

Systematic review and meta-analysis of remotely delivered interventions using self-monitoring or tailored feedback to change dietary behavior

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ABSTRACT

Background: Self-monitoring (SM) of diet and tailored feedback (TF) have been suggested as tools for changing dietary behavior. New technologies allow users to monitor behavior remotely, potentially improving reach, adherence, and outcomes.

Objective: We conducted a systematic literature review and meta-analysis to address the following question: are remotely delivered standalone (i.e., no human contact) interventions that use SM or TF effective in changing eating behaviors?

Design: Five databases were searched in October 2016 (updated in September 2017). Only randomized controlled trials published after 1990 were included. Trials could include any adult population with no history of disordered eating which delivered an SM or TF intervention without direct contact and recorded actual dietary consumption as an outcome. Three assessors independently screened the search results. Two reviewers extracted the study characteristics, intervention details, and outcomes, and assessed risk of bias using the Cochrane tool. Results were converted to standardized mean differences and incorporated into a 3-level (individuals and outcomes nested in studies) random effects meta-analysis.

Results: Twenty-six studies containing 21,262 participants were identified. The majority of the studies were judged to be unclear or at high risk of bias. The meta-analysis showed dietary improvement in the intervention group compared to the control group with a standardized mean difference of 0.17 (95% CI: 0.10, 0.24; $P < 0.0001$). The I^2 statistic for the meta-analysis was 0.77, indicating substantial heterogeneity in results. A “one study removed” sensitivity analysis showed that no single study excessively influenced the results.

Conclusions: Standalone interventions containing self-regulatory methods have a small but significant effect on dietary behavior, and integrating these elements could be important in future interventions. However, there was substantial variation in study results that could not be explained by the characteristics we explored, and there were risk-of-bias concerns with the majority of studies. *Am J Clin Nutr* 2018;107:247–256.

Keywords: systematic review, diet, nutrition, self-monitoring, tailored feedback, remote delivery, multilevel meta-analysis

INTRODUCTION

A “Western diet” typically consists of intake high in saturated fats, salt, and sugars and low in fruit and vegetables, with most of the population in developed countries not meeting the WHO nutrient recommendations (1). This kind of poor diet is implicated in several chronic noncommunicable diseases (diabetes, some cancers, and cardiovascular disease) (2), and responsible in England for >10% of mortality and morbidity (3); hence, the development of public health initiatives targeting this area (4–6).

The mechanisms by which interventions can induce behavior change have been classified into 93 different techniques in the latest taxonomy iteration (7). One review of components associated with increased effectiveness in dietary and physical activity (PA) interventions found that self-regulatory behavior change techniques (SBCTs), e.g., self-monitoring (SM) and tailored feedback (TF), were associated with positive changes in dietary outcomes and differences in how interventions were delivered (provider,

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Abbreviations used: EDNP, Energy dense, nutrient poor; GP, General Practice; PA, physical activity; SBCT, self-regulatory behavior change techniques; SM, self-monitoring; SMD, standardized mean difference; SSB, sugar-sweetened beverage; TF, tailored feedback; WMD, weighted mean difference.

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settings, or modality); moreover, study population characteristics did not appear to be associated with differences in effectiveness (8). Additionally, synergistic effects may occur when SBCTs are combined with other methods that target future performance, particularly those derived from control theory (9).

For diet and PA interventions, SM requires the recording of behavior, e.g., intake or activity, by an individual to actively track trends (10), primarily initiated to motivate modification of unwanted dietary or PA behavior. For SM to be successful, consistent and frequent recording is required (11), with self-evaluation being the next step, followed by self-reinforcement (12, 13). To achieve the recommended behavioral change, i.e., to promote meaningful alterations and maintain wanted behaviors, individuals must analyze their actions, change them accordingly, and preferably repeat the cycle of evaluating behavior against their incorporated standards (13).

On the same continuum as SM, providing TF [where a user's unique characteristics are utilized—e.g., previous actions (14)] can be effective in changing future behavior. Compared to generic information, TF has the potential to provide more individualized information that is perceived as more salient by the user, increasing the likelihood of adhering to such advice (15, 16).

We did not distinguish between interventions that use SM or TF in this review, though they differ in who is providing the results of previous behavior, because they often intertwine and hence can be difficult to separate out; indeed, under the behavior change technique classification, they come under the same cluster (7). This is especially pertinent when technology is used, as many apps contain both SM and TF as integral components, e.g., an app that provides users with a breakdown of the nutrient composition of their meal after they enter the foods they have eaten.

Aim

Our systematic review aimed to answer the question: are remotely delivered interventions that use SM or TF effective in changing eating behaviors?

METHODS

We used initial searches to identify keywords in PubMed to develop a strategy for adaptation to other databases (Embase, CENTRAL, PSYCHINFO, and Web of Science). The search, which was conducted in October 2016 and updated in September 2017, was restricted to those articles published after 1990 in peer-reviewed literature, in English, French, or Spanish. The protocol was placed in advance on PROSPERO: CRD42016042015 (http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016042015) and contains the search strategies used.

In order to be included, trials needed to use a remotely delivered (i.e., any standalone method that does not use direct human support) dietary SM or TF intervention in the intervention arm only and contain outcomes pertaining to most dietary consumption behaviors. We limited our study type to randomized controlled trials. Studies were excluded if they were based on populations that included children < 18 y of age; those with impairments leading to disordered eating (e.g., anorexia nervosa); mixed behavior interventions (e.g., diet and exercise); interventions delivered face-to-face, in groups, or via telephone or video calls; feedback solely tailored to characteristics other than previous dietary

behavior (e.g., feedback tailored by demographics); outcomes only measuring weight, calories, micronutrients (except salt), total carbohydrates, or protein (these outcomes were not included as, depending on study aims and populations of interest, these outcomes could be intended to increase, decrease, or remain the same. However, all other dietary consumption behaviors were included as outcomes for the review).

Three assessors independently screened consequent samples of 5%, calculating interrater agreement with Cohen's and Fleiss's κ . At 10%, substantial agreement had been reached (Cohen's $\kappa = 0.62$ – 0.87 , Fleiss's $\kappa = 0.67$ – 0.72) (17) and the remainder was split between the assessors. Two reviewers extracted the study characteristics, intervention details, and outcomes and assessed the risk of bias using the Cochrane tool (18). Subgroup analyses were conducted stratified by risk of bias, with studies categorized as being at a high risk of bias if they were rated as a high risk for any bias included in the Cochrane tool with the exception of performance bias (due to the nature of the intervention, virtually all of the studies did not blind the participants to their intervention status).

Data synthesis

For each study, data were extracted on the first reported measures either during the intervention period or instantly after it to assess the immediate impact of the intervention. For each dietary outcome, we extracted data on the mean and SD within the control and intervention groups. Where results were reported for > 1 control or intervention group, the mean and SD were combined using standard methods described in the Cochrane handbook (18). In some cases, data were extracted on the mean and SD in the change of outcome between intervention period and baseline, but only when data on mean and SD of the outcomes themselves were not available; this was not chosen as the primary outcome as it was only adequately reported in a small minority of studies. All results were converted to standardized mean differences (SMDs) using Hedge's *g* statistic, as described in the Cochrane handbook (18). For dietary outcomes where the intervention aims to reduce consumption (e.g., saturated fat intake), we multiplied the SMD by -1 , so that in each case a positive SMD represented an improvement in diet.

All of the dietary outcomes were included in a 3-level, random-effects meta-analysis, with both individuals and dietary outcomes nested in studies. This method explicitly accounts for correlation within studies of different dietary outcomes (19). Heterogeneity was measured using the I^2 statistic. The inclusion of multiple outcomes from single studies precludes the use of funnel plots to assess the risk of publication bias, and therefore we conducted a multilevel (outcomes nested in studies) meta-regression of the effect of standard error on effect size; in the absence of publication bias, these 2 variables should not be related. As a sensitivity analysis, we conducted a "one study removed" analysis to assess whether our meta-analysis results were overly influenced by any of the included studies. We explored reasons for heterogeneity by conducting univariate multilevel (outcomes nested in studies) regression analyses of the impact of the following variables on the effect size: risk of bias; type of dietary outcome (fruit and vegetables, fatty acids, or other); geography (Europe, United States, or other); mode of delivery of intervention (mobile phone, website, or other); length of intervention period; population type

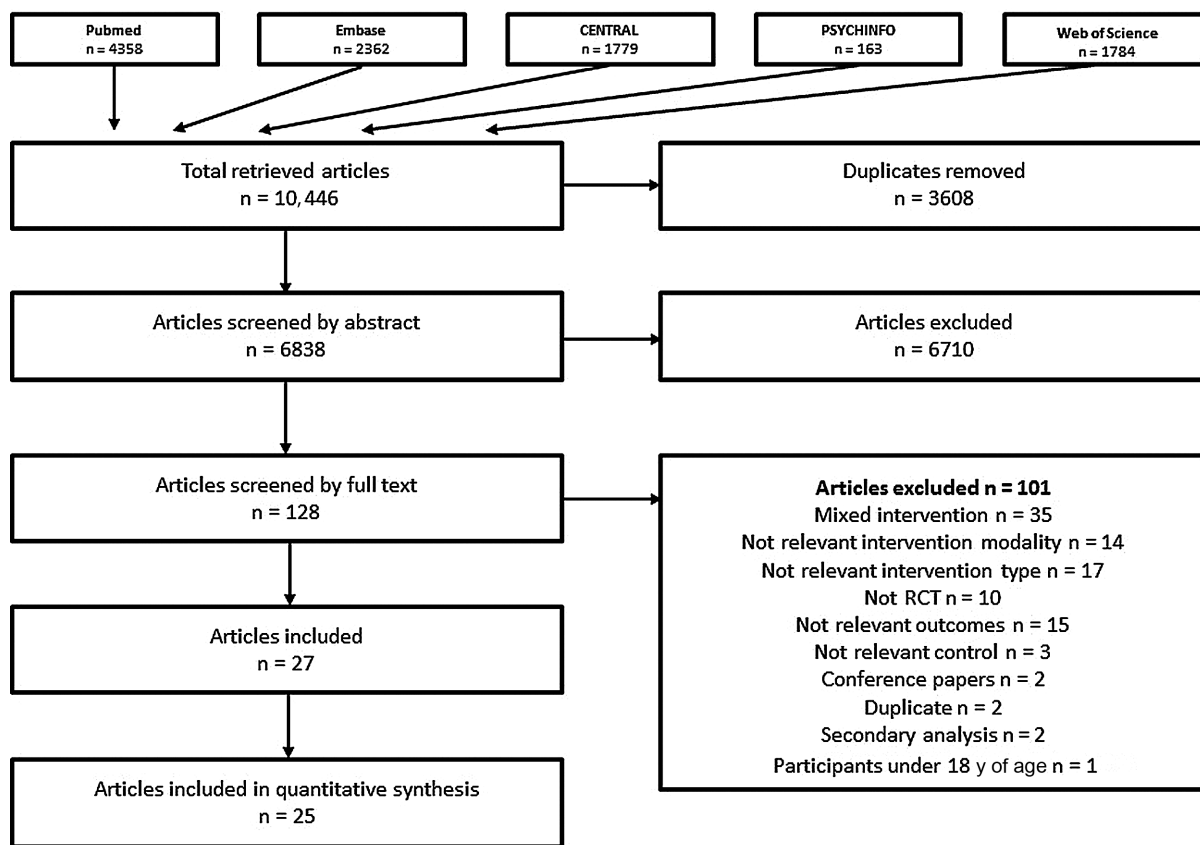


FIGURE 1 Study selection. RCT, randomized controlled trial.

(general population, or specified by cardiovascular risk factor, e.g., overweight); and method of diet measurement (food diaries, food frequency questionnaires, or other). All analyses were conducted in R version 3.2.2, using the metafor and lme4 packages (20–22).

RESULTS

As shown in Figure 1, after duplicates were removed, we retrieved 6838 articles. After abstract and paper screening, this was narrowed down to 27 articles (see Table 1) (23–49) reporting on 26 studies containing 37 interventions for inclusion, of which 23 studies (23, 24, 27–39, 41–49) were included in the meta-analysis.

Population

All studies were performed in high-income countries, with the majority (n = 11) held in the United States (23, 25, 26, 29–33, 37, 38, 40), followed by the Netherlands (n = 5) (27, 28, 36, 39, 42, 43), with the rest comprised of Australia, the United Kingdom, Italy, France, and a single trial conducted in multiple European countries. There were 21,262 participants in total. Where the information was provided, ages ranged from 18 to 79 y with the average number of participants at baseline being 818 (median 517), dropping to 598 (median 456) at study completion. Participants were found from: the general population in 6 studies (25, 28, 35,

36, 42, 43, 49); those with risk factors such as obesity or diabetics (n = 4) (38, 45–47); employees (n = 5) (24, 27, 39, 41); recruited from healthcare networks, e.g., primary care patients (n = 4) (23, 29, 33, 37); those with low income (n = 3) (26, 30, 31); and the 4 remaining used students (40, 48), internet shoppers (34), and those who wished to improve their diet (44).

Delivery of intervention

The interventions, which had a mean and median length of 6 mo, were carried out in a variety of ways: paper reports, letters, or booklets were used by 11 (24, 27–29, 31–33, 36, 37, 41, 47), 1 using this in conjunction with a computer (36). The internet was used in 7 cases (23, 34, 39, 40, 42–44, 49)—again, 1 study used this method alongside offline computer use (39). Those solely using computers accounted for 2 studies (26, 30), with the remainder using either handheld devices (n = 3), divided up into mobile phones (35, 38, 48) and personal digital assistants (25), or Minitel (n = 2)—a French version of teletext (45, 46).

The majority of the studies used TF solely; only 2 studies used SM on its own (38, 48). Tailoring was rarely based on observed behavior in the intervention, happening in 4 occurrences (34, 42, 43, 45, 46), but on data collected through surveys (n = 18) (23–33, 36, 37, 39, 40, 44, 47, 49) or twice with food diaries (35, 41). The control in 16 cases was given general untailed nutritional information (23–25, 27–29, 31–34, 36, 37, 39, 42, 43, 48, 49), 3 of which also had another control group receiving no information

TABLE 1
Characteristics of included studies¹

Study first author, year, country (ref)	Population	Length (mo)	Intervention(s)	Tailored on	Comparison(s)	Outcomes	Measurement method
Alexander, 2010, USA (23)	2513 healthcare members	12	1. "MENU" program (website) 2. Program + e-mail counselling	Latest FFQ	General nutritional information website	F + V (serv)	2-item FFQ
Armitage, 2001, UK (24)	801 hospital workers	5	A letter with an additional sentence on current fat intake	Baseline FFQ	A general nutritional information leaflet	Fat %/sat fat (g)	63-item FFQ
Atienza, 2008, USA (25)	36 participants from general population	2	PDA program (notified to SM 2 times/d)	PDA FFQ	General nutritional information material	Vegetables (serv)/fiber (serv)	FFQ, unknown length
Block, 2004, USA (26)	491 low-income women	9	"Little by Little" CD-ROM (once)	CD-ROM survey	Stress-management CD-ROM	F + V (serv)	1-d dietary recall
Brug, 1996, Netherlands (27)	507 oil company employees	1.5	A tailored report	Baseline survey	General nutritional information material	Fat (score)/F + V (serv)	30-item FFQ
Brug, 1998, Netherlands (28)	762 participants from general population	2	1. A tailored report 2. Two tailored reports	Baseline survey Latest survey	General nutritional information material	Fat (score)/F + V (serv)	32-item FFQ
Campbell, 1994, USA (29)	558 patients	4	A tailored report	Baseline survey	1. An untailored report 2. No information	Fat (g)/sat fat (g)/F + V (serv)	28-item FFQ
Campbell, 1998, USA (30)	526 low-income women	3	"Sisters at Heart" computer program (once)	Survey in program	No information	Fat (score)	16-item FFQ
Gans, 2009, USA (31)	1841 low-income adults	7	1. A tailored report 2. The tailored report split into 4 3. Four tailored reports	Baseline survey Latest survey	An untailored report	Fat (score)/F + V (serv)	FFQ, unknown length
Gans, 2015, USA (32)	2525 employees from 43 worksites	8	1. Three tailored reports 2. Three tailored reports + 3 videos	Latest survey	3 untailored reports	Fat %/F + V (cups)	FFQ, unknown length
Heimendinger, 2005, USA (33)	3402 callers to cancer hotline	12	1. A tailored report 2. Four tailored reports 3. Four tailored reports	Baseline survey Latest survey	An untailored report	F + V (serv)	1-item FFQ
Huang, 2006, Australia (34)	497 internet shoppers	5	Feedback while shopping online	Food selected	General nutritional information website	Sat fat %	Food purchased
Kerr, 2016, Australia (35)	247 participants from general population	6	1. Two feedback texts (once) 2. The 2 initial texts before weekly motivational texts	Baseline food diary	Wait listed	F + V (serv)/SSB (serv)/EDNP (serv)	4-d food diary (photos using mobile app)
Kroeze, 2008, Netherlands (36)	442 participants from general population	6	1. CD-ROM program 2. A tailored report	Baseline FFQ	General nutritional information material	Fat (g %)/sat fat (g %)	35-item FFQ

(Continued)

TABLE 1
(Continued)

Study first author, year, country (ref)	Population	Length (mo)	Intervention(s)	Tailored on	Comparison(s)	Outcomes	Measurement method
Lutz, 1999, USA (37)	710 medical insurance subscribers	6	1. Four tailored reports 2. The reports also including goalsetting	Baseline survey	1. Four untailored reports 2. No newsletters	F + V (serv)	17-item FFQ
Mummah, 2016, USA (38)	17 overweight iPhone users	3	“Vegethon” mobile app (requested daily use)	N/A	Wait-listed	Vegetables (serv)	28-item FFQ
Onema, 2005, Netherlands (39)	782 employees from 7 work sites	0.75	Program (CD-ROM/intranet)	Survey in program	1. General nutritional information material 2. No information	Fat (score)/F + V (serv.)	49-item FFQ
Poddar, 2010, USA (40)	294 students	5	Internet course (requested daily use)	Latest FFQ on course	No course	Dairy (serv)	7-d food diary
Raats, 1999, UK (41)	171 university staff	4	A tailored report	Baseline food diary	No report	Carbs %fat %/protein %	7-d food diary
Springyloet, 2015 a & b, Netherlands (42, 43)	1,349 participants from general population	9	1. “Basic” internet program (requested use 3 times/wk) 2. “Plus” program	Past behavior in program	General nutritional information material	Fruit (pieces)/veg (g)/sat fat (points)/high-energy snacks (pieces)	66-item FFQ
Tapper, 2014, UK (44)	100 people wanting to improve diet	6	“Health Values” internet program (requested weekly use)	Latest online FFQ	No information	F + V (cups)/sat fat (g)/added sugar (g)	55-item FFQ
Turnin, 1992, France (45)	105 diabetic subjects	12	“Diabeto” program (Mimitel)	Meals entered	Wait-listed	Carbs %fat %	3-d diet analysis by dietician
Turnin, 2001, France (46)	557 obese people	12	“Nutri-Expert” program (Mimitel)	Meals entered	7 dietitian/doctor visits	Carbs %fat %/protein %	3-d food diary
Wright, 2011, Australia (47)	178 people with cardiovascular risk factors	3	3 reports	Latest FFQ	1. Two group education sessions by dietician 2. Wait list	Sat fat (g)/fiber (g)/F + V—not potatoes (serv)/grain (serv)	1. 63-item FFQ 2. 7-d food diary
Carfora, 2017, Italy (48)	244 students	0.25	Daily text messages encouraging self-monitoring of red meat consumption	N/A	No contact	Red meat consumption	Food diaries
Celis-Morales, 2017, 7 European countries (49)	1607 adults	6	1. Personalized feedback on diet 2. Personalized feedback on diet + phenotype 3. Personalized feedback on diet + phenotype + genotype	Baseline FFQ	General dietary advice	Fruit, vegetables, whole grains, oily fish, red meat, salt, total fat	157-item FFQ

¹ EDNP, energy dense, nutrient poor; FFQ, food-frequency questionnaire; F + V, fruit and vegetables; N/A, not applicable; PDA, personal digital assistant; ref, reference; sat fat, saturated fat; serv, servings; SM, self-monitoring; SSB, sugar-sweetened beverages.

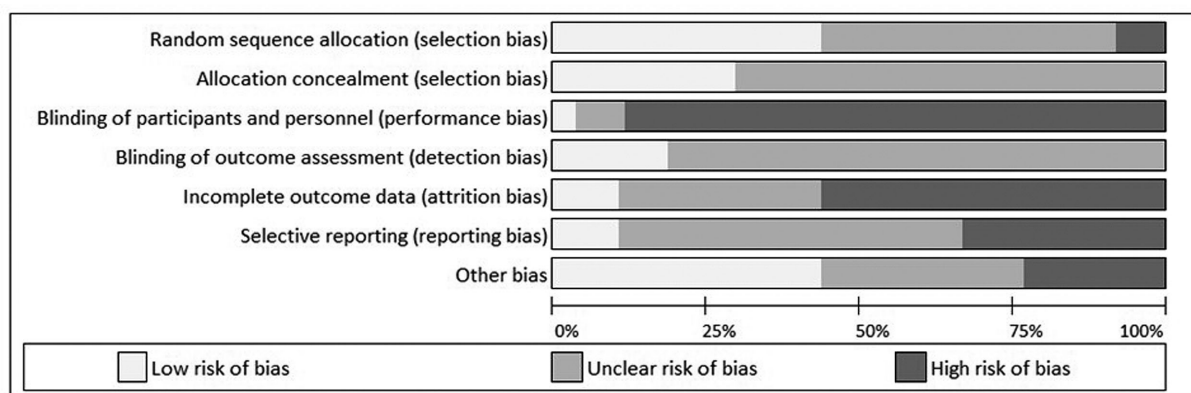


FIGURE 2 Bias assessment using the Cochrane assessment of bias tool.

(29, 37, 39). No information was provided to the control group in 4 studies (30, 40, 41, 44). In 4 studies the intervention was provided to the control group at the end of the study (35, 38, 45, 47); additionally, in 1, another part was given group education instead (47). The remaining 2 were given either health professional visits (46) or nonnutritional information, i.e., stress management (26).

Outcomes

Multiple dietary outcomes were collected in most of the studies included in the meta-analysis, including: total fat ($n = 11$) (24, 27–32, 36, 41, 45, 46), saturated fat ($n = 8$) (24, 29, 34, 36, 39, 42–44, 47), fruit ($n = 8$) (27, 28, 32, 35, 39, 42, 43, 47, 49), vegetables ($n = 9$) (27, 28, 32, 35, 38, 39, 42, 43, 47, 49), fruit and vegetables together ($n = 7$) (23, 29, 31, 33, 37, 44, 49), and assorted others ($n = 7$) (35, 42–44, 47–49). No studies included fiber as an outcome. These dietary outcomes were measured in 2 main ways: either food-frequency questionnaires ($n = 17$) (23–25, 27–33, 36–39, 42–44, 49) or via a food diary ($n = 7$) (26, 35, 40, 41, 45, 46, 48). In the remaining 2 studies, 1 used both the questionnaire and the diary (47), whereas purchased food was assessed in the other (34).

Three trials were excluded from the meta-analysis as we could not extract numeric outcome data (25, 26, 40); 2 of these showed no change in the intake amount of either fruit and vegetables (26) or dairy (40). Atienza showed an increase of vegetables by 1.5–2.5 servings/d ($P = 0.02$) and in fiber by 3.7–4.5 servings/d ($P = 0.10$) (25).

Bias

As shown in Figure 2, most studies were found to have an unclear risk of bias in the domains of random sequence generation, allocation concealment, blinding of outcome assessment, and selective reporting due to a lack of clarity about how randomization, blinding, or analysis was undertaken. No studies had a high risk of bias in either allocation concealment or blinding of outcome assessment. Due to the nature of the interventions, it is difficult to blind participants, and hence most studies were found to have a high risk of bias in the related section. If this domain is disregarded, only 5 studies did not contain high risk of bias judgments.

Meta-analysis

The multilevel meta-analysis revealed a pooled SMD of 0.17 (0.10, 0.24; $P < 0.0001$), indicating a significant improvement in diets as a result of tailored feedback and/or self-monitoring of diets (Figure 3). An SMD < 0.2 is sometimes described as a small effect (50). The I^2 statistic for the meta-analysis was 0.77, indicating that 77% of the variance in the final result was due to between studies variance.

Multilevel regression (outcomes nested in studies) showed that the standard error was strongly positively associated with effect size, indicating potential publication bias. However, 1 study (38) was an outlier in the regression, with very large SE and effect size compared to the other results. Therefore, we conducted the regression analysis again with this study excluded. The results showed no effect of SE on effect size ($\beta = 1.11$, $SE = 0.73$, $P = 0.131$), indicating no evidence of publication bias. The “one study removed” sensitivity analysis revealed that no single study unduly influenced the results of the multilevel meta-analysis. The pooled effect size in the sensitivity analyses ranged from 0.12 to 0.18 and the P values were always < 0.001 . The subgroup analyses stratified by risk of bias showed very little difference in studies with low risk of bias [SMD 0.17 (0.05, 0.29), $P < 0.01$] and high risk of bias [SMD 0.17 (0.08, 0.26), $P < 0.001$] (see Supplemental Figure 1 and Supplemental Figure 2). Our multilevel regression analyses exploring reasons for the heterogeneity in results found only 1 variable where differences in effect size were significant at the $P < 0.05$ level. Studies that measured diet quality using means other than food diaries or food-frequency questionnaires produced larger results ($P = 0.028$). The only other result with borderline significance was that results for dietary outcomes other than fruit, vegetables, or fatty acids tended to be larger ($P = 0.077$) (see Supplemental Table 1 for full results).

DISCUSSION

Our review showed a positive but small change in diet as a result of SM or TF (based predominantly on studies of TF), although with high heterogeneity between results. That is to say, remote interventions using self-regulation methods do influence dietary change for the better and, potentially, if this effect was extrapolated over a population, it could produce a significant impact (51). This is despite potential barriers such as cost

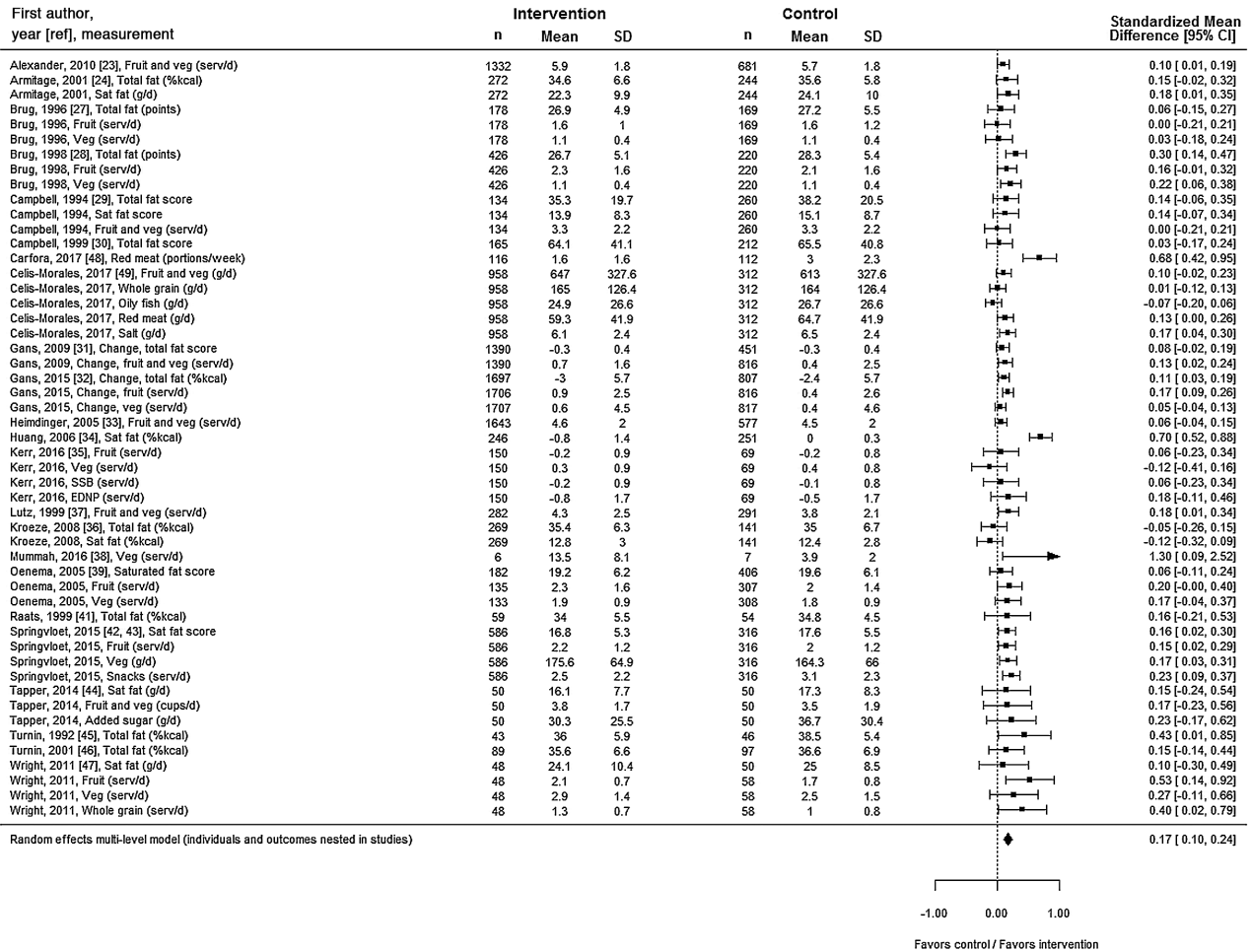


FIGURE 3 Forest plot of the 51 dietary outcomes nested in 23 studies included in the meta-analysis. Fat scores or points are as described in Brug et al., 1998 (28): “The fat score that ranges between 12 and 60 is the result of a short [FFQ] in which the frequency of use and portion size of the 12 main fat sources in the Dutch diet are assessed”; Campbell et al., 1994 (29): “Dietary fat and saturated fat scores were obtained by multiplying frequency of consumption (calculated as servings per day) by portion data for each item and summing the items”; Campbell et al., 1999 (30): “Dietary fat scores were obtained by multiplying frequency of consumption adjusted to daily intake (3, 2, 1, 0.5, 0.14, 0.07 and 0) by fat content per serving of each item and summing items”; Gans et al., 2009 (31): “The FHQ fat summary score was calculated by taking the mean of all behavioral FHQ questions ... response categories for the behavioral questions were: 0 = almost always, 1 = often, 2 = sometimes, 3 = rarely, and 4 = never”; Oenema et al., 2005 (39): “Answers to the [FFQ] items were converted into a fat score ranging from 0 to 80, reflecting total saturated fat intake”; Springvloet et al., 2015 (42, 43): “Saturated fat intake was measured with [an FFQ] ... Based on this questionnaire, fat points were calculated ... The total ‘fat score’ was based on 35 ... food products [to which] ... fat points were assigned for each product group, ranging from zero ... -5 (...summed up to create a total fat points measure).” EDNP, energy dense, nutrient poor; FFQ, food-frequency questionnaire; FHQ, food habits questionnaire; Sat, saturated; serv, servings; SSB, sugar-sweetened beverage; Veg, vegetables; %kcal, percentage of total.

(52)—following dietary recommendations has been found to cost more and hence can become unaffordable amongst lower socio-economic classes (53, 54)—as well as restrictions that participants face on time, motivation, social support, organizational demands, and emotional availability (55, 56).

As this review shows that approaches not requiring instantaneous personal contact can positively impact on diet, this has implications for rolling out and integrating digital health interventions into mainstream clinical practice. Media that have a high potential reach and widespread usage, such as supermarket loyalty cards (57) and health apps—both mobile (58) and online (5, 59)—can potentially raise adherence and the measurement accuracy of SBCTs. In addition, they can be programmed to provide advice that accommodates personal needs and preferences, leading to potential improvements in associated health behaviors (56,

59, 60). It is easier to implement digital interventions at scale (8, 56), but most of the evidence identified in this review is from studies that used more traditional research media (e.g. paper diaries).

Other literature

Although there have been previous systematic reviews that have looked at SM and TF interventions (9, 10, 15, 60–67), our review was more inclusive on population characteristics, outcomes, and delivery methods. In contrast, prior reviews have the following limitations: 1) they have focused on those without health difficulties (9) or a narrow population such as obese participants (10); 2) they have concentrated on the intention to change (67) or weight loss (60); 3) they were restricted to particular food groups (63); 4) they used only specific delivery media (61, 66);

and 5) they did not discriminate between a wide variety of behavioral techniques (65) or did not isolate the dietary component of the intervention (15, 62). Our work shows similar results to these systematic reviews discussed below which have shown small positive effect sizes on several discrete outcomes (9, 62, 64). Additionally our review extends this, through combining a broad range of dietary outcomes to show an overall effect, by using the technique of multilevel meta-analysis (19), enabling us to cope with within-study correlations between study outcomes.

The review by Broekhuizen et al. (62) looked into computer tailoring of education for nutrition and PA compared to generic or no information. In the dietary domains, a favorable significant effect was found in fat (81%), fruit and vegetables (83%), and both studies on fiber. However, this was not the case in interventions on grain, added sugar, or dairy, which were comprised of one study each.

Eyles and Mhurchu (64) analyzed the long-term effectiveness (≥ 6 mo) of nutritional TF. For fruit and vegetables, 4 studies comparing TF against generic information showed a weighted mean difference (WMD) of 0.35 servings/d (95% CI: 0.19, 0.52; $P < 0.0001$) increasing to a WMD of 0.59 servings/d (95% CI: 0.21, 0.98; $P = 0.002$) when contrasted against no education in 6 trials. Likewise for energy from total fat, 3 papers using TF compared with generic information showed a WMD of -2.2% (95% CI: -3.0 , -1.4 ; $P < 0.00001$) and a WMD of -2.45% energy (95% CI: -4.08 , -0.82 ; $P = 0.0005$) in the 6 cases where the control was presented with no information.

Michie et al. (9) classified behavioral techniques in healthy eating and PA. Uniting both of these interventions, they found an effect size of 0.41 (95% CI: 0.29, 0.52) in the 46 cases using SM compared with 0.26 (95% CI: 0.21, 0.30) in the 76 which did not use SM ($P = 0.189$). On the other hand, the effect size was 0.32 (95% CI: 0.24, 0.39) in the feedback domain ($n = 61$), as opposed to 0.30 (95% CI: 0.24, 0.37) in the other 61 occurrences. In a different analysis, healthy eating was looked at separately from PA, though SM was not examined independently but combined with the following: 1) provision of feedback on performance; 2) prompt intention formation; and 3) specific goal-setting or review of behavioral goals. In these 13 trials, the effect size grew to 0.54 (95% CI: 0.21, 0.86), in contrast to 0.24 (95% CI: 0.18, 0.29) in the remaining 40 studies.

Strengths

As mentioned above, compared with others, our review includes a broader range of population characteristics, outcomes, and intervention types despite focusing purely on the area of diet. The multilevel meta-analysis meant that we could include multiple dietary outcome results from single studies and could include results from different dietary outcomes across different studies. This greatly increased the statistical power of our meta-analysis and expanded the range of our systematic review, under the assumption that the different interventions were comparable examples of SM or TF (68). Due to the large amount of heterogeneity in the intervention designs, we conducted random-effects meta-analysis.

Limitations

As we did not consult gray literature, we may have not identified all the relevant literature. Moreover, although the studies comprised a wide array of participants, environments, and modalities, they were only performed in high-income countries and mostly using nondigital methods, and therefore caution needs to be exercised in extrapolating the conclusions. Additionally, our results may be affected by misreporting; dietary intake is well known to be underreported (69) and this is not helped by having no consensus over the questionnaire or diary used for recording outcomes.

Finally, we were not able to assess long-term effectiveness of SM and TF as we only analyzed the data at the 6-mo stage and did not consider any follow-up results. Indeed, in comparison to other methods that are not SM or TF, it has been postulated that there is no sustained change long term, and when used for weight management, a decline in adherence tends to occur after 1 mo (56). Perhaps this is due to shifting motivations from those who prompted the initial change or an increased requirement of limited self-regulatory effort as automatic habitual responses are not yet fixed (65, 70).

Due to the sparse use of SM as an intervention on its own twice and together with TF in 3 trials, it is difficult to draw conclusions about its effectiveness, alone or combined. Additionally, we did not measure other intervention methods used in the trials such as goal setting (7), and as such it is hard to distinguish the individual contribution to the overall effect.

Recommendations

We noticed that no studies had fiber as an outcome, despite evidence that an increased fiber intake can have health benefits (2). There were no trials in low- or middle-income countries. Therefore, we recommend the above areas for future research. It would also be beneficial to improve the reporting of group sizes, determine the reasons for drop-outs, ascertain the blinding procedures (particularly for data analysis) and consider how missing data have been dealt with so that discerning bias is easier. It will also be important to develop strategies to overcome the obstacles to using SM and TF, such as declining motivation, that have been identified.

Conclusion

This systematic review of the literature set out to answer the question: are remote interventions that use SM or TF effective in changing eating behaviors? The meta-analysis showed a significant—albeit small, heterogeneous, and at risk of bias—positive effect of standalone SM and TF on dietary change (based predominantly on TF studies in this review). At a population level, such an intervention could have an appreciable impact. Given the ability of digital health interventions to deliver interventions remotely and to reach wide audiences (6), such interventions have the potential to make a contribution to improving the healthiness of diets.

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NT and RS: conducted the data extraction; NT, RS, and PS: conducted the analyses; NT and PS: wrote the first draft of the manuscript; and all authors: read and approved the final manuscript. None of the authors have any conflicts of interest related to this study.

REFERENCES

- Mazzocchi M, Brasili C, Sandri E. Trends in dietary patterns and compliance with World Health Organization recommendations: a cross-country analysis. *Public Health Nutr* 2008;11:535–40.
- GBD 2015 Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet* 2016;388:1659–724.
- Newton JN, Briggs ADM, Murray CJL, Dicker D, Foreman KJ, Wang H, Naghavi M, Forouzanfar MH, Ohno SL, Barber RM et al. Changes in health in England, with analysis by English regions and areas of deprivation, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2015;386:2257–74.
- Hyseni L, Atkinson M, Bromley H, Orton L, Lloyd-Williams F, McGill R, Capewell S. The effects of policy actions to improve population dietary patterns and prevent diet-related non-communicable diseases: scoping review. *Eur J Clin Nutr* 2017;71:694–711.
- Kohl LF, Crutzen R, de Vries NK. Online prevention aimed at lifestyle behaviors: a systematic review of reviews. *J Med Internet Res* 2013;15:e146.
- Public Health England. Change4Life Sugar Smart app. Version current 17 July 2015. Internet: <http://www.nhs.uk/Tools/Pages/Change4Life-SugarSwaps.aspx> (accessed 17 June 2017)
- Michie S, Richardson M, Johnston M, Abraham C, Francis J, Hardeman W, Eccles MP, Cane J, Wood CE. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Ann Behav Med* 2013;46(1):81–95.
- Greaves CJ, Sheppard KE, Abraham C, Hardeman W, Roden M, Evans PH, Schwarz P, The IMAGE Study Group. Systematic review of reviews of intervention components associated with increased effectiveness in dietary and physical activity interventions. *BMC Public Health* 2011;11:119.
- Michie S, Abraham C, Whittington C, McAteer J, Gupta S. Effective techniques in healthy eating and physical activity interventions: a meta-regression. *Health Psychol* 2009;28:690–701.
- Hartmann-Boyce J, Jebb SA, Fletcher BR, Aveyard P. Self-help for weight loss in overweight and obese adults: systematic review and meta-analysis. *Am J Public Health* 2015;105:e43–57.
- Peterson ND, Middleton KR, Nackers LM, Medina KE, Milsom VA, Perri MG. Dietary self-monitoring and long-term success with weight management. *Obesity* 2014;22:1962–7.
- Bandura A. Health promotion from the perspective of social cognitive theory. *Psychol Health* 1998;13(4):623–49.
- Kanfer FH, Gaelick L. Self-management methods. Helping people change. Oxford: Pergamon Press; 1975.
- Kreuter MW, Strecher VJ, Glassman B. One size does not fit all: the case for tailoring print materials. *Ann Behav Med* 1999;21:276–83.
- Noar SM, Benac CN, Harris MS. Does tailoring matter? Meta-analytic review of tailored print health behavior change interventions. *Psychol Bull* 2007;133:673–93.
- Hawkins RP, Kreuter M, Resnicow K, Fishbein M, Dijkstra A. Understanding tailoring in communicating about health. *Health Educ Res* 2008;23:454–66.
- Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;33:159–74.
- Higgins JP, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD, Savovic J, Schulz KF, Weeks L, Sterne JA et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ* 2011;343:d5928.
- Van den Noortgate W, López-López JA, Marín-Martínez F, Sánchez-Meca J. Meta-analysis of multiple outcomes: a multilevel approach. *Behav Res Methods* 2015;47:1274–94.
- R Core Team. R. A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2015.
- Viechtbauer W. Conducting meta-analyses in R with the metafor package. *J Stat Softw* 2010;36:1–48.
- Bates D, Maechler M, Bolker B, Walker S, Christensen R, Singmann H, Dai B, Grothendieck G, Green P. lme4. Vienna: CRAN Repository; 2016.
- Alexander GL, McClure JB, Calvi JH, Divine GW, Stopponi MA, Rolnick SJ, Heimendinger J, Tolsma DD, Resnicow K, Campbell MK et al. A randomized clinical trial evaluating online interventions to improve fruit and vegetable consumption. *Am J Public Health* 2010;100:319–26.
- Armitage C, Conner M. Efficacy of a minimal intervention to reduce fat intake. *Soc Sci Med* (1982) 2001;52:1517–24.
- Atienza AA, King AC, Oliveira BM, Ahn DK, Gardner CD. Using handheld computer technologies to improve dietary intake. *Am J Prev Med* 2008;34:514–8.
- Block G, Wakimoto P, Mandel R, Metz D, Fujii ML, Feldman N, Sutherland B. A randomized trial of the Little by Little CD-ROM: demonstrated effectiveness in increasing fruit and vegetable intake in a low-income population. *Prev Chronic Dis* 2004;1:A08.
- Brug J, Glanz K, Van Assema P, Kok G, van Breukelen GJ. The impact of a computer-tailored nutrition intervention. *Prev Med* 1996;25:236–42.
- Brug J, Glanz K, Van Assema P, Kok G, van Breukelen GJ. The impact of computer-tailored feedback and iterative feedback on fat, fruit, and vegetable intake. *Health Educ Behav* 1998;25:517–31.
- Campbell MK, DeVellis BM, Strecher VJ, Ammerman AS, DeVellis RF, Sandler RS. Improving dietary behavior: the effectiveness of tailored messages in primary care settings. *Am J Public Health* 1994;84:783–7.
- Campbell MK, DeVellis BM, Strecher VJ, Ammerman AS, DeVellis RF, Sandler RS. A tailored multimedia nutrition education pilot program for low-income women receiving food assistance. *Health Educ Res* 1999;14:257–67.
- Gans KM, Risica PM, Dulin-Keita A, Mello J, Dawood M, Strolla LO, Harel O. Effectiveness of different methods for delivering tailored nutrition education to low income, ethnically diverse adults. *Int J Behav Nutr Phys Act* 2009;6:24.
- Gans KM, Risica PM, Dulin-Keita A, Mello J, Dawood M, Strolla LO, Harel O. Innovative video tailoring for dietary change: final results of the Good for you! cluster randomized trial. *Int J Behav Nutr Phys Act* 2015;12:130.
- Heimendinger J, O'Neill C, Marcus AC, Wolfe P, Julesburg K, Morra M, Allen A, Davis S, Mowad L, Perocchia RS et al. Multiple tailored messages are effective in increasing fruit and vegetable consumption among callers to the Cancer Information Service. *J Health Commun* 2005;10 Suppl 1:S65–82.
- Huang A, Barzi F, Huxley R, Denyer G, Rohrlach B, Jayne K, Neal B. The effects on saturated fat purchases of providing Internet shoppers with purchase-specific dietary advice: a randomised trial. *PLoS Clin Trials* 2006;1(5):e22.
- Kerr DA, Harray AJ, Pollard CM, Dhaliwal SS, Delp EJ, Howat PA, Pickering MR, Ahmad Z, Meng X, Pratt IS et al. The connecting health and technology study: a 6-month randomized controlled trial to improve nutrition behaviours using a mobile food record and text messaging support in young adults. *Int J Behav Nutr Phys Act* 2016;13:52.
- Kroeze W, Oenema A, Campbell M, Brug J. The efficacy of web-based and print-delivered computer-tailored interventions to reduce fat intake: Results of a randomized, controlled trial. *J Nutr Educ Behav* 2008;40:226–36.
- Lutz SF, Ammerman AS, Atwood JR, Campbell MK, DeVellis RF, Rosamond WD. Innovative newsletter interventions improve fruit and vegetable consumption in healthy adults. *J Am Diet Assoc* 1999;99:705–9.
- Mummah SA, Mathur M, King AC, Gardner CD, Sutton S. Mobile technology for vegetable consumption: a randomized controlled pilot study in overweight adults. *JMIR Mhealth Uhealth* 2016;4:231–43.
- Oenema A, Tan F, Brug J. Short-term efficacy of a web-based computer-tailored nutrition intervention: main effects and mediators. *Ann Behav Med* 2005;29:54–63.
- Poddar KH, Hosig KW, Anderson ES, Nickols-Richardson SM, Duncan SE. Web-based nutrition education intervention improves self-efficacy

- and self-regulation related to increased dairy intake in college students. *J Am Diet Assoc* 2010;110:1723–7.
41. Raats MM, Sparks P, Geekie MA, Shepherd R. The effects of providing personalized dietary feedback. A semi-computerized approach. *Patient Educ Counsel* 1999;37:177–89.
 42. Springvloet L, Lechner L, de Vries H, Candel MJJM, Oenema A. Short- and medium-term efficacy of a web-based computer-tailored nutrition education intervention for adults including cognitive and environmental feedback: randomized controlled trial. *J Med Internet Res* 2015;17:e23.
 43. Springvloet L, Lechner L, de Vries H, Oenema A. Long-term efficacy of a Web-based computer-tailored nutrition education intervention for adults including cognitive and environmental feedback: a randomized controlled trial. *BMC Public Health* 2015;15:372.
 44. Tapper K, Jiga-Boy G, Maio GR, Haddock G, Lewis M. Development and preliminary evaluation of an internet-based healthy eating program: randomized controlled trial. *J Med Internet Res* 2014;16:e231.
 45. Turnin MC, Beddock RH, Clottes JP, Martini PF, Abadie RG, Buisson JC, Soulé-Dupuy C, Bonneau M, Camaré R, Anton JP et al. Telematic expert system Diabeto. New tool for diet self-monitoring for diabetic patients. *Diabetes Care* 1992;15:204–12.
 46. Turnin MC, Bourgeois O, Cathelineau G, Leguerrier AM, Halimi S, Sandre-Banon D, Coliche V, Breux M, Verlet E, Labrousse F et al. Multicenter randomized evaluation of a nutritional education software in obese patients. *Diabetes Metab* 2001;27:139–47.
 47. Wright JL, Sherriff JL, Dhaliwal SS, Mamo JC. Tailored, iterative, printed dietary feedback is as effective as group education in improving dietary behaviours: results from a randomised control trial in middle-aged adults with cardiovascular risk factors. *Int J Behav Nutr Phys Act* 2011;8:43.
 48. Carfora V, Caso D, Conner M. Correlational study and randomised controlled trial for understanding and changing red meat consumption: the role of eating identities. *Soc Sci Med* 2017;175:244–52.
 49. Celis-Morales C, Livingstone KM, Marsaux CFM, Macready AL, Fallaize R, O'Donovan CB, Woolhead C, Forster H, Walsh MC, Navas-Carretero S et al. on behalf of the Food4Me Study Effect of personalized nutrition on health related behaviour change: evidence from the Food4Me European randomized controlled trial. *Int J Epidemiol* 2017;46:578–88.
 50. Sullivan GM, Feinn R. Using effect size—or why the p value is not enough. *J Grad Med Educ* 2012;4:279–82.
 51. Rose G, Sick individuals and sick populations. *Int J Epidemiol* 1985;14:32–8.
 52. Kruger J, Blanck HM, Gillespie C. Dietary and physical activity behaviors among adults successful at weight loss maintenance. *Int J Behav Nutr Phys Act* 2006;3:17.
 53. Lee JH, Ralston RA, Truby H. Influence of food cost on diet quality and risk factors for chronic disease: a systematic review. *Nutr Diet* 2011;68:248–61.
 54. Rao M, Afshin A, Singh G, Mozaffarian D. Do healthier foods and diet patterns cost more than less healthy options? A systematic review and meta-analysis. *BMJ Open* 2013;3:e004277.
 55. Burke LE, Wang J, Sevick MA. Experiences of self-monitoring: successes and struggles during treatment for weight loss. *Qual Health Res* 2009;19:815–28.
 56. Yu ZP, Sealey-Potts C, Rodriguez J. Dietary self-monitoring in weight management: current evidence on efficacy and adherence. *J Acad Nutr Diet* 2015;115:1931–8.
 57. Cook L. Which loyalty cards are best to have in your wallet? *Financial Times*, 24 March 2016. Internet: <https://www.ft.com/content/2c6645c6-e9f9-11e5-888e-2eadd5fbc4a4> (accessed 17 June 2017).
 58. Franco RZ, Fallaize R, Lovegrove JA, Hwang F. Popular nutrition-related mobile apps: a feature assessment. *JMIR Mhealth Uhealth* 2016;4:e85.
 59. Lindenmeyer A, Powell J, Lowe P, Thorogood M. Why are health care interventions delivered over the internet? A systematic review of the published literature. *J Med Internet Res* 2006;8:e10.
 60. Burke LE, Wang J, Sevick MA. Self-monitoring in weight loss: a systematic review of the literature. *J Am Diet Assoc* 2011;111:92–102.
 61. Sempier HM, Povey R, Clark-Carter D. A systematic review of the effectiveness of smartphone applications that encourage dietary self-regulatory strategies for weight loss in overweight and obese adults. *Obes Rev* 2016;17:895–906.
 62. Broekhuizen K, Kroeze W, van Poppel MNM, Oenema A, Brug J. A systematic review of randomized controlled trials on the effectiveness of computer-tailored physical activity and dietary behavior promotion programs: an update. *Ann Behav Med* 2012;44:259–86.
 63. Celis-Morales C, Abraham S, Keenan P, Ashor AW, Livingstone KM, Laraand J, Mathers JC. Effect of web-based tailored lifestyle interventions on fruit and vegetable consumption in adults: a systematic review and meta-analysis of randomised controlled trials. *Proc Nutr Soc* 2015;74(OCE1):E41.
 64. Eyles HC, Mhurchu CN. Does tailoring make a difference? A systematic review of the long-term effectiveness of tailored nutrition education for adults. *Nutr Rev* 2009;67:464–80.
 65. Fjeldsoe B, Neuhaus M, Winkler E, Eakin E. Systematic review of maintenance of behavior change following physical activity and dietary interventions. *Health Psychol* 2011;30:99–109.
 66. Harris J, Felix L, Miners A, Murray E, Michie S, Ferguson E, Free C, Lock K, Landon J, Edwards P. Adaptive e-learning to improve dietary behaviour: a systematic review and cost-effectiveness analysis. *Health Technol Assess* 2011;15:1–160.
 67. McDermott MS, Oliver M, Iverson D, Sharma R. Effective techniques for changing physical activity and healthy eating intentions and behaviour: a systematic review and meta-analysis. *Br J Health Psychol* 2016;21:827–41.
 68. Higgins JP, Green S. *Cochrane handbook for systematic reviews of interventions*. Vol. 4. Oxford: John Wiley & Sons; 2011.
 69. Rumpler WV, Kramer M, Rhodes DG, Moshfegh AJ, Paul DR. Identifying sources of reporting error using measured food intake. *Eur J Clin Nutr* 2007;62:544–52.
 70. Kwasnicka D, Dombrowski SU, White M, Sniehotta F. Theoretical explanations for maintenance of behaviour change: a systematic review of behaviour theories. *Health Psychol Rev* 2016;10:277–96.