RESEARCH ARTICLE

Systematic review of dietary salt reduction policies: Evidence for an effectiveness hierarchy?

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Abstract

Background
Non-communicable disease (NCD) prevention strategies now prioritise four major risk factors: food, tobacco, alcohol and physical activity. Dietary salt intake remains much higher than recommended, increasing blood pressure, cardiovascular disease and stomach cancer. Substantial reductions in salt intake are therefore urgently needed. However, the debate continues about the most effective approaches. To inform future prevention programmes, we systematically reviewed the evidence on the effectiveness of possible salt reduction interventions. We further compared “downstream, agentic” approaches targeting individuals with “upstream, structural” policy-based population strategies.

Methods
We searched six electronic databases (CDSR, CRD, MEDLINE, SCI, SCOPUS and the Campbell Library) using a pre-piloted search strategy focussing on the effectiveness of population interventions to reduce salt intake. Retrieved papers were independently screened, appraised and graded for quality by two researchers. To facilitate comparisons between the interventions, the extracted data were categorised using nine stages along the agentic/structural continuum, from “downstream”: dietary counselling (for individuals, worksites or communities), through media campaigns, nutrition labelling, voluntary and mandatory reformulation, to the most “upstream” regulatory and fiscal interventions, and comprehensive strategies involving multiple components.

Results
After screening 2,526 candidate papers, 70 were included in this systematic review (49 empirical studies and 21 modelling studies). Some papers described several interventions. Quality was variable. Multi-component strategies involving both upstream and downstream interventions, generally achieved the biggest reductions in salt consumption across an
entire population, most notably 4g/day in Finland and Japan, 3g/day in Turkey and 1.3g/day recently in the UK. Mandatory reformulation alone could achieve a reduction of approximately 1.45g/day (three separate studies), followed by voluntary reformulation (-0.8g/day), school interventions (-0.7g/day), short term dietary advice (-0.6g/day) and nutrition labelling (-0.4g/day), but each with a wide range. Tax and community based counselling could, each typically reduce salt intake by 0.3g/day, whilst even smaller population benefits were derived from health education media campaigns (-0.1g/day). Worksite interventions achieved an increase in intake (+0.5g/day), however, with a very wide range. Long term dietary advice could achieve a -2g/day reduction under optimal research trial conditions; however, smaller reductions might be anticipated in unselected individuals.

Conclusions

Comprehensive strategies involving multiple components (reformulation, food labelling and media campaigns) and “upstream” population-wide policies such as mandatory reformulation generally appear to achieve larger reductions in population-wide salt consumption than “downstream”, individually focussed interventions. This ‘effectiveness hierarchy’ might deserve greater emphasis in future NCD prevention strategies.

Introduction

Non-communicable diseases (NCDs) kill over 35 million people annually. Common cancers, cardiovascular diseases, diabetes, respiratory diseases and dementia together now account for over two thirds of the entire global burden of disability and death.[1,2] These NCDs are mainly attributable to just four major risk factors. Furthermore, the contribution from poor diet exceeds the combined contribution from alcohol, tobacco and physical inactivity.[3] This poor diet mainly reflects a predominantly unhealthy global food environment, dominated by processed foods high in sugar, saturated fat, trans-fat and, crucially, salt.[3]

In the UK and other high income countries, over 70% of dietary salt is consumed in processed foods such as bread, breakfast cereals, processed meats, snack foods, soups and sauces.[4–6] This food environment contributes to excessive salt intake among adults, on average 10g/day or more,[7] far in excess of what the body actually needs.[8] High salt intake is a major risk factor for increasing blood pressure,[9–11] cardiovascular disease,[12–14] stroke,[15,16] and stomach cancer.[17–19] Moreover, a reduction in salt intake would substantially reduce this risk.[10]

WHO recommends a maximum adult salt intake of 5g/day.[20] Different strategies and policy options have been proposed to achieve this goal. Individual level interventions often involve behavioural approaches, for example dietary counselling, leaflets or medical advice. These are sometimes termed “downstream” or “agentic” interventions, and are dependent on the individual responding. [21,22] Conversely, “upstream” structural interventions take place at the population level and typically involve policies such as regulatory approaches, taxes or subsidies. Finally, intermediate interventions target subgroups in worksites, schools or communities.[23]

National salt reduction strategies were identified in 75 countries in 2015, a substantial increase from 32 in 2010.[24] However, the debate regarding the most effective and acceptable salt reduction strategy continues.
Notable policy approaches have been seen in Finland,[25] Japan,[26] and more recently, the United Kingdom.[27] In the UK, a combination of awareness campaigns, agreed target settings, voluntary reformulation from industry and population monitoring of salt consumption have led to a 1.4g per day reduction in population salt intake between 2001 and 2011 (the campaign started in 2003).[27] However, health inequalities in salt consumption have persisted.[28,29] Furthermore, the introduction of the UK Responsibility Deal in 2010 shifted emphasis to ‘downstream’ interventions, coupled with ineffective voluntary agreements and, controversially, the direct involvement of the industry in policy decisions.[30,31]

Geoffrey Rose famously advocated population wide approaches rather than targeting high-risk individuals.[32] Furthermore, there seems to be some evidence for a public health ‘effectiveness hierarchy’ whereby “upstream” structural interventions consistently achieve larger improvements in population health, are more equitable and often reduce health inequalities [33,34] compared to “downstream” agentic interventions targeting individuals, for instance in tobacco control and alcohol policies.[35,36] Emerging evidence suggests that a comparable effectiveness hierarchy might also exist for salt reduction strategies, whereby upstream interventions apparently achieve bigger reductions in salt intake.[37,38]. To test this hypothesis and hence inform future preventive health strategies, we have systematically reviewed the evidence for studies focusing on the effectiveness of salt interventions to reduce salt intake.

**Methods**

**Study design**

We conducted a systematic review of interventions intended to decrease population dietary salt intake. To ensure proper conduct, we adhered to the PRISMA checklist (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)(S1 Table).[39] We used a narrative synthesis and formally investigated evidence to support or refute an effectiveness hierarchy. The research protocol can be found in S1 File.

**Search strategy**

We first identified exemplar studies to define and refine search terms needed for targeted searches. The search strategy consisted of a combination of four sets of key words:

1) salt, sodium; 2) health promotion, nutrition education, campaigns, dietary counselling, regulation, legislation, tax, self-regulation, reformulation, social marketing, promotion, provision, labelling, marketing control, primary care advice, food industry; 3) public policy, health policy, nutrition policy, policies, interventions, strategies, initiatives, programmes, policy option, actions; and 4) effectiveness, effect, intake, consumption, reduction, cost-benefit analysis, and cardiovascular diseases.

A pilot search was conducted to determine appropriate databases, identify relevant studies and highlight potential issues to be addressed. This process identified six databases which were then used for the targeted searches: Ovid MEDLINE, Science Citation Index, SCOPUS, Cochrane Database of Systematic Reviews, The Campbell Collaboration Library of Systematic Reviews and the CRD Wider Public Health database. We searched for all studies published in the last four decades (from 1975 onwards). The final searches were conducted on 30 October 2015. All papers identified by the searches were imported into the Zotero data management programme to identify duplicates and help screen titles, abstracts and full texts as appropriate. The reference lists of included studies were scanned for potential additional papers and topic experts (FPC and SC) were also consulted for additional data sources.[40,41]
Study selection and inclusion criteria

Studies were included if they investigated the effectiveness of specific interventions on population dietary salt intake and contained quantitative outcomes. Only studies in English were included. We included a wide range of study designs including meta-analyses, trials, observational studies and natural experiments. Empirical studies and modelling studies were analysed separately, in view of their profound differences. The retrieved studies were assessed using the PICOS approach (Participants, Interventions, Comparators, Outcomes and Study design), summarised in Table 1. The primary outcome was salt intake (g/day). Studies reporting urinary sodium excretion (mmol/day) or sodium mg/day were converted to g/day. Where necessary, we simultaneously considered studies reporting solely on salt intake data in a specific population with the corresponding studies describing the interventions during that same time period.

One reviewer (LH) conducted the searches; extracted potential papers and removed duplicates. Two reviewers (LH and AEG) then independently screened titles and abstracts for eligibility using the inclusion and exclusion criteria. Full text was retrieved for all papers deemed potentially eligible and these were also screened independently by the two reviewers. Any discrepancies were resolved by consensus or by involving the senior author (SC).

Data extraction and management

Pre-designed and pre-piloted tables were used to extract data from all included studies. To ensure that all relevant information was captured, extracted data included: first author; year of publication; funder(s); study aim(s); sample size; study design; methods; participants; policies analysed; geographical scope; length of follow-up; outcomes, effect and response;

Table 1. PICOS; Inclusion/exclusion criteria.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Include</th>
<th>Exclude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Studies for all age groups from all populations, from high-, middle- and low-income countries</td>
<td></td>
<td>Studies on animals, cells and pregnant women</td>
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<table>
<thead>
<tr>
<th>Interventions</th>
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<tbody>
<tr>
<td>Systematic Reviews and primary studies evaluating the effects of actions to promote salt reduction by government policy or adopted in specific real or experimental settings</td>
<td>Studies evaluating the effect of a general or specific diet</td>
</tr>
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<tr>
<th>Comparators</th>
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<tbody>
<tr>
<td>Systematic and non-systematic reviews where actions to promote salt reduction were evaluated or compared</td>
<td>No comparisons of different actions to promote salt reduction presented</td>
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<tr>
<th>Outcomes</th>
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<tbody>
<tr>
<td>Primary outcome of interest was dietary salt intake (g/day). Studies including urinary sodium excretion as an outcome were converted to g/day. Secondary outcomes included changes in clinical/physiological indicators related to NCDs and behaviours associated with a healthy diet</td>
<td>Process evaluations reporting on implementation of interventions/policies without any quantitative outcome data; feasibility or acceptability without an assessment or primary outcomes (intake); studies on individuals as opposed to populations; data on cost only and BMI</td>
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<tr>
<th>Study design</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Primary studies, RCTs, Systematic Reviews (SRs), empirical observational studies, natural experiments, and modelling studies, secondary analysis, and before vs. after interventions</td>
<td>Commentary/opinion articles and purely qualitative evaluations with no quantitative assessment</td>
</tr>
</tbody>
</table>

https://doi.org/10.1371/journal.pone.0177535.t001
authors’ assessment of limitations and our own assessment of potential risk of bias. The sources referenced for the effect sizes used in each modelling study were also specified in the tables (recognising that some modelling studies are based on empirical studies, potentially some included in this review). This data extraction was done independently by two reviewers (LH and AEG).

Quality assessment of included studies
Two reviewers (LH and AEG) independently assessed the methodological quality of each study (poor, fair or good). We used the National Heart, Lung and Blood Institute (NHLBI) tools specific for each research design (i.e. RCTs, cross-sectional studies, before and after studies, and systematic reviews).

Several questions were asked for each study design (varying from 8 to 14) and depending on the points scored, the studies were labelled as good, fair or poor. However, we also took into consideration as to which questions points were allocated. For example, if an RCT scored 10 out of 14 points, but did not conduct an intention to treat analysis, it would be rated as fair rather than good. Modelling studies were independently assessed by two modelling experts (MOF & CK) using a different tool adapted from Fattore et al. (2014).

Discrepancies in quality assessment were reconciled by consensus or by involving a third, senior member of the team (SC or HB).

Data synthesis and effectiveness hierarchy continuum
The evidence was summarised as a narrative synthesis according to intervention type, ranging from downstream to upstream interventions, to facilitate comparisons between the interventions. Summary tables of the studies included in this review can be found in Tables 2-10 for empirical studies and Table 11 for modelling studies. A more detailed data extraction of these studies can be found in S2 Table. We defined UPSTREAM interventions as those targeting the entire population (not a subset, however large) and creating structural changes (effectively removing individual choice from the equation). This accorded with the Nuffield’s ladder taxonomy, and with McLaren’s structural/agentic continuum. Conversely, we defined DOWNSTREAM interventions as those where the principal mechanism of action is “agentic”, being dependent on an individual altering their behaviour.

Interventions were then categorised according to their position in the McLaren et al. (2010) continuum from “upstream” to “downstream” (Fig 1).

Multi-component interventions were considered separately.

Patient involvement
Individual patients were not involved in this research; this is a secondary analysis of published data.

Results
The literature search identified 3336 potentially relevant papers. An additional 26 papers were identified through other sources, including reference lists and key informants. After removing 836 duplicates, 2526 publications were left to be screened by title and abstract, after which 134 full-text papers were assessed for eligibility. A total of 70 papers were finally included (49 empirical studies and 21 modelling studies, Fig 2). The interventions and their effect sizes are presented in Fig 3 (empirical studies) and Fig 4 (modelling studies).
Table 2. Dietary counselling (individuals).

<table>
<thead>
<tr>
<th>Study</th>
<th>Study type</th>
<th>Geographical scope</th>
<th>Aim and main outcomes</th>
<th>Policies analysed</th>
<th>Relevant results</th>
<th>Quality assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hooper et al.</td>
<td>SR and meta-analysis of RCTs</td>
<td>US, Australia, New Zealand, UK</td>
<td>Aim: to assess the long term effects of advice to restrict dietary sodium in adults with and without hypertension. Outcomes: salt intake as measured by urinary sodium excretion</td>
<td>Dietary advice</td>
<td>Meta-analysis (11 studies included). They found reductions in salt intake at both intermediate, &lt;12 months (2.8g/day) and late follow up, 13–60 months (2.0g/day).</td>
<td>Good</td>
</tr>
<tr>
<td>Appel et al.</td>
<td>Randomised trial</td>
<td>US</td>
<td>Aim: to determine the effect on BP of 2 multicomponent, behavioral interventions Outcomes: salt intake as measured by urinary sodium excretion</td>
<td>Dietary advice</td>
<td>Only the reduction in the established group differed significantly from that of advice only group. 24-hour dietary recall data indicated both behavioral interventions significantly reduced sodium intake in comparison with advice only group (P value = 0.01). Advice group  • Baseline = 10.0g/day  • 6 months = 8.8g/day  • Mean difference = -1.2g/day Intervention group  • Established: mean difference = -1.82 g/day  • Established + DASH: mean difference = -1.83 g/day</td>
<td>Good</td>
</tr>
<tr>
<td>Brunner et al.</td>
<td>Meta-analysis of RCTs</td>
<td>UK, US, Netherlands and Australia</td>
<td>Aim: to evaluate the effectiveness of dietary advice in primary prevention of chronic disease. Outcomes: salt intake</td>
<td>Dietary advice</td>
<td>Overall mean net reduction of 1.8g/day which is a 20% reduction in salt intake. The heterogeneity test was highly significant (P &lt; .0005) for the 3- to 6-month trials, with a net reduction of 3.4 (95% CI = 45, 72) g/day. Summary effect of the two trials with SE was somewhat larger at 9–18 months than at 3–6 months.</td>
<td>Fair</td>
</tr>
<tr>
<td>Francis &amp; Taylor</td>
<td>Randomised control group study</td>
<td>US</td>
<td>Aim: to implement a health-healthy diet-education programme. Outcomes: salt intake</td>
<td>Dietary counselling</td>
<td>Intervention salt consumption decreased significantly (P0.020) from record 1 to record 3. The reduction in control group participants’ sodium intake was not significant Intervention: (Mean ± SEM (g/day); P-value)  • Record 1: 7.0 ± 0.5; 0.020e  • Record 2: 5.9 ± 0.3; 0.067  • Record 3: 5.9 ± 0.4; 0.937 Control (Mean ± SEM (g/day), P-value)  • Record 1: 6.2 ± 0.5; 0.323  • Record 2: 6.1 ± 0.4; 0.880  • Record 3: 5.7 ± 0.4; 0.284 Mean effect size:- 0.6g/day</td>
<td>Fair</td>
</tr>
<tr>
<td>Parekh et al.</td>
<td>RCT</td>
<td>Australia</td>
<td>Aim: to evaluate the effectiveness of a minimal intervention on multiple lifestyle factors including diet using computer tailored feedback. Outcomes: salt intake (%)</td>
<td>Health promotion–computer tailored advice</td>
<td>Salt (%) Intervention +5.43 net change. Control -1.23 net change. Significant changes between groups were observed for reduced salt intake (OR 1.19, CI 1.05–1.38). The intervention group were 20% more likely to reduce salt intake</td>
<td>Fair</td>
</tr>
</tbody>
</table>

(Continued)
Dietary counselling—individual level (Table 2)

Nine empirical studies (two of good quality,[45–46] five of fair quality,[47–51] and two of poor quality[52–53]), and three modelling studies (all of good quality [54–56]) investigated the effect on salt intake of dietary counselling targeted at consenting individuals.

Two separate meta-analyses investigated the effect of dietary advice on salt intake. The first included eleven randomised controlled trials (RCTs) and found a 1.8g/day salt reduction after up to 18 months of dietary advice.[47] The second meta-analysis included eight RCTs and

![Table 2. (Continued)](https://doi.org/10.1371/journal.pone.0177535.t002)
Table 3. Dietary counselling (worksite/schools).

<table>
<thead>
<tr>
<th>Study</th>
<th>Study type</th>
<th>Geographical scope</th>
<th>Aim and main outcomes</th>
<th>Policies analysed</th>
<th>Relevant results</th>
<th>Quality assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>He et al. (2015)⁴⁰</td>
<td>Cluster RCT</td>
<td>China</td>
<td><em>Aim</em>: to determine whether an education programme targeted at schoolchildren could lower salt intake in children and their families. <em>Outcomes</em>: salt intake as measured by urinary excretion.</td>
<td>Health education</td>
<td>At baseline, the mean salt intake in children was 7.3 (SE 0.3) g/day in the intervention group and 6.8 (SE 0.3) g/day in the control group. The mean effect on salt intake for intervention versus control group was −1.9 g/day (95% confidence interval −2.6 to −1.3 g/day; P&lt;0.001). In adult family members the salt intakes were 12.6 (SE 0.4) and 11.3 (SE 0.4) g/day, respectively. During the study there was a reduction in salt intake in the intervention group, whereas in the control group salt intake increased. The mean effect on salt intake for intervention versus control group was −2.9 g/day (−3.7 to −2.2 g/day; P&lt;0.001)</td>
<td>Good</td>
</tr>
</tbody>
</table>
| Cotter et al. (2013)⁵⁷          | School based RCT | Portugal          | *Aim*: to examine the influence on salt intake and blood pressure of three different educational interventions for 6 months. *Outcomes*: salt intake as measured by urinary sodium excretion. | Nutrition education             | *Baseline*: mean salt intake of 7.8 ± 2.5 g per day. Estimated salt intake (g/d):  
  • CRT: Baseline: 7.7 ± 2.0  
  • Final: 7.4 ± 3.0  
  • Change: 0.35 ± 2.42  
  • THEOR: Baseline: 8.1 ± 3.0  
  • Final: 7.5 ± 3.0  
  • Change: 0.60 ± 3.24  
  • PRACT: Baseline: 7.5 ± 2.4  
  • Final: 6.4 ± 2.2  
  • Change: 1.08 ± 2.47* | Fair               |
| Katz et al. (2011)⁵⁸            | School based RCT | US                | *Aim*: to evaluate the effects of a nutrition education programme in distinguishing between healthful and less healthful choices in diverse food categories. *Outcomes*: salt intake. | Nutrition education             | There were no statistically significant improvements in dietary patterns from baseline between the intervention (-0.23g/day) and control groups (-0.04g/day) for salt intake (p = .44) | Poor               |
| Aldana et al. (2005)⁵⁹          | RCT          | US                 | *Aim*: to determine behavioral and clinical impact of a worksite chronic disease prevention program. *Outcomes*: salt intake. | Health education                | *Intervention group (salt g/day)*:  
  • Baseline: 7.5  
  • Δ6 weeks: -0.5  
  • Δ6 months: -1.7  
  *Control group (salt g/day)*:  
  • Baseline: 6.3  
  • Δ6 weeks: -0.5  
  • Δ6 months: -0.5  
  Significant differences in mean change scores were not observed at 6 weeks (P = 0.88) but they were seen at 6 months (P = 0.0097) | Fair               |
| Chen et al. (2008)⁶⁰            | Intervention control trial | China          | *Aim*: to report the effects of these two programmes on blood pressure and changes in morbidity and mortality from CHD and stroke. *Outcomes*: salt intake. | Health education                | Mean daily salt intake declined from 16.0 to 10.6 g d-1 in the intervention factory, compared with the control factory from 16.9 to 15.4 g d-1, with the net reduction of 3.9 g d-1, which was significantly different (P < 0.05). | Fair               |
reported an overall reduction in salt consumption of 2.8g/day at 12 months and 2g/day up to 60 months.[45] The two meta-analyses overlapped in respect of only three studies.

One additional RCT found a statistically significant net reduction of 0.6g/day between the groups,[48] whilst a second RCT found no effect between the control and intervention group.[50]

All three modelling studies predicted that dietary advice is less effective in reducing the disease burden of high salt intake, only gaining 180–2,600 quality-adjusted life years (QALYs) compared to other interventions (7,900–195,000 QALYs).[54–56]

Dietary counselling–school based and worksite interventions (Table 3)

Three school-based interventions (one of good quality;[40] one of fair quality;[57] one of poor quality[58]) and three worksite-based studies (all of fair quality) were included.[59–61] No modelling studies were identified for this section.

Schools. A nutrition programme in schools aimed at distinguishing between healthy and less healthy choices reported a non-significant reduction.[58] In the second school based RCT, the practical intervention group achieved a significant net reduction of 0.7g/day compared with the control group.[57] In a cluster RCT in China, education and training significantly reduced salt intake by a mean of −1.9 g/day in 279 school children (and −2.9 g/day in adult family members).[40]

Worksites. A randomised trial of a chronic disease prevention programme achieved a net reduction of 1.2g/day between the intervention and control group (P = 0.01).[59] A factory-based intervention study in China assessed health education aimed at altering diet, together with a high-risk strategy of hypertension control. Salt intake was reduced by 3.9g/day from a mean of 16g/day (P < 0.05).[60]

Dietary counselling–community level (Table 4)

Four empirical studies and one review, all of fair quality,[62–66] investigated community based dietary counselling. One study reported a statistically significant difference of −0.4g/day in salt intake between the intervention and control groups.[62] Two intervention trials of nutrition education reported significant reductions of 0.7g/day and 2.2g/day reductions

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**Table 3. (Continued)**

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<thead>
<tr>
<th>Study</th>
<th>Study type</th>
<th>Geographical scope</th>
<th>Aim and main outcomes</th>
<th>Policies analysed</th>
<th>Relevant results</th>
<th>Quality assessment</th>
</tr>
</thead>
</table>
| Levin et al. (2009)[61] | Worksite based dietary intervention | US | **Aim:** to examine whether a worksite nutrition programme using a low-fat vegan diet could significantly improve nutritional intake  
**Outcomes:** salt intake | Dietary counselling | Intervention group participants significantly increased the reported intake and mean intake (P = 0.04) of salt compared to the control group.  
**Salt (g/day)**  
**Intervention group:**  
• Baseline: 4.1 ± 0.1  
• 22 weeks: 5.0 ± 0.2  
• Mean difference: 0.9 ± 0.2  
**Control group:**  
• Baseline: 4.5 ± 0.2  
• 22 weeks: 4.9 ± 0.2  
• Mean difference: 0.4 ± 0.2  
Mean effect size: +0.5 (95% CI 9.2, 394.4; P = 0.04) | Fair |

https://doi.org/10.1371/journal.pone.0177535.t003
respectively in salt intake after 12 months.[63–64] One RCT reported a favourable trend; however, this was non-significant and could have been caused by contamination between the groups.[63]

**Mass media campaigns (Table 5)**

One empirical study of fair quality [67] and five modelling studies; four of good quality[56, 68–70] and one of fair quality[71] were included.
The UK FSA salt reduction programme involved media campaigns to discourage table salt use, plus sustained pressure on industry to reformulate. Although salt consumption declined by 0.9g/day using spot urinary sodium readings from 2003–2007, the media contribution was unclear but likely modest.[67]

The modelling studies likewise suggested media campaigns were generally considered less effective than food labelling or reformulation.[56, 69–71] The Change4Life campaign in the UK was predicted to reduce salt intake by 0.16g/day, less than labelling or reformulation.[68] Gillespie et al. (2015) similarly estimated that social marketing might modestly reduce salt consumption by 0.03g/day to 0.13g/day.[69]

### Nutrition labelling (Table 6)

Two empirical studies, both of poor quality, investigated the effect of nutrition labelling on salt intake [72–73]. Reduced salt intake was not observed in participants who reported frequent vs. non-frequent label use (7.7g/day vs. 7.6g/day). [73]

Ten modelling studies also examined labelling, four of good quality[56,68–70] and two of fair quality.[71, 74–77] These suggested that labelling might modestly reduce UK salt intake by

Table 6. Labelling.

<table>
<thead>
<tr>
<th>Study</th>
<th>Study type</th>
<th>Geographical scope</th>
<th>Aim and main outcomes</th>
<th>Policies analysed</th>
<th>Relevant results</th>
<th>Quality assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Babio et al. (2013)[72]</td>
<td>Randomised cross-over trial</td>
<td>Spain</td>
<td><em>Aim:</em> to compare two models of front-of-pack guideline daily amounts (GDA) and the ability to choose a diet that follows the nutritional recommendations. <em>Outcomes:</em> salt intake based on choices</td>
<td>Labelling</td>
<td>Participants using the multiple-traffic-light GDA system chose significantly less salt (0.4g/day; P &lt;0.001) than those using the monochrome GDA labels</td>
<td>Poor</td>
</tr>
<tr>
<td>Elfassy et al. (2015)[73]</td>
<td>Cross-sectional</td>
<td>US</td>
<td><em>Aim:</em> to examine independent association between hypertension and frequency use of NF label for sodium information and whether this was associated with differences in intake <em>Outcomes:</em> salt intake as measured by urinary sodium excretion</td>
<td>Labelling (use)</td>
<td>Daily sodium intake was not lower in those who reported frequent vs non-frequent use of the NF label for sodium information (7.7g/day vs 7.6g/day; P = 0.924)</td>
<td>Poor</td>
</tr>
</tbody>
</table>

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The modelling studies likewise suggested media campaigns were generally considered less effective than food labelling or reformulation.[56, 69–71] The Change4Life campaign in the UK was predicted to reduce salt intake by 0.16g/day, less than labelling or reformulation.[68] Gillespie et al. (2015) similarly estimated that social marketing might modestly reduce salt consumption by 0.03g/day to 0.13g/day.[69]

Table 5. Media campaigns.

<table>
<thead>
<tr>
<th>Study</th>
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<th>Aim and main outcomes</th>
<th>Policies analysed</th>
<th>Relevant results</th>
<th>Quality assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shankar et al. (2012)[67]</td>
<td>Cross-sectional</td>
<td>UK</td>
<td><em>Aim:</em> to examine the trend in salt intake over a set period and deduce the effects of the policy on the intake of socio-demographic groups <em>Outcomes:</em> salt intake as measured by spot urinary sodium readings</td>
<td>Salt campaign (and potential effect on reformulation and table salt use)</td>
<td>The results are consistent with a previous hypothesis that the campaign reduced salt intakes by approximately 10%. The impact is shown to be stronger among women than among men. Salt as measured by spot urinary sodium readings • 2003: 6.3 g/day • 2004: 6.4 g/day • 2005: 5.7 g/day • 2006: 5.6 g/day • 2007: 5.4 g/day Difference in g/day between 2003–2007 = 0.9 g/day = 13.5%</td>
<td>Fair</td>
</tr>
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https://doi.org/10.1371/journal.pone.0177535.t005

https://doi.org/10.1371/journal.pone.0177535.t006
0.03g/day to 0.16g/day [68, 69]; much less than the 0.9g/day estimated by Roodenburg et al. (2013).[77] Another study suggested that salt intake might be lowered by 1.2g/day if the population were to choose products labelled as low-salt, or increased by 1.6g/day if they choose products labelled as high salt content.[74]

**Reformulation (Table 7)**

Very few studies which focused on reformulation included quantified results of salt intake. In one empirical Taiwanese study of fair quality,[78] salt was enriched with potassium in the intervention group and their outcomes were an apparent reduction in cardiovascular deaths by 41%, compared to the control group rather than salt intake. Furthermore, people in the intervention group lived 0.3–0.9 years longer.[78]

Fourteen modelling studies evaluated reformulation, eleven of good quality[41, 54–56, 68–70, 79–82] and three of fair quality[71, 83, 84]. Mandatory reformulation could consistently achieve bigger salt reductions than voluntary reformulation; 1.6g/day compared with 1.2g/day; [68] and 1.4g/day versus 0.5g/day.[69] Mandatory reformulation might also achieve higher reductions in disability-adjusted life years (DALYs) and QALYs compared to voluntary reformulation.[54, 56, 79]
Table 9. Multi-component interventions.

<table>
<thead>
<tr>
<th>Study</th>
<th>Study type</th>
<th>Geographical scope</th>
<th>Aim and main outcomes</th>
<th>Policies analysed</th>
<th>Relevant results</th>
<th>Quality assessment</th>
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</thead>
<tbody>
<tr>
<td>He et al. (2014)</td>
<td>Comprehensive analysis</td>
<td>UK</td>
<td><strong>Aim:</strong> to analyse the UK salt reduction programme. <strong>Outcomes:</strong> Salt intake as measured by urinary sodium excretion 1) Reformulation 2) Labelling 3) Health promotion campaigns 15% decrease, there have been a steady fall in salt intake at a rate of ~2% per year since the introduction of the salt reduction strategy. The 0.9g/day reduction in salt intake achieved by 2008 led to a 6000 fewer CVD deaths per year.</td>
<td>2000–2001: salt intake = 9.5g/day 2005–2006: salt intake = 9.0g/day 2008: salt intake = 8.6g/day 2011: salt intake = 8.1g/day</td>
<td>Good</td>
<td>2014</td>
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<tr>
<td>Pietinen et al. (2010)</td>
<td>Before and after study</td>
<td>Finland</td>
<td><strong>Aim:</strong> to describe the main actions in Finnish nutrition policy during the past decades. <strong>Outcomes:</strong> Salt intake 1) Education 2) Voluntary reformulation 3) Labelling 1981: Eastern Finland - salt intake was about 13 g in men and 11 g in women. Salt intake has decreased continuously to a level of about 9 g in men and 7 g in women in 2007.</td>
<td>1981: Eastern Finland - salt intake was about 13 g in men and 11 g in women. Salt intake has decreased continuously to a level of about 9 g in men and 7 g in women in 2007.</td>
<td>1981: Eastern Finland - salt intake was about 13 g in men and 11 g in women. Salt intake has decreased continuously to a level of about 9 g in men and 7 g in women in 2007.</td>
<td>Good</td>
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Table 9. (Continued)

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<tr>
<th>Study</th>
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<th>Relevant results</th>
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<tbody>
<tr>
<td>Wang et al. (2011)³²</td>
<td>Literature review</td>
<td>US</td>
<td>Aim: to summarize cost-effectiveness evidence on selected interventions to reduce sodium intake that would be intended as population-wide approaches to control hypertension. Outcomes: stroke and MI averted.</td>
<td>1) Reformulation 2) Sodium tax</td>
<td>Smith-Spangler et al. For US adults aged 40–85 years, collaboration with industry that decreased mean intake of sodium by 9.5% was estimated to avert 513 885 strokes and 480 358 myocardial infarctions over their lifetimes and to save US$ 32.1 billion in annual medical costs. Over the same period, a tax on sodium that decreased the population’s intake of sodium by 6% was projected to save US$ 22.4 billion in such costs.</td>
<td>Fair</td>
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<tr>
<td>Webster et al. (2011)³³</td>
<td>Review</td>
<td>Finland, France, Japan and UK</td>
<td>Aim: to provide an overview of national salt reduction initiatives around the world and describe core characteristics. Outcomes: salt intake, LVQ, CHD and stroke mortality</td>
<td>1) Reformulation 2) Labelling 3) Health promotion campaigns</td>
<td>Finland started salt reduction strategy in 1978 (reformulation, labelling and mass media campaigns) and by 2002 had demonstrated a 3 g reduction in average population salt intake (from 13 to 9 g/person per day). During the same period there was a corresponding 60% fall in CHD and stroke mortality. UK: the Food Standards Agency (FSA) started working with the food industry in 2003 and launched its consumer education campaign in 2005. By 2008 the UK had achieved an average 0.9 g/person per day reduction in daily salt consumption, which is predicted to be saving some 6000 lives a year. France: the Food Safety Authority recommended a reduction in population salt consumption in 2000 and has since reported a decline in intake provided by foods from 8.1 to 7.7 g/day in the overall adult population.</td>
<td>Fair</td>
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<tr>
<td>Wang &amp; Bowman (2013)³⁴</td>
<td>Literature review</td>
<td>US, UK</td>
<td>Aim: to summarize recent economic analyses of interventions to reduce sodium intake. Outcomes: SBP, hypertension, cardiovascular events</td>
<td>1) reducing the sodium content of all foods 2) reducing sodium content by labelling foods and by promoting, subsidising, and providing low sodium food options 3) Legislation</td>
<td>US (1&amp;2): If the sodium-reduction strategies were implemented, adults in the county would reduce their intake of sodium by 233 mg per day, on average, in 2010. This would correspond to an average decrease of 0.71 mmHg in SBP among adults with hypertension. 388 fewer cases of uncontrolled hypertension, and a decrease per year of $629,724 in direct health care costs. UK (3): Legislation or other measures to reduce the intake of salt by 3 g per person per day (in a population where the current mean intake was about 8.5 g per person per day) would reduce the mean population SBP by approximately 2.5 mmHg, prevent about 30,000 cardiovascular events and approximately 4,450 deaths, and produce discounted savings overall of approximately £347 million (about $684 million) over a decade, which would be equivalent to annual savings of approximately £40 million.</td>
<td>Fair</td>
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<tr>
<td>He et al. (2014)³⁵</td>
<td>Cross-sectional</td>
<td>England</td>
<td>Aim: to determine the relationship between the reduction in salt intake that occurred in England, and BP, as well as mortality from stroke and IHD. Outcomes: salt intake as measured by urinary sodium excretion.</td>
<td>Combined 1) Reformulation 2) Health promotion campaigns 3) Labelling</td>
<td>From 2003 to 2011, salt intake decreased by 1.4 g/day (15%, p&lt;0.05 for the downward trend). From 2003 to 2011, stroke mortality decreased from 128/1 000 000 to 82/1 000 000 (36% reduction, p&lt;0.001) and IHD mortality decreased from 423/1 000 000 to 272/1 000 000 (36% reduction, p&lt;0.001). 2003: 9.5g/day 2005/2006: 9.0g/day 2008: 8.6g/day 2011: 8.1g/day</td>
<td>Fair</td>
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<tr>
<td>Enkhtungalag et al. (2015)³⁶</td>
<td>Before and after study</td>
<td>Mongolia</td>
<td>Aim: to reduce salt intake of the employees of three of the main food producing factories. Outcomes: salt intake as measured by 24 h urine excretion.</td>
<td>Education on salt consumption and provision of reduced salt foods</td>
<td>Salt intake reduced from 11.5g/day in 2011 to 8.7g/day in 2013</td>
<td>Fair</td>
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<td>Study</td>
<td>Study type</td>
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<td>Trieu et al. (2015)</td>
<td>Systematic review</td>
<td>75 countries</td>
<td>Aim: to quantify progress with the initiation of salt reduction strategies around the world in the context of the global target to reduce population salt intake by 30% by 2025. Outcomes: salt (g/day)</td>
<td>Labelling, mass media campaigns, education, reformulation</td>
<td>Denmark: from 2006 to 2010 salt intake reduced from 10.7 to 9.9g/day in men and 7.5g to 7.0g/day in women (7%)</td>
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<td>Japan: salt intake reduced from 13.5in 1997 to 10.4g/day in 2012 (23%)</td>
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<td>Korea: salt intake reduced from 13.4g in 2005 to 11.6g/day in 2012 (13.6%)</td>
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<td>Slovenia: salt intake reduced from 12.4g in 2007 to 11.3g/day in 2012 (8.9%)</td>
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<td>China: salt intake reduced from 16.8g in 1999 to 12g/day in 2011 (28%)</td>
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<td>Finland from 1979 to 2007 salt intake reduced from 19g to 8.3g/day in men and 11g to 7g/day in women (36%)</td>
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<td>European commission (2008) France: salt intake reduced from 8.1g in 1999 to 7.7g/day in 2007(4.9%)</td>
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<td>WHO (2013) Iceland: salt intake reduced from 8.4g in 2002 to 7.9g/day in 2010 (6%)</td>
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<td>Walton (2013) Iceland: salt intake reduced from 8.1g in 2001 to 7g/day in 2011(13.6%)</td>
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<td>National Food and Veterinary Risk Assessment Institute Lithuania: salt intake reduced from 10.8g in 1997 to 8.8g/day in 2007(18.6%)</td>
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<td>WHO (2013) Turkey: salt intake reduced from 18.0g in 2008 to 15g/day in 2012(16.7%)</td>
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<td>Sadler et al. (2011) UK: Salt intake reduced from 9.5g in 2001 to 8.1g/day in 2011(14.7%)</td>
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<tr>
<td>Luft et al. (1997)</td>
<td>Review</td>
<td>Finland and US</td>
<td>Aim: to discuss the approaches used in a community-wide salt-reduction project. Outcomes: salt intake as measured by urinary excretion</td>
<td>1) Nutrition education 2) Reformulation</td>
<td>Pietinen et al. (1984)—Health education &amp; reformulation. After 3 y salt intake had not changed significantly. Hypertensive subjects Men Women 1979: 13.8 ± 5.3 1979: 10.4 ± 4.7 1982: 13.7 ± 5.5 1982: 10.0 ± 4.1 Normotensive subjects Men Women 1979: 12.4 ± 4.8 1979: 9.8 ± 3.8 1982: 12.2 ± 4.8 1982: 9.1 ± 3.6 Lang et al. (1985)—Dietary counselling. Women reduced their salt intake from 7.5 ± 0.4 to 3.6 ± 0.2 g/day and men reduced their salt intake from 10.3 ± 0.8 to 4.7 ± 0.3 g/day. Wassertheil-Smoller et a. (1992)—Education. Salt intake as measured by urinary sodium excretion was reduced from 7.9 to 1.6 4 g/day. Analysis of 3-d food records indicated that sodium intake decreased from 8.1 to 4.9 g/day. Hypertension prevention collaborative research group (1992)—Nutrition education. Salt intake as measured by urinary sodium excretion</td>
<td>Poor</td>
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<tr>
<td>Mohan et al. (2009)</td>
<td>Review</td>
<td>UK</td>
<td>Aim: to review the evidence related to dietary sodium and health in the context of the Ottawa Charter for health promotion. Outcomes: salt intake, stroke, CVD &amp; coronary artery mortality</td>
<td>1) Reformulation 2) Labelling 3) Health promotion campaign</td>
<td>UK: Consumer-friendly labelling indicating sodium content in processed foods by use of a colour system implemented in several UK food chains. Together with other efforts population salt intake decreased from 9.5g/day in 2004 to 8.6g/day in 2008</td>
<td>Poor</td>
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</table>
In the Netherlands, reformulation of processed foods was predicted to reduce median salt intake by 2.3g/day,[84] compared with a 0.9g/day from a two-year salt reformulation initiative in Argentina.[82]

Fiscal interventions (Table 8)

Two systematic reviews of fair quality [85, 86] included three modelling studies eligible for this review. Furthermore, three additional tax modelling studies were included, all of good quality. [56, 81, 87] Two studies included in Niebylski et al.’s systematic review (2015) modelled a 1% tax on salty snacks or on cheese and butter; neither reduced salt consumption.[86] Another modelling study suggested that a very high (40%) tax might achieve a 6% reduction in salt consumption (0.6g/day).[81]

One modelling study predicted that a 20% tax on major dietary sodium sources might prevent or postpone 2000 deaths annually,[87] whilst Nghiem et al. (2015) predicted that a sodium tax might gain more QALYs than other interventions.[56]

Multi-component interventions (Table 9 and Table 10)

Fifteen papers were included under multi-component interventions. Most studies came from Japan, Finland and the UK. Two were of good quality;[88, 89] ten of fair quality;[24, 43, 89–96] and four of poor quality.[97–100] Four studies were included which presented dietary salt intake and linked to papers describing the interventions; (one of good quality;[25]; two of fair quality;[101, 102] and one of poor quality.[103]

Japan. The Japanese government initiated a sustained campaign in the 1960s.[26] Over the following decade, mean salt intake fell from 13.5g/day to 12.1g/day overall (and from 18g/day to 14g/day in Northern Japan). Miura et al. (2000) reported that salt intake subsequently decreased from 14.5g/day in 1972 to 10.6g/day in 2010, a fall of almost 4g/day.[103] Stroke mortality was predicted to fall by 80%.[90, 93]

Finland. Starting in 1978, Finland pursued a comprehensive salt reduction strategy using mass media campaigns, mandatory labelling and voluntary reformulation by the food industry. Population salt consumption was monitored regularly by using 24h urinary assessment and dietary survey data.[72] By 2007, salt intake had reduced by approximately 4g/day, from
13 to 8.3g/day in men, and from 11 to 7g/day in women.[24, 25] Stroke and coronary heart disease (CHD) mortality fell by over 75% during that period.[90]

**United Kingdom.** The UK salt reduction strategy included voluntary reformulation, a consumer awareness campaign, food labelling, target settings and population monitoring.[95] By 2011, population salt intake, measured by 24h urinary sodium excretion, had decreased by 1.4g/day (9.5g/day to 8.1g/day)[88]. He et al. (2014b) estimated that this might reduce stroke and coronary heart disease mortality by some 36%.[88]
Table 11. Modelling studies included in the systematic review.

<table>
<thead>
<tr>
<th>Study</th>
<th>Study type</th>
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<tbody>
<tr>
<td>Cobiac et al.</td>
<td>Modelling</td>
<td>Australia</td>
<td>Aim to evaluate population health benefits and cost-effectiveness of interventions for reducing salt in the diet. Outcomes: DALYs and proportion of DALYs averted</td>
<td>1) Voluntary reformulation&lt;br&gt;2) Mandatory reformulation&lt;br&gt;3) Dietary advice</td>
<td>Mandatory reformulation could avert 18% of the disease burden (110,000 DALYs). Voluntary reformulation and mandatory salt reduction had a 100% probability of being dominant (i.e., cost saving to the health sector) under all modelled scenarios. Dietary advice had zero probability of being cost-effective.</td>
<td>Good</td>
</tr>
<tr>
<td>Cobiac et al.</td>
<td>Modelling</td>
<td>Australia</td>
<td>Aim to evaluate the optimal mix of lifestyle, pharmaceutical and population-wides interventions for primary prevention of cardiovascular disease. Outcomes: DALYs</td>
<td>1) Mandatory reformulation&lt;br&gt;2) Community heart health programme&lt;br&gt;3) Dietary advice</td>
<td>Mandatory reformulation in breads, margarines and cereals is easily the most effective and cost-effective strategy for primary prevention of CVD; (80,000 DALYs) and cost saving (dominant). Community heart health program (3,000 DALYs) is the least cost-effective of all primary prevention strategies ($1,000,000 to $1,400,000).</td>
<td>Good</td>
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<tr>
<td>Nghiem et al.</td>
<td>Modelling</td>
<td>New Zealand</td>
<td>Aim to compare the impact of eight sodium reduction interventions</td>
<td>1) Salt tax (195,000)&lt;br&gt;2) Labelling (180–370 DALYs)</td>
<td>QALYs gained in order of effectiveness: 1)Salt tax (195,000)&lt;br&gt;2) Mandatory salt reformulation (85,100)&lt;br&gt;3) Mandatory 3G reformulation (85,100)&lt;br&gt;4) Mandatory salt reformulation (61,700)&lt;br&gt;5) Mass media campaign as per the UK one (25,200)&lt;br&gt;6) Voluntary labelling (7,900)&lt;br&gt;7) Dietary counselling (205)</td>
<td>Good</td>
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<tr>
<td>Collins et al.</td>
<td>Modelling</td>
<td>UK</td>
<td>Aim to evaluate the cost-effectiveness of four population health policies to reduce dietary salt intake on an English population to prevent coronary heart disease (CHD). Outcomes: Life years gained and salt intake</td>
<td>1) Health promotion campaign&lt;br&gt;2) Labelling&lt;br&gt;3) Voluntary salt reformulation&lt;br&gt;4) Mandatory salt reformulation</td>
<td>Primary outcome: Salt intake reductions: Campaign = 0.16g/d; Labelling = 0.16g/d; Social marketing (50% impact) = 0.13g/d; Nutrition labelling (50% impact) = 0.16g/d. Secondary outcome: Gains: Change4life and labelling might each gain approximately 1900 life-years; Voluntary reformulation = 14,590 life-years; and Mandatory reformulation 19,320 life-years.</td>
<td>Good</td>
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<tr>
<td>Gillespie et al.</td>
<td>Modelling</td>
<td>England</td>
<td>Aim to forecast the potential impact on English adults of policies implemented during the 2015 UK parliament, projecting the health consequences to 2035. Outcomes: Salt intake, CHD deaths prevented, LYG</td>
<td>1) Mandatory reformulation&lt;br&gt;2) Voluntary reformulation&lt;br&gt;3) Social marketing&lt;br&gt;4) Nutrition labelling</td>
<td>Mandatory reformulation (30% reduction in salt content): • Salt intake = -1.45g/day • SBP = -0.27mmHg • CHD deaths = 4.500 prevented or postponed • LYG = 44,000 Mandatory reformulation (10% reduction in salt content): • Salt intake = -0.48g/day • SBP = -0.27mmHg • CHD deaths = 1,500 prevented or postponed • LYG = 15,000 Voluntary reformulation: • Salt intake = -0.48g/day • SBP = -0.27mmHg • CHD deaths = 1,500 prevented or postponed • LYG = 14,000 Social marketing (50% impact): • Salt intake = -0.13g/day • SBP = -0.091mmHg • CHD deaths = 500 prevented or postponed • LYG = 5,000 Social marketing (10% impact): • Salt intake = -0.027g/day • SBP = -0.018mmHg • CHD deaths = 100 prevented or postponed • LYG = 780 Nutrition labelling (50% impact): • Salt intake = -0.16g/day • SBP = -0.091mmHg • CHD deaths = 500 prevented or postponed • LYG = 5,000 Nutrition labelling (10% impact): • Salt intake = -0.031g/day • SBP = -0.018mmHg • CHD deaths = 100 prevented or postponed • LYG = 1,000</td>
<td>Good</td>
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<tr>
<td>Wilcox et al.</td>
<td>Modelling</td>
<td>Syria</td>
<td>Aim to present a cost-effectiveness analysis of salt reduction policies to lower coronary heart disease in Syria. Outcomes: Salt intake, deaths prevented and life years gained</td>
<td>1) Health promotion campaign&lt;br&gt;2) Labelling&lt;br&gt;3) Reformulation</td>
<td>Health promotion campaign: 5% reduction in salt intake 252 deaths prevented 5,679 LYG&lt;br&gt;Labelling: 10% reduction in salt intake 467 deaths prevented 11,192 LYG&lt;br&gt;Reformulation: 10% reduction in salt intake 497 deaths prevented 11,192 LYG&lt;br&gt;Reformulation + HP: 15% reduction in salt intake 736 deaths prevented 16,541 LYG&lt;br&gt;All 3 policies: 30% reduction in salt intake 1,413 deaths prevented 31,674 LYG</td>
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<th>Geographical scope</th>
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| Mason et al. (2014) | Modelling study | Tunisia, Syria, Palestine and Turkey | Aim to present an economic evaluation of population-based salt reduction policies in Tunisia, Syria, Palestine and Turkey. Outcome: Life years gained | 1) Health promotion campaign (HP) 2) Labeling (L) 3) Mandatory reformulation (R) | Tunisia: HP = 1.151 LYG; L = 2.272 LYG; R = 2.272 LYG; All 3 policies = 6.455 LYG  
Palestine: HP = 0.679 LYG; L = 1.182 LYG; R = 1.192 LYG; All 3 policies = 3.674 LYG | Fair |
| Pietinen et al. (2008) | Modelling study | Finland | Aim: to estimate the impact of choosing food products labelled either as low or high in salt. Outcome: Salt intake | Labelling | If the entire population were to choose low-salt breads, cheeses, processed meats, and breakfast cereals, then salt intake could be lowered by 1.5 g/day in men and by 0.9 g in women. In order to select high-salt products, then salt intake would go up by 1.9 g in men and by 1.2 g in women. | Fair |
| Pietinen et al. (2008) | Modelling study | Finland | Aim: to estimate the impact of choosing food products labelled either as low or high in salt. Outcome:盐摄入 | Reformulation (restaurants and manufacturers) | Restaurateurs and manufacturers reaching agreed-upon sodium targets would be expected to lower sodium by 0.9 to 3.0 mg/day (1.6%–5.4% reduction) and 0.5 to 2.8 g/day for those with a 1%–2% reduction. | Good |
| Rubenstein et al. (2010) | Modelling study | South East Asia (SEA), Latin America (LA), Europe (EU) | Aim: to report estimates of the population health effects and costs of selected interventions to reduce the risks associated with high cholesterol and blood pressure in areas of the world with differing epidemiological profiles. Outcome: DALYs | 1) Voluntary reformulation 2) Mandatory reformulation | 1) DALYs averted: 672.80  
International Dollars per DALY saved: 1,406.93 | Good |
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| Smith-Spangler et al.  | US                 | Modelling study | Aim to assess the cost-effectiveness of two population strategies to reduce sodium intake. Outcomes: strokes and MIs averted, life years and QALYs gained | 1) Voluntary reformulation  
2) Sodium tax                  | Collaboration with the industry: a 9.5% reduction in sodium intake resulted in  
- Averted strokes = 513,885 s  
- Averted MIs = 400,398  
- LYGs = 1.3 million  
- QALYs = 0.2 million  
Sodium tax would lead to a 6% decrease in sodium intake.  
- Averted strokes = 327,892  
- Averted MIs = 306,137  
- LYGs = 0.86  
- QALYs = 0.13 million | Good                |
| Konfino et al. (2013)  | Argentina          | Modelling study | Aim to use Argentina-specific data to project impact of Argentina’s sodium reduction policies under two scenarios—the 2-year intervention currently being undertaken or a more persistent 10-year sodium reduction strategy. Outcomes: salt intake as measured by urinary sodium excretion, systolic blood pressure, deaths and cases averted, mortality | Reformulation  
Scenario 1: current initiative (2 year intervention)  
- Projected to reduce mean salt consumption by 0.96 g/day in men and 0.79 g/day in women  
- SBP would reduce by 0.93 mmHg to 1.81 mmHg depending on population subgroup  
- 19,000 deaths, 6,000 CHD deaths and 2,000 stroke deaths, 13,000 MIs and 10,000 stroke cases averted  
- Overall mortality reduction of 0.6% in adults > 35 years, 1.5% in total MIs, 1% in total stroke cases in the next decade  
Scenario 2: current initiative maintained for 10 years  
- Projected to reduce mean salt consumption by 4.83 g/day in men and 3.98 g/day in women  
- SBP would reduce by 4.66 mmHg to 9.04 mmHg depending on subgroup  
- 95,000 deaths, 16,000 CHD deaths and 5,000 stroke deaths, 38,000 MIs and 27,000 strokes averted  
- Overall mortality decreased by 2% in adults > 35 years, 4.3% MIs and 2.7% stroke cases in the next decade | Good                |
| Rubinstein et al. (2009) | Argentina         | Modelling study | Aim to use generalised cost-effectiveness analysis to identify the most efficient interventions to decrease CVD. Outcomes: cost-effectiveness, DALYs | Reformulation in bread  
Lowering salt intake in the population through reducing salt in bread was found to be the most cost-effective ($17 per DALY averted). Less salt in bread  
- Total Cost per year (ARS$): $ 9.644  
- DALY Age weighted, 3% discounted per year: 579  
- DALY No age-weight 3% discounted per year: 713  
- DALY # age-weight, undiscounted per year: 1,107  
- ARS$ (1)/DALY (2): $ 17 | Fair                |
| Hendriksen et al. (2014) | Netherlands       | Modelling study | Aim to evaluate the health benefits of salt-reduction strategies related to processed foods. Outcomes: AMI, CHF and CVA averted, life expectancy and DALYs gained, salt intake (g/day) | 1) Reformulation  
2) Substitution of high salt foods with low salt foods  
3) Adherence to the recommended intake  
If salt intake is reduced to the recommended maximum salt intake (6 g/d): Prevented cases  
- 31,800 cases of AMI;  
- 15,300 cases of CHF;  
- 51,900 cases of CVA;  
- Mortality reduction: 0.7%;  
- LE increased by 0.15 years  
- 56,000 DALYs gained  
Salt reduction processed foods scenario median salt intake would decrease by -2.3g/d (28%). Prevented Cases:  
- 39,300 AMI cases;  
- 16,200 CHF cases;  
- 53,400 CVA  
- Mortality reduction: 0.8%;  
- LE increased by 0.15 years  
- 95,400 DALYs gained  
Substitution median salt intake would decrease by -3.0g/d (33%). Prevented Cases:  
- 38,900 cases of AMI;  
- 20,000 cases of CHF;  
- 64,300 cases of CVA  
- LE increased by 0.18 years  
- 67,900 DALYs gained | Fair                |
| Ni Mhurchu et al. (2015) | New Zealand       | Modelling study | Aim to estimate the effects of health-related food taxes and subsidies. Outcomes: deaths prevented or postponed | Tax on major dietary sodium products  
A 20% tax on major dietary sources of sodium might result in 2.0 million (1.3 million to 2.7 million) DPP (8.9%) | Good                |
| Asare et al. (2007) | 23 low and middle income countries | Modelling study | Aim to investigate potential deaths averted over 10 years by implementation of selected population-based interventions. Outcomes: CVD deaths averted, salt reduction (g/day) | Combined:  
1) Mass media campaign  
2) Voluntary reformulation  
8.5 million deaths would be averted by implementation of the salt-reduction strategy (13%) alone. Salt interventions:  
- 15% reduction in mean salt intake  
  - risk factor reduction of 1.69g/day  
  - 8.4 million CVD deaths averted  
- 30% reduction in mean intake  
  - risk factor reduction of 3.38g/day  
  - 16.0 million CVD deaths averted  
Reducing salt intake to 5g/day  
- risk factor reduction of 6.2g/day  
- 38.3 million CVD deaths averted  
Reduction in deaths  
- CVD: 17.6%  
- Respiratory disease: 15.4%  
- Cancer: 8.7% | Good                |
<table>
<thead>
<tr>
<th>Study</th>
<th>Study type</th>
<th>Geographical scope</th>
<th>Aim and main outcomes</th>
<th>Policies analysed</th>
<th>Relevant results</th>
<th>Quality assessment</th>
</tr>
</thead>
</table>
| Dodhia et al. (2012)  | Modelling study | England            | Aim: to assess the impact of cost-effective interventions in terms of the avoidable CVD burden and costs by comparing these strategies to the current situation. Outcomes: IHD and stroke events and deaths avoided, DALYs. | Combined: 1) Health promotion 2) Reformulation | 30% reformulation through agreement with the food industry. Interventions:  
  Na–2mmHg:  
  • IHD events avoided: 98.497  
  • Stroke events avoided: 25.781  
  • Stroke deaths avoided: 39.357  
  • DALYs averted: 238.043  
  • Cost per DALY ($): -4.228  
  Na–5mmHg:  
  • IHD events avoided: 120.138  
  • Stroke events avoided: 257.508  
  • Stroke deaths avoided: 103.492  
  • DALYs averted: 579.869  
  • Cost per DALY ($): -5.021  
  Reducing salt intake to 6g/day through reformulation  
  NA–MRC review:  
  • IHD events avoided: 80.366  
  • Stroke events avoided: 128.032  
  • Stroke deaths avoided: 51.419  
  Reducing salt intake in the population with a 5 mmHg reduction in SBP had the greatest population impact and cost-saving to the NHS. | Good               |
| Gasee et al. (2011)   | Modelling study | US                 | Aim: to examine approaches to reduce sodium content of food served in settings operated or funded by the government of the County of Los Angeles, California. Outcomes: salt intake and BP. | Combined: 1) Labelling 2) Promotion 3) Subsidy 4) Provide low sodium food options | Hospital cafeterias: Average sodium reduction: 1.8g/day (23%). Overall SBP: 1.09  
  County government cafeterias: Average sodium reduction of 0.7g/day (11%). Overall SBP: 0.63 | Fair               |
| Ha & Chrisholm (2011) | Modelling study | Vietnam            | Aim: to assess costs, health effects and cost-effectiveness prevention strategies to reduce CVD. Outcomes: DALYs. | Combined: 1) Mass media campaign 2) Voluntary reformulation | Media salt campaign:  
  • Cost per year (USD, million): 4.1  
  • DALYs averted per year: 45.393  
  • VND per DALY saved: 89.2  
  County government cafeterias: Average sodium reduction of 0.7g/day (11%). Overall SBP: 0.63 | Fair               |
  Reducing salt intake by 3g/day might reduce mean population systolic blood pressure by approximately 2.5 mm Hg preventing approximately 4460 deaths from cardiovascular disease | Good               |
Other countries have implemented several strategies including labelling, media campaigns and voluntary reformulation and effect sizes ranged from -0.4g/day in France [24, 93] to -4.8g/day in China [24, 102].

**Modelling studies of combined interventions.** Six modelling studies investigated the effect of multi-component interventions, three were of good quality;[70, 104, 105] whilst three others were of fair quality.[70, 106, 107]

Several modelling studies consistently suggested that multi-component salt reduction strategies (e.g. labelling, health promotion and reformulation) would be more effective than any single intervention.[70, 71] For instance, Gase et al. (2011) suggested that using labelling, promotion, subsidies and provision of low sodium options could lead to a 0.7–1.8g/day reduction. [106]

**Discussion**

**Main results**

This systematic review of salt reduction interventions suggests that comprehensive strategies could generally achieve the biggest reductions in salt consumption across an entire population, approximately 4g/day in Finland and Japan, 3g/day in Turkey and 1.3g/day recently in the UK. Mandatory reformulation alone could achieve a reduction of approximately 1.4g/day, followed by voluntary reformulation (median 0.7g/day) school interventions (0.7g/day) and worksite interventions (+0.5g/day). Smaller population benefits were generally achieved by short-term dietary advice (0.6g/day), community-based counselling (0.3g/day), nutrition labelling (0.4g/day), and health education media campaigns (-0.1g/day). Although dietary advice to
individuals achieved a -2g/day reduction, this required optimal research trial conditions (smaller reductions might be anticipated in unselected individuals).

Comparison with other research

Geoffrey Rose famously argued that a greater net benefit came from the population-wide approach, (achieving a small effect in a large number of people) when compared with targeting high risk individuals (a large effect but only achieved in a small number of people).[32]
#### Fig 3. Effectiveness of interventions to reduce salt intake (empirical studies)

Forest plot of the empirical studies that were included in this systematic review. Negative values of salt reduction are interpreted as reported increase in salt consumption. For most combined interventions the sample size and confidence intervals were not reported. NA denotes not applicable or not reported.

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Multi-component interventions. Multi-component salt reduction strategies involving a series of structural initiatives together with campaigns to increase population awareness have been successful in Japan and Finland where they substantially reduced dietary salt consumption, and associated high stroke and cardiovascular disease mortality rates. In Finland, some credit should also go to other dietary changes e.g. fat quality.[108]

Between 2003 and 2010, a multi-component approach in the UK including voluntary reformulation and political pressure on industry to agree category-specific targets achieved some success (1.3g/day reduction in population salt consumption over 8 years to 8.1g/day in 2011). Interestingly, pre-existing health inequalities in salt consumption persisted.[29] However,
from 2010, the Responsibility Deal simply advocated a voluntary scheme. This was ineffective, and MacGregor therefore subsequently recommended mandatory reformulation.[31] Other useful reductions were demonstrated in other countries mostly using dietary surveys and some from grey literature. However, the -4.8g/day reduction reported in China appears extra-ordinarily large and perhaps merits some caution [24]. Multi-component interventions clearly have more potential than single interventions, and synergies might be anticipated. [13,93] Similarly powerful benefits have also been observed with comprehensive strategies for tobacco control and alcohol reduction.[35,36]

**Reformulation.** In high income countries, the majority of dietary salt intake comes in processed food (75%) and reformulation can be very effective in reducing salt consumption. [109] Though mandatory reformulation is more powerful, most countries currently use voluntary reformulation.[54,56,68,69,110] Success may then be very dependent on the degree of political pressure applied to the food industry and on regular, independent monitoring, as recently achieved in the UK. [111,112]

**Food labelling.** Nutrition labelling can be potentially effective, as demonstrated in Finland [72] and Brazil.[74] Nutrition labelling allows consumers to make informed choices whilst also putting pressure on the food industry to reformulate.[89] However, interpretation of labels depends on health literacy and different labelling systems may confuse consumers, [113] and reinforce inequalities.[29]. Consumers generally want simple (traffic light) labels which are easier to understand.[76,77,113,114]

Dietary interventions in diverse settings: communities, worksites, schools and homes.
Dietary interventions can be delivered at different levels, such as communities, worksites, schools or to individuals. However, effectiveness varies widely.[45,47,50] Furthermore, the benefits of dietary counselling decrease over time and are thus generally not sustainable; much smaller reductions might therefore be anticipated in unselected individuals in the general population.[44] Furthermore, for many individuals, issues such as competing priorities and financial constraints might reduce compliance and adherence,[8,13,21,22] and thus reduce net population benefits.

**Mass media campaigns.** Few empirical studies have examined salt media campaigns. However, benefits appear to be generally modest.[56, 67,68,69,115] or negligible.[111] Many individuals may not perceive any personal relevance and hence fail to engage in any behaviour change.[22,116,117]

**Taxation.** Price increases can powerfully reduce consumption of tobacco or alcohol. [35,36] However, salt is cheap, and a substantial tax of at least 40% might be needed to reduce consumption by just 6%. [81,118]

## Public health benefits and cost-effectiveness

Most economic analyses have consistently predicted substantial reductions in cardiovascular mortality, and consequent gains in life-years, QALYs, DALYs and healthcare savings. This is consistent with the growing evidence that population-wide prevention policies can often be powerful, rapid, equitable and cost-saving.[38,119–122]

Several modelling studies also investigated the cost-effectiveness of the salt interventions described above. Mandatory and voluntary reformulation appeared far more cost-effective than labelling or [54,55,68] dietary advice targeting individuals.[122]

## Strengths and limitations

This systematic review has multiple strengths. Firstly, two independent reviewers screened all papers and assessed quality using appropriate validated tools. Secondly, the inclusion of
modelling studies (presented separately) adds value by allowing the evaluation of certain interventions where empirical studies failed (e.g. labelling). In addition, we recorded the effect size used in each modelling paper together with the source reference. Furthermore, most of the better quality modelling studies confirmed the superiority of upstream approaches. Finally, the studies reviewed included a wide variety of interventions, thus providing a useful spread of estimates.

Our review also has limitations. We were unable to conduct a formal meta-analysis due to the profound heterogeneity of the diverse studies, many of which included multiple interventions. Furthermore, studies were only included if the full text was available in English (15 non-English papers were excluded). We also had to exclude two potentially relevant studies which lacked the full text.[123,124] Publication bias remains possible, potentially over-estimating the true effect of some interventions. The primary outcome of this study was dietary intake (consumption); we excluded studies considering other dietary behaviours such as awareness, knowledge, preferences or purchasing behaviour. Also, the positive benefits of policy changes may sometimes appear larger if favourable underlying secular trends have not been formally considered. Furthermore, we did not contact authors for missing data. However, all the key information was presented in all but two papers. [123,124] Finally, generalization of the results should be cautioned as countries may vary in baseline salt intake.

Socio-economic Inequalities

More deprived groups more often consume foods high in salt, (and sugar and fat); all are associated with poor health.[125–127] These inequalities persist in Britain [28,29] and Italy.[128] Downstream interventions focused on individuals typically widen inequalities whereas upstream “structural” interventions may reduce inequalities.[33,129,130]

Future research

This review highlights the greater power of combined (multi-component) strategies, mandatory reformulation and traffic light labelling. Most were cost-effective and many were cost-saving. However, the feasibility of implementing policy changes also deserves further study. Many factors can facilitate or obstruct successful policy development, notably including political feasibility and stakeholder influence.[114,131,132]

Stoeckle and Zola’s “upstream”/“downstream” concept was disseminated by John McKinlay,[133] critiqued by Krieger,[134] and then refined as a structural/agentic continuum by McLaren et al 2010.[21] To test our effectiveness hierarchy hypothesis, one ideally needs to quantify the “average” effect of each category of salt reduction intervention. Yet, the limited number and heterogeneity of these studies precludes a formal meta-analysis. However, the consistency with the effectiveness hierarchies demonstrated by tobacco and alcohol control interventions is encouraging. The effectiveness hierarchy hypothesis now clearly needs to be tested in other fields.

Conclusions

There are clear implications for public health. The biggest population-wide reductions in salt consumption were consistently achieved by comprehensive multi-component strategies involving “upstream” population-wide policies (regulation, mandatory reformulation, and food labelling). “Downstream” individually-based interventions appear relatively weak (e.g. dietary counselling to individuals and school children, and media campaigns in isolation).

This ‘effectiveness hierarchy’ might deserve greater emphasis on the agendas of the WHO and other global health organizations reviewing action plans for NCD prevention.
Supporting information

S1 Table. PRISMA checklist.
(DOCX)

S2 Table. Full data extraction tables empirical and modelling studies.
(DOC)

S1 File. Research protocol.
(DOCX)

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References


