Lead Article

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 (eg, 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]; $P < 0.001$; $I^2 = 92\%$) and dietary sodium in 19 trials (N = 3750 participants; mean difference –399.86 mg/d [95%CI, –581.51 to –218.20]; $P < 0.001$; $I^2 = 96\%$), 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 (ie, 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.* ***Systematic Review Registration:*** *PROSPERO registration no. CRD42020185639.*

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INTRODUCTION

Salt (sodium chloride) is one of the oldest ingredients for preserving food. Despite the introduction of refrigeration and other preservation techniques,[1] the food industry continues to use salt to reduce pathogen growth, to maintain color, and to enhance the taste and sensory attributes of foods.[1] 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.[2] The daily sodium requirement to maintain these functions is very low (<500 mg)[2,3] 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,[4] almost twice the World Health Organization recommended limit of 2000 mg (2 g sodium or 5 g salt) per day.[5]

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]).[3,6] 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.[7] Thus, high sodium intake is a product of multiple factors, including lifestyle and genetic predisposition, it is a major contributor to hypertension and CVD.[8,9] In fact, approximately 10% of all CVD-related deaths worldwide annually (~1.8 million lives) can be attributed to excess sodium consumption.[9]

Different behavioral strategies, including face-to-face and online (app or internet-based) interventions have been developed to reduce salt intake.[10] 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.[10] 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.

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[11] 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

Table 1 **PICOS criteria used to define research questions**

Parameter	Description
Population	Adult men or women
Intervention	Any of education, health education, internet-based intervention, online, website, Internet, mobile application, user-computer interface, telemedicine, lifestyle intervention, risk reduction behavior, behavior therapy, healthy lifestyle, behavior change, life style
Comparison	Control or usual care
Outcomes	Any of sodium chloride, sodium, sodium, dietary, salt, salt intake
Setting/design	Any of intervention, trial, clinical trial, controlled clinical trial, randomized controlled trial, nonrandomized controlled trial

English, full-text format available. Studies in which general salt-intake behaviors (eg, intake of salty foods, changes in food choices) or salt (sodium) intake specifically (eg, 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 (ie, 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.[12] Given the biological variability in urinary sodium excretion[12] and bias in self-reporting dietary sodium intake,[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).[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 (ie, websites or smartphone apps). Studies that used telephone, messaging, email, or websites to deliver only part of the intervention (eg, 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.[15] Methodological quality of included studies was examined using the Rosendal scale[16] and the Cochrane risk-of-bias assessment tool[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.[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]:

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

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

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

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 I^2 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 $\geq 130/85$ 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 which3 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).

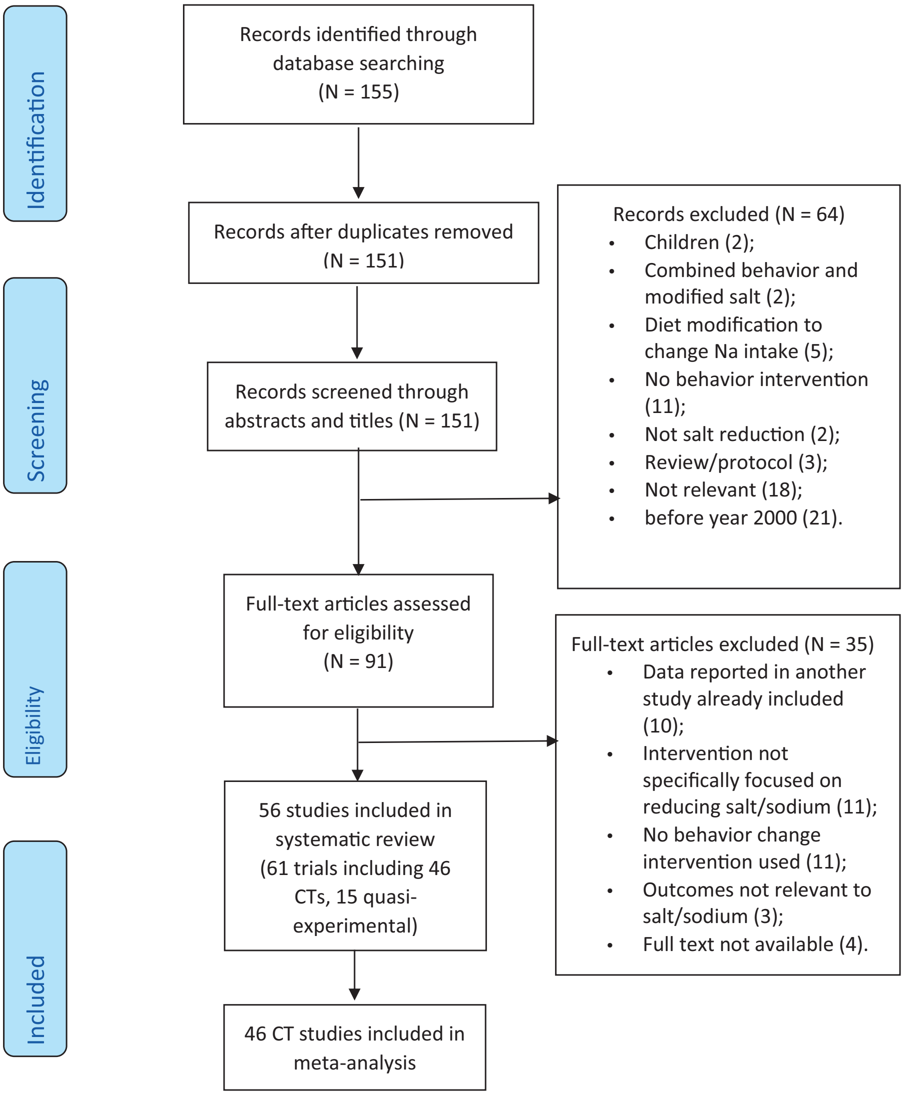

Figure 1 **Diagram indicating article selection process**. CT, controlled trial; Na, sodium.

Face-to-face delivery was the main method of intervention delivery in the majority of included CTs. Online interventions were used in 5 CTs.[32,35,40–42] 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[21,27] 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%),[28,29,56,60] and 1 study reported the 82% of participants completed the final assessment (at 12 months) but few completed the 6-month assessment.[25]

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[43,58,60] and reduction in the household purchase of salt,[35] use of salt in cooking,[29] self-reported intake,[59] and salt habits[44]; and increase in the purchase and use of salt substitutes[46] and a better attitude toward a low-sodium diet[61] were the

Table 2 **Characteristics of included controlled trials**

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 al[21]	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 al[22a]	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 al[22b]	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 al[23]	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 al[24]	Brazil, OW/OB, 41.1 ± 1.2	Lifestyle behavior (97[a])/usual care (95)	6 mo	N, 19.2% attrition	D (FFQ)	−371.5 ± 112.7	33.0 ± 109.1
Brown et al[25]	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 al[26]	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 Lee[27]	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 al[28]	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
Cornelio et al[29]	Brazil, HTN women, 60.5 ± 11.2	Salt behavior intervention (43)/usual care with general lifestyle information (49)	3 mo	Y (TPB and SE), 30.6% dropped out	U (24 h) B	−624 ± 1189.5 Improvement in salt self-efficacy, reduced habitual salt use in cooking	−429 ± 1189.5
de Freitas Agondi et al[30]	Brazil, HTN women, 59 ± 8	Salt behavior intervention (49)/usual care, medical and nursing consultation (49)	40 d	Y (TPB & IIS) 13 dropped out	D (self-estimate) U (24 h) B	−1800 ± 3800 −2000 ± 3345.6 Reduction in the measure of salt habit in both groups but more in intervention group	−400 ± 3756 −900 ± 2561.6
Donner Alves et al[31]	Brazil, HF (65% HTN), 58 ± 10	Diet behavior + usual care (23)/usual care (23)	6 wk	N, 1 dropout	D (FFQ) U (24 h)	−316 ± 237.1 −954 ± 2295.8	−74 ± 86.5 −123 ± 1854.4
Dorsch et al[32]	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) U (24 h)	−1553 ± 1764 −637 ± 1537	−515 ± 1081 −322 ± 1485
Dunbar et al[33a]	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	D (3DFR) U (24 h)	−789 ± 1424 (n = 29) −433 ± 2095.7 (n = 14.5)	−23 ± 696 (n = 14.5) −359 ± 2113.3 (n = 14.5)

(continued)

Table 2 **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 ± 2113.3 (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 Reduction in the mean household purchase of salt	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 Improvement in no. of days with <6 g daily salt intake in both groups	−245.7 ± 1201.2
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 ± 5.4[5]	Diet and salt education and individualized feedback (38)/no education (26)	5 mo	N, 1 dropout	U (spot) B	−1833 ± 3985.6 Reduction in consuming salty noodle soup and preserved vegetables	−2400 ± 3997.3
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)

Table 2 **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 al[46]	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) B	Final: 5451 ± 2231 Increase in salt substitute use; more likely to know the salt recommendations and modify intake[a]	Final: 5773 ± 2162
Lin et al[47]	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 −301.3 ± 1431 (n = 105)	−217 ± 792 −524.4 ± 1638 (n = 104)
Meuleman et al[48]	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 al[49a]	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 al[49b]	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 al[50]	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 al[51]	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 al[52]	Australia, T2DM (76% HTN), 62.9 ± 10.8	Slat and label education (39)/no education (39)	3 mo	N, high adherence	D (24 h) U (24 h)	−63 ± 249 23 ± 345	−701 ± 190 138 ± 322
Philipson et al[53]	Sweden, CHF, 74 ± 8	Salt recommendation and individualized counseling (17)/general dietary advice (13)	12 wk	N	U (24 h)	−345 ± 1126	−253 ± 1022
Pisani et al[54]	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 al[55]	United States, hemodialysis, 51–70	Hemodialysis diet and salt education and counselling + technology-based sodium tracking (93)/hemodialysis diet education (86)	16 wk	Y (SCT), 14 withdrawals	D (24 h)	59 ± 1483	131 ± 993
Shahnazari et al[56]	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)

Table 2 **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[57]	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[58]	Japan, 56.3 ± 7.7	Tailored community-based dietary intervention (231)/observation only (239)	10 mo	N, 7 dropped out	D (FFQ) U (48 h) B	−384 ± 1973.5 −406 ± −1794.6 (n = 96) Significant reduction in salted-food intake	255 ± 1984.2 583 ± 1894.6 (n = 95)
Towfighi et al[59]	United States, stroke and IA, 57 ± 8.7	Culturally tailored chronic disease self-management and counselling + usual care (241)/control: usual care (246)	12 mo	Y, CCM, 85% completion	B	Greater improvement in self−reported salt intake	
Veroff et al[60]	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[61]	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) B	−618 ± 1180 (n = 15) More positive attitude in the intervention group about following a low-sodium diet.	97 ± 834.5 (n = 17)
Williams et al[62]	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[63]	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.	

[a]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 reminder 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 studies[21,51] reported an increase in salt intake in the intervention group, and another 2 studies[52,65] 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 3[65–77] (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 methodology 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 alstudy.[66]

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 support[72]; the MyFitnessPal application to record sodium content and feedback[73]; weekly web-based educational newsletters and text messages[74]; and a mass-media campaign to increase salt awareness.[75] Three studies use different labelling techniques[76–78] 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 study[73] 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; $P < 0.001$; $I^2 = 92\%$), equivalent to an approximate 12% reduction below baseline urinary sodium levels (Figure 2).[21,22,26–35,38] 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; $I^2 = 86.9\%$).

Nine studies were identified as outliers.[26,27,38,41,44,45,47,51,52] 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 Layeghiasl 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 al[65]	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.
Do, et al[66]	Vietnam, 45.3 ± 11.8	Salt, community-based behavioral intervention (88)[2]	12 mo	Y (COMBI)	U (spot) B	−822.2 ± 2177.5 Improvement in salt reduction behavior (added salt or sauces when cooking or at the table and processed food intake)
Fujii, et al[67]	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 al[68]	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 Johnsto[69a]	United States, 35.5 ± 14.9	Online app-based salt-reduction intervention (15)	4 wk	N, 92% adherence	U (spot)	−838 ± 1093
Ipjian and Johnston[69b]	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 al[70a]	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 al[70b]	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 al[71]	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 al[72]	Iran, 36.34 ± 13.14	Healthy lifestyle, community-based trial (374)	5 y	NA	D	−1860
Land, et al[73]	Australia, ≤20	Salt reduction, community-based intervention + FoodSwitch app (572)	18 mo	Y (COMBI), low response	U (24 h) B	−312 (95%CI, −483.6, −132.6) Reduction in eating out, increase in spice use but also a reduction in label reading.

(continued)

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/behavior (method)	Intervention changes from baseline, mean ± SD (mg/d)
Robare, et al[74]	United States, older adults, 75.1 ± 5.3	Lifestyle and diet (DASH) intervention and counseling (103)	10 wk	Y (BM and SLT)	U (24 h)	−138 (95%CI, −132.0, 186.3)
Scourboutakos, et al[75]	Canada, adults 20–69	Restaurant menu labeling experiment: calorie; calorie + sodium; calorie + sodium + serving size (3080)	One-off	N	B	Calorie + sodium, ordered meals containing less sodium
Wang, et al[76]	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 al[77]	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.

−277.58], I^2 = 88%; and MD, −446.33 mg [95%CI, −616.59 to −276.08], I^2 = 90%, respectively).

Meta-regression analysis demonstrated that the effectiveness of the behavior change intervention was not associated with the quality of study methodology ($Q = 0.19$; $P = 0.65$) (Figure S3 in the Supporting Information online) or baseline urinary sodium concentration ($Q = 3.36$; P 0.06) (Figure S4 in the Supporting Information online). A subgroup analysis of studies with Rosendal quality scores <60% and a high risk of bias compared with studies of higher quality and low risk of bias did not reveal a significant difference (between-group $Q = 0.15$; $P = 0.70$). Subgroup analysis of studies that reported using behavior change theories or frameworks to guide the intervention did not result in a significantly different amount of urinary sodium excretion compared with those that did not use behavior change theories or frameworks ($Q = 0.93$; $P = 0.33$) (Table 4). The reduction in urinary sodium excretion observed across the subgroup of trials specifically enrolling participants with elevated or high baseline BP did not differ significantly from trials not specified to participants with high BP (Table 4). Similarly, the urinary sodium reduction in the subgroup of studies including participants with medical conditions was not statistically different from that including healthy adults (Table 4). Subgroup analysis based on the delivery method suggested no statistically significant differences in urinary sodium excretion between trials that primarily used a face-to-face method to deliver an intervention compared with those that used online methods of intervention delivery ($Q = 0.46$; $P = 0.49$; Table 4).

Dietary sodium (measured by dietary recalls) Nineteen CTs reported changes in salt intake as dietary sodium (n = 3750). Mean baseline dietary sodium intake was 3144.68 mg/d (95%CI, 2507.18–3782.19). Behavior change interventions resulted in a significant reduction in dietary sodium intake of sodium (MD, −399.86 mg/d; 95%CI, −581.51 to −218.20; $P < 0.001$; I^2 = 96%), which was equivalent to an approximate 13% decrease from baseline dietary sodium intake (Figure 3).[23–25,30,31,33,34,36,37,39,42,47,52,55,56,58,61,62]

Three studies were identified as outliers.[34,39,52] Excluding these studies reduced the heterogeneity of the analysis but did not alter the magnitude or direction of the overall effect (MD, −352.52 mg/d; 95%CI, −456.07 to −248.96; $P < 0.001$; I^2 = 80.2%). Results of Baujat plot and influence analyses suggested that the overall meta-analysis was sensitive to the Petersen et al[52] study (Figure S5 and S6 in the Supporting Information online). Excluding this study reduced the heterogeneity to 83% but did not alter the magnitude or

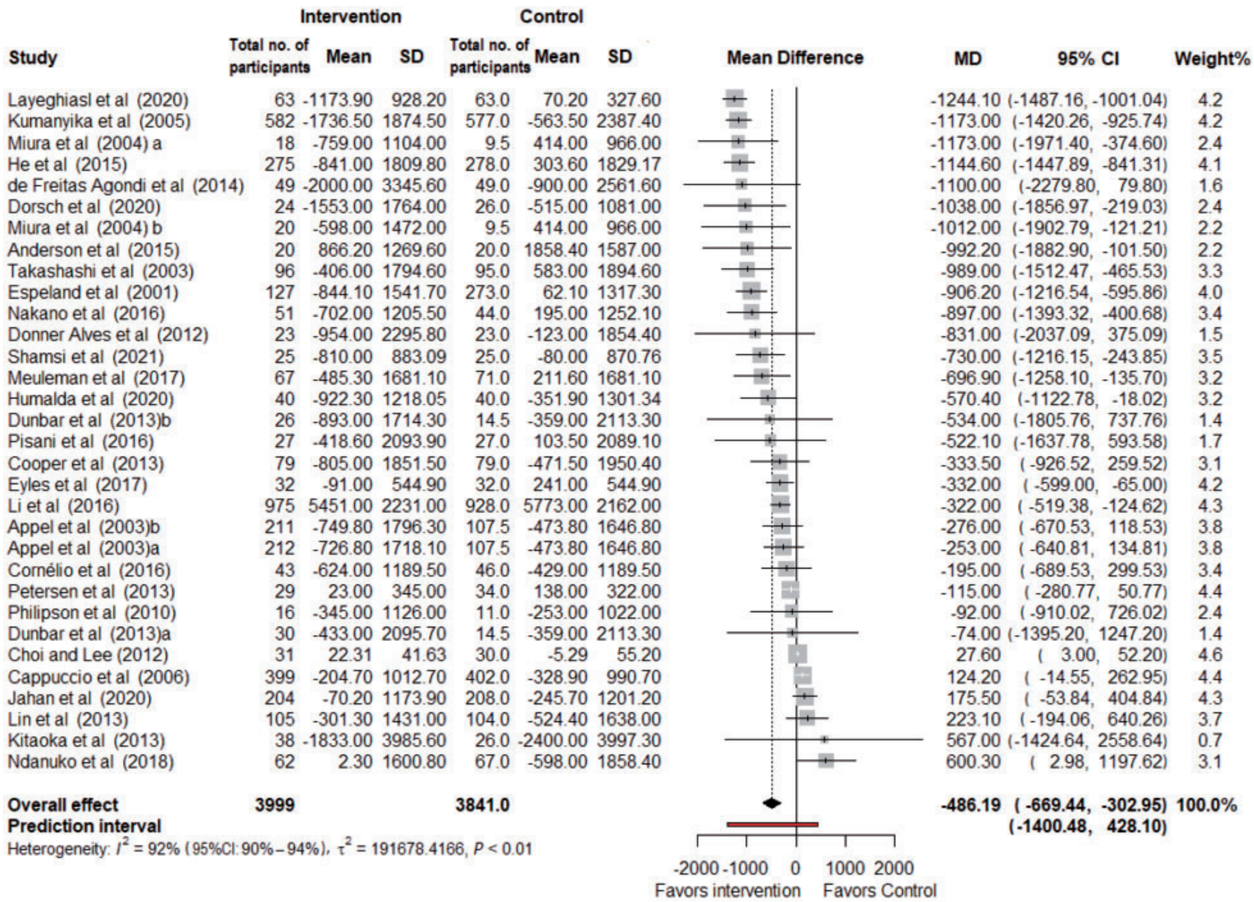

Figure 2 **Forest plot reporting the effect of behavior change interventions on urinary sodium excretion**. MD, mean difference.

direction of the effect (MD, −416.86 mg/d; 95%CI, −527.46, −306.26).

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 study[42] 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. The meta-analysis of CTs indicated that a reduction of >1 g of salt/d can be expected from these interventions. 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

Table 4 **Subgroup analyses of included behavior change interventions and their effect on dietary sodium intake and urinary sodium excretion**

Subgroup	Dietary sodium intake Mean difference, mg/d (95%CI), I^2, (no.)	Urinary sodium excretion Mean difference, mg/d (95%CI), I^2, (no.)
Theory driven		
Yes	−187.74 (−302.77, −72.70), 36.4%, (9)	−596.71 (−903.45, −289.96), 76.4%, (14)
No	−491.99 (−779.56, −204.41), 97.7, (10)	−411.51 (−628.08, −194.94), 92.9%, (18)
Test for subgroup difference	$Q = 3.71$, $P = 0.05$	$Q = 0.93$, $P = 0.33$
Elevated/high blood pressure		
Yes	−459.72 (−816.34, −103.11), 96.8%, (10)	−423.52 (−609.56, −237.45), 71.3%, (20)
No	−364.17 (−469.11, −259.24), 60.8%, (9)	−533.68 (−890.21, −177.16), 96.0%, (12)
Test for subgroup difference	$Q = 0.25$, $P = 0.61$	$Q = 0.29$, $P = 0.59$
Disease status[a]		
With health condition	−428.74 (−719.14, −138.35), 96.1% (13)	−382.63 (−547.17, −218.10), 81.0% (24)
Without health condition	−354.69 (−499.61, −209.76), 73.3% (5)	−761.18 (−1427.09, −95.26), 96.6% (6)
Test for subgroup difference	$Q = 0.09$, $P = 0.76$	$Q = 1.17$, $P = 0.28$
Main delivery method		
Online (web/app based)	NA[b]	−338.30 (−783.62, 107.01), 81.5% (4)
Face-to-face	−421.61 (−621.66, −221.56), 95.5%, (18)	−508.92 (−715.00, −302.85), 92.6%, (28)
		$Q = 0.46$, P- value $= 0.49$

[a]Three studies[38,51,56] were excluded from this subgroup analysis because they included participants regardless of their health conditions.
[b]Only 1 study was included in this subgroup.
Abbreviation: NA, not applicable.

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 heterogenous, 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

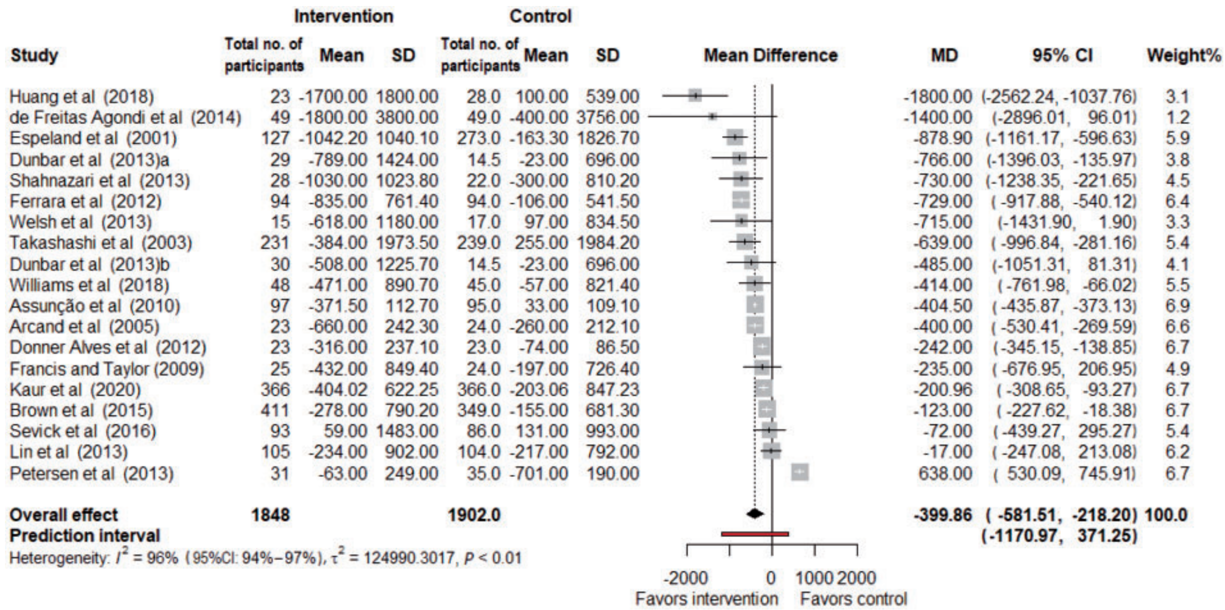

Figure 3 **Forest plot reporting the effectiveness of behavior change interventions on dietary sodium intake.**

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.[86] 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 (>1 g/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 5 g/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**

REFERENCES

1. Boon CS, Taylor CL, Henney JE. Strategies to Reduce Sodium Intake in the United States. Washington, DC: National Academies Press; 2010.
2. Strazzullo P, Leclercq C. Sodium. *Adv Nutr.* 2014;5:188–190.
3. Farquhar WB, Edwards DG, Jurkovitz CT, et al. Dietary sodium and health: more than just blood pressure. *J Am Coll Cardiol.* 2015;65:1042–1050.
4. Powles J, Fahimi S, Micha R, et al.; on behalf of the Global Burden of Diseases Nutrition and Chronic Diseases Expert Group (NutriCoDE). Global, regional and national sodium intakes in 1990 and 2010: a systematic analysis of 24 h urinary sodium excretion and dietary surveys worldwide. *BMJ Open*. 2013;3:e003733.
5. World Health Organization. Salt reduction. 2020. Available at: https://www.who.int/news-room/fact-sheets/detail/salt-reduction. Accessed August 2020.
6. Grillo A, Salvi L, Coruzzi P, et al. Sodium intake and hypertension. *Nutrients.* 2019;11:1970. doi:10.3390/nu11091970.
7. World Health Organization. Cardiovascular diseases (CVDs) [Fact sheet]. World Health Organization; 2017. Available at: https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds). Accessed July 2020.
8. Lloyd-Jones DM, Hong Y, Labarthe D, et al. Defining and setting national goals for cardiovascular health promotion and disease reduction: the American Heart Association's strategic impact goal through 2020 and beyond. *Circulation.* 2010;121:586–613.
9. Mozaffarian D, Fahimi S, Singh GM, et al.; Global Burden of Diseases Nutrition and Chronic Diseases Expert Group. Global sodium consumption and death from cardiovascular causes. *N Engl J Med.* 2014;371:624–634.
10. Trieu K, McMahon E, Santos JA, et al. Review of behaviour change interventions to reduce population salt intake. *Int J Behav Nutr Phys Act.* 2017;14:17.
11. Page MJ, Moher D, Bossuyt PM, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ.* 2021;372:N160.
12. Lerchl K, Rakova N, Dahlmann A, et al. Agreement between 24-hour salt ingestion and sodium excretion in a controlled environment. *Hypertension.* 2015;66:850–857.
13. Subar AF, Freedman LS, Tooze JA, et al. Addressing current criticism regarding the value of self-report dietary data. *J Nutr.* 2015;145:2639–2645.
14. National Health and Medical Research Council. Nutrient reference values for Australia and New Zealand: Sodium. Available at: https://www.nrv.gov.au/nutrients/sodium. Accessed June 2021.
15. Higgins JPT, Thomas J, Chandler J, Cumpston, et al. *Cochrane Handbook for Systematic Reviews of Interventions*, version 6.0. Updated July 2019. Available at: www.training.cochrane.org/handbook. Accessed December 2020.
16. van Rosendal SP, Osborne MA, Fassett RG, et al. Guidelines for glycerol use in hyperhydration and rehydration associated with exercise. *Sports Med.* 2010;40:113–129.
17. Higgins JP, Altman DG, Gotzsche PC, et al.; Cochrane Statistical Methods Group. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ.* 2011;343:d5928.
18. RStudio Team. RStudio: integrated development environment for R. RStudio. Available at: http://www.rstudio.com/. Accessed March 2021.
19. Balduzzi S, Rucker G, Schwarzer G. How to perform a meta-analysis with R: a practical tutorial. *Evid Based Ment Health.* 2019;22:153–160.
20. Harrer M, Cuijpers P, Furukawa T, et al. dmetar: Companion R package for the guide 'Doing Meta-Analysis in R'. R package version 0.0.9000. Available at: http://dmetar.protectlab.org. Accessed March 2021.
21. Anderson CA, Cobb LK, Miller ER, et al. Effects of a behavioral intervention that emphasizes spices and herbs on adherence to recommended sodium intake: results of the SPICE randomized clinical trial. *Am J Clin Nutr.* 2015;102:671–679.
22. Appel LJ, Champagne CM, Harsha DW, et al. Effects of comprehensive lifestyle modification on blood pressure control: main results of the PREMIER clinical trial. *JAMA.* 2003;289:2083–2093.
23. Arcand JA, Brazel S, Joliffe C, et al. Education by a dietitian in patients with heart failure results in improved adherence with a sodium-restricted diet: a randomized trial. *Am Heart J.* 2005;150:716.
24. Assuncao MC, Gigante DP, Cardoso MA, et al. Randomized, controlled trial promotes physical activity and reduces consumption of sweets and sodium among overweight and obese adults. *Nutr Res.* 2010;30:541–549.

25. Brown DL, Conley KM, Sanchez BN, et al. A multicomponent behavioral intervention to reduce stroke risk factor behaviors: the Stroke Health and Risk Education cluster-randomized controlled trial. *Stroke*. 2015;46:2861–2867.
26. Cappuccio FP, Kerry SM, Micah FB, et al. A community programme to reduce salt intake and blood pressure in Ghana [ISRCTN88789643]. *BMC Public Health*. 2006;6:13.
27. Choi ES, Lee J. Effects of a face-to-face self-management program on knowledge, self-care practice and kidney function in patients with chronic kidney disease before the renal replacement therapy. *J Korean Acad Nurs*. 2012;42:1070–1078.
28. Cooper JN, Fried L, Tepper P, et al. Changes in serum aldosterone are associated with changes in obesity-related factors in normotensive overweight and obese young adults. *Hypertens Res*. 2013;36:895–901.
29. Cornelio ME, Godin G, Rodrigues RC, et al. Effect of a behavioral intervention of the SALdavel program to reduce salt intake among hypertensive women: a randomized controlled pilot study. *Eur J Cardiovasc Nurs*. 2016;15:e85–e94.
30. de Freitas Agondi R, Cornelio ME, Rodrigues RC, Gallani MC. Implementation intentions on the effect of salt intake among hypertensive women: a pilot study. *Nurs Res Pract*. 2014;2014:196410.
31. Donner Alves F, Correa Souza G, Brunetto S, et al. Nutritional orientation, knowledge and quality of diet in heart failure: randomized clinical trial. *Nutr Hosp*. 2012;27:441–448.
32. Dorsch MP, Cornellier ML, Poggi AD, et al. Effects of a novel contextual just-in-time mobile app intervention (LowSalt4Life) on sodium intake in adults with hypertension: pilot randomized controlled trial. *JMIR Mhealth Uhealth*. 2020;8:e16696.
33. Dunbar SB, Clark PC, Reilly CM, et al. A trial of family partnership and education interventions in heart failure. *J Card Fail*. 2013;19:829–841.
34. Espeland MA, Kumanyika S, Wilson AC, et al. Lifestyle interventions influence relative errors in self-reported diet intake of sodium and potassium. *Ann Epidemiol*. 2001;11:85–93.
35. Eyles H, McLean R, Neal B, et al. A salt-reduction smartphone app supports lower-salt food purchases for people with cardiovascular disease: findings from the SaltSwitch randomised controlled trial. *Eur J Prev Cardiol*. 2017;24:1435–1444.
36. Ferrara AL, Pacioni D, Di Fronzo V, et al. Lifestyle educational program strongly increases compliance to nonpharmacologic intervention in hypertensive patients: a 2-year follow-up study. *J Clin Hypertens (Greenwich)*. 2012;14:767–772.
37. Francis SL, Taylor ML. A social marketing theory-based diet-education program for women ages 54 to 83 years improved dietary status. *J Am Diet Assoc*. 2009;109:2052–2056.
38. He FJ, Wu YF, Feng XX, et al. School based education programme to reduce salt intake in children and their families (School-EduSalt): cluster randomised controlled trial. *BMJ*. 2015;350:h770.
39. Huang B, Li Z, Wang Y, et al. Effectiveness of self-management support in maintenance haemodialysis patients with hypertension: a pilot cluster randomized controlled trial. *Nephrology (Carlton)*. 2018;23:755–763.
40. Humalda JK, Klaassen G, de Vries H, et al. A self-management approach for dietary sodium restriction in patients with CKD: a randomized controlled trial. *Am J Kidney Dis*. 2020;75:847–856.
41. Jahan Y, Rahman MM, Faruque ASG, et al. Awareness development and usage of mobile health technology among individuals with hypertension in a rural community of Bangladesh: randomized controlled trial. *J Med Internet Res*. 2020;22:e19137.
42. Kaur J, Kaur M, Chakrapani V, et al. Effectiveness of information technology-enabled 'SMART Eating' health promotion intervention: a cluster randomized controlled trial. *PLoS One*. 2020;15:e0225892.
43. Kitaoka K, Nagaoka J, Matsuoka T, et al. Dietary intervention with cooking instructions and self-monitoring of the diet in free-living hypertensive men. *Clin Exp Hypertens*. 2013;35:120–127.
44. Kumanyika SK, Cook NR, Cutler JA, et al. Sodium reduction for hypertension prevention in overweight adults: further results from the trials of Hypertension Prevention Phase II. *J Hum Hypertens*. 2005;19:33–45.
45. Layeghiasl M, Malekzadeh J, Shams M, et al. Using social marketing to reduce salt intake in Iran. *Front Public Health*. 2020;8:207.
46. Li N, Yan LL, Niu W, et al. The effects of a community-based sodium reduction program in rural China - a cluster-randomized trial *PLoS One*. 2016;11:e0166620.
47. Lin PH, Yancy WS, Jr., Pollak KI, et al. The influence of a physician and patient intervention program on dietary intake. *J Acad Nutr Diet*. 2013;113:1465–1475.
48. Meuleman Y, Hoekstra T, Dekker FW, et al.; ESMO Study Group. Sodium restriction in patients with CKD: a randomized controlled trial of self-management support. *Am J Kidney Dis*. 2017;69:576–586.
49. Miura S, Yamaguchi Y, Urata H, et al. Efficacy of a multicomponent program (patient-centered assessment and counseling for exercise plus nutrition [PACE+ Japan]) for lifestyle modification in patients with essential hypertension. *Hypertens Res*. 2004;27:859–864.
50. Nakano M, Eguchi K, Sato T, et al. Effect of intensive salt-restriction education on clinic, home, and ambulatory blood pressure levels in treated hypertensive patients during a 3-month education period. *J Clin Hypertens*. 2016;18:385–392.
51. Ndanuko RN, Tapsell LC, Charlton KE, et al. Effect of individualised dietary advice for weight loss supplemented with walnuts on blood pressure: the HealthTrack Atudy. *Eur J Clin Nutr*. 2018;72:894–903.
52. Petersen KS, Torpy DJ, Chapman IM, et al. Food label education does not reduce sodium intake in people with type 2 diabetes mellitus. A randomised controlled trial. *Appetite*. 2013;68:147–151.
53. Philipson H, Ekman I, Swedberg K, et al. A pilot study of salt and water restriction in patients with chronic heart failure. *Scand Cardiovasc J*. 2010;44:209–214.
54. Pisani A, Riccio E, Bellizzi V, et al. 6-tips diet: a simplified dietary approach in patients with chronic renal disease. A clinical randomized trial. *Clin Exp Nephrol*. 2016;20:433–442.
55. Sevick MA, Piraino BM, St-Jules DE, et al. No difference in average interdialytic weight gain observed in a randomized trial with a technology-supported behavioral intervention to reduce dietary sodium intake in adults undergoing maintenance hemodialysis in the United States: primary outcomes of the BalanceWise Study. *J Ren Nutr*. 2016;26:149–158.
56. Shahnazari M, Ceresa C, Foley S, et al. Nutrition-focused wellness coaching promotes a reduction in body weight in overweight US veterans. *J Acad Nutr Diet*. 2013;113:928–935.
57. Shamsi SA, Salehzadeh M, Ghavami H, et al. Impact of lifestyle interventions on reducing dietary sodium intake and blood pressure in patients with hypertension: a randomized controlled trial. *Turk Kardiyol Dern Ars*. 2021;49:143–150.
58. Takashashi Y, Sasaki S, Takahashi M, et al. A population-based dietary intervention trial in a high-risk area for stomach cancer and stroke: changes in intakes and related biomarkers. *Prev Med*. 2003;37:432–441.
59. Towfighi A, Cheng EM, Ayala-Rivera M, et al.; Secondary Stroke Prevention by Uniting Community and Chronic Care Model Teams Early to End Disparities (SUCCEED) Investigators. Effect of a coordinated community and Chronic Care Model Team intervention vs usual care on systolic blood pressure in patients with stroke or transient ischemic attack: the SUCCEED randomized clinical trial. *JAMA Netw Open*. 2021;4:E2036227.
60. Veroff DR, Sullivan LA, Shoptaw EJ, et al. Improving self-care for heart failure for seniors: the impact of video and written education and decision aids. *Popul Health Manag*. 2012;15:37–45.
61. Welsh D, Lennie TA, Marcinek R, et al. Low-sodium diet self-management intervention in heart failure: pilot study results. *Eur J Cardiovasc Nurs*. 2013;12:87–95.
62. Williams A, de Vlieger N, Young M, et al. Dietary outcomes of overweight fathers and their children in the Healthy Dads, Healthy Kids community randomised controlled trial. *J Hum Nutr Diet*. 2018;31:523–532.
63. Zhang J, Astell-Burt T, Seo DC, et al. Multilevel evaluation of 'China Healthy Lifestyles for All', a nationwide initiative to promote lower intakes of salt and edible oil. *Prev Med*. 2014;67:210–215.
64. Ma Y, He FJ, Li N, et al. Salt sales survey: a simplified, cost-effective method to evaluate population salt reduction programs–a cluster-randomized trial. *Hypertens Res*. 2016;39:254–259.
65. Svetkey LP, Pollak KI, Yancy WS, Jr, et al. Hypertension improvement project: randomized trial of quality improvement for physicians and lifestyle modification for patients. *Hypertension*. 2009;54:1226–1233.
66. Land MA, Wu JH, Selwyn A, et al. Effects of a community-based salt reduction program in a regional Australian population. *BMC Public Health*. 2016;16:388.
67. Do HT, Santos JA, Trieu K, et al. Effectiveness of a Communication for Behavioral Impact (COMBI) intervention to reduce salt intake in a Vietnamese province based on estimations from spot urine samples. *J Clin Hypertens (Greenwich)*. 2016;18:1135–1142.
68. Ireland DM, Clifton PM, Keogh JB. Achieving the salt intake target of 6 g/day in the current food supply in free-living adults using two dietary education strategies. *J Am Diet Assoc*. 2010;110:763–767.
69. Khosravi A, Kelishadi R, Sarrafzadegan N, et al. Impact of a community-based lifestyle intervention program on blood pressure and salt intake of normotensive adult population in a developing country. *J Res Med Sci*. 2012;17:235–241.
70. Robare JF, Milas NC, Bayles CM, et al. The key to life nutrition program: results from a community-based dietary sodium reduction trial. *Public Health Nutr*. 2010;13:606–614.
71. Wang J, Olendzki BC, Wedick NM, et al. Challenges in sodium intake reduction and meal consumption patterns among participants with metabolic syndrome in a dietary trial. *Nutr J*. 2013;12:163.
72. Fujii H, Nakade M, Haruyama Y, et al. Evaluation of a computer-tailored lifestyle modification support tool for employees in Japan. *Ind Health*. 2009;47:333–341.
73. Ipjian ML, Johnston CS. Smartphone technology facilitates dietary change in healthy adults. *Nutrition*. 2017;33:343–347.
74. Khokhar D, Nowson CA, Margerison C, et al. The digital education to limit salt in the home program improved salt-related knowledge, attitudes, and behaviors in parents. *J Med Internet Res*. 2019;21:e12234.
75. Wentzel-Viljoen E, Steyn K, Lombard C, et al. Evaluation of a mass-media campaign to increase the awareness of the need to reduce discretionary salt use in the South African population. *Nutrients*. 2017;9:1238.
76. Byrd K, Almanza B, Ghiselli RF, et al. Adding sodium information to casual dining restaurant menus: beneficial or detrimental for consumers? *Appetite*. 2018;125:474–485.
77. Goodman S, Hammond D, Hanning R, et al. The impact of adding front-of-package sodium content labels to grocery products: an experimental study. *Public Health Nutr*. 2013;16:383–391.

78. Scourboutakos MJ, Corey PN, Mendoza J, et al. Restaurant menu labelling: is it worth adding sodium to the label? *Can J Public Health.* 2014;105:e354–e361.
79. Frisoli TM, Schmieder RE, Grodzicki T, Messerli FH. Salt and hypertension: is salt dietary reduction worth the effort? *Am J Med.* 2012;125:433–439.
80. George Institute for Global Health. The potential impact of salt reduction in Australia. Available at: https://www.georgeinstitute.org/sites/default/files/documents/potential-impact-of-salt-reduction-in-australia.pdf. Accessed April 2021.
81. Clement J. Internet usage worldwide – statistics & facts. Statista. https://www.statista.com/topics/1145/internet-usage-worldwide/. Accessed June 2021.
82. Wantland DJ, Portillo CJ, Holzemer WL, et al. The effectiveness of web-based vs. non-web-based interventions: a meta-analysis of behavioral change outcomes. *J Med Internet Res.* 2004;6:e40.
83. Muller AM, Alley S, Schoeppe S, et al. The effectiveness of e- & mHealth interventions to promote physical activity and healthy diets in developing countries: a systematic review. *Int J Behav Nutr Phys Act.* 2016;13:109.
84. Gainforth HL, Dineen TE, Giroux EE, et al. Teaching behavior change theory in Canada: establishing consensus on behavior change theories that are recommended to be taught to undergraduate students in courses addressing health behavior change. *Pedagogy Health Promotion*. 2021;7:51–59.
85. Glanz K, Bishop DB. The role of behavioral science theory in development and implementation of public health interventions. *Annu Rev Public Health*. 2010;31:399–418.
86. Bazzano LA, Green T, Harrison TN, et al. Dietary approaches to prevent hypertension. *Curr Hypertens Rep*. 2013;15:694–702.