of behavior change interventions on dietary sodium associated with the baseline dietary sodium levels

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