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A systematic review with meta-analyses of text message-delivered behaviour change interventions for weight loss and weight loss maintenance

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ABSTRACT

Short Message Service (SMS)-delivered behaviour change interventions are frequently used to support weight management. This systematic review examines the effectiveness of SMS-delivered behaviour change interventions for weight management. Electronic databases were searched for randomised controlled trials (RCTs) comparing SMS-delivered adult weight management interventions to control groups, published between 1990 and 2018. Weight change was examined using random effects meta-analyses at intervention cessation and post intervention follow-up. Subgroup analyses examined intervention duration, SMS frequency, theory use, SMS interactivity, and SMS tailoring. Fifteen studies met inclusion criteria (2,705 participants). For weight loss interventions (n=12, 1,977 participants), the mean differences in weight change was -2.28kg (95% confidence interval [CI] -3.17 to -1.36kg). No studies reported post intervention follow-up. For weight loss maintenance interventions (n=3, 728 participants) the mean differences in weight change was -0.68kg (95% CI, -1.31 to -0.05kg) and post intervention follow-up (n=2, 498 participants) effects were -0.57kg (95% CI, -1.67 to 0.53kg). No subgroup differences were found. SMS-delivered behaviour change interventions for weight loss led to significant small to moderate weight loss and weight loss maintenance compared to control groups. Evidence on long-term effects is limited. SMS-delivered behaviour change interventions are a potentially effective and scalable intervention option for obesity treatment.

INTRODUCTION

Carrying excess weight is a leading cause of preventable morbidity and mortality[1]. In 2017, 52% of adults worldwide and 65% of adults in the UK were classified as overweight or obese [1,2]. A reduction in weight can have clinically significant health improvements. Achieving 5-10% weight loss is associated with reductions in cardiovascular risk factors, morbidity and mortality[3], with some guidelines suggesting that weight change of 3-5% may lead to clinically meaningful health benefits[4,5] . Behavioural changes in diet and physical activity can lead to weight reductions in individuals with excess weight and reduce the risk of co-morbidities and chronic conditions[6] and can be effective for long-term weight reduction[7,8]. The rising prevalence of mobile phone ownership worldwide, has created a new avenue for behaviour change interventions[9]. Mobile phones can be used to deliver interventions through Short Message Service (SMS), often referred to as text messages[10]. Evidence-based weight management delivered through mobile phones is potentially scalable and cost-effective to support weight loss and weight loss maintenance[9]. The widespread use of mobile phones increases the potential to reach large population segments, including those from disadvantaged and less privileged backgrounds who are at greater risk of overweight and obesity[11,12].

The effectiveness of weight management interventions delivered via SMS remains unclear. Several systematic reviews have shown promising results for behaviour change and weight management interventions which include SMS alongside other components [10,13-16]. A systematic review of weight management interventions using SMS reports a weighted mean change in intervention participants of -2.56kg (95% CI, -3.46 to -1.65kg) based on six studies[17]. However, the review includes interventions using additional components such as

mobile applications or mobile linked devices such as Fitbits and studies included children and non-RCT studies. Another systematic review of a range of mobile phone delivered weight loss interventions including SMS reported a pooled effect size of -0.23 (95% CI = -0.38, -0.08) based on ten studies, equivalent to a 3.1kg weight loss[18]. This review also found that personal contact and more frequent interactions (1-4 interactions per day) were associated with greater weight reduction. An additional systematic review of SMS-delivered weight maintenance interventions reported a weighted effect size of -0.82kg (95% CI -1.43 to -0.21kg) based on three studies[19], suggesting potential for SMS to support weight loss maintenance following weight loss. Another systematic review of mobile phone delivered weight management interventions on weight change in adults with obesity and found a weighted effect size of -2.35kg (95% CI, -2.84 to -1.87kg) based on 20 studies[15]. This review examined the association between intervention duration and weight loss. Weighted effect sizes were -2.25kg (95% CI -3.34, -1.16 I^2=92%) at 3-4 months, -2.66kg (95% CI -3.94, -1.38 I^2=95%) at 6 months, -2.62kg (95% CI -4.81, -0.43 I^2=85%) at 9 months and -1.23kg (95% CI -2.25, -0.21, I^2=0%) at 12 months. However, the focus of this review was mHealth in general and not SMS-delivered interventions specifically.

The current literature suggests that SMS-delivered weight management interventions can lead to clinically significant weight loss for health. The effectiveness of weight loss and weight loss maintenance behaviour change interventions primarily delivered via SMS remains unclear, and limited evidence exists as to the intervention characteristics that may be associated with more effective SMS-delivered weight management behaviour change interventions.

This systematic review examined a) the effectiveness of SMS-delivered behaviour change interventions for weight loss and weight loss maintenance in adults with overweight or obesity, and b) intervention characteristics which might explain variation in effectiveness.

METHODS

This systematic review was conducted in line with Cochrane guidelines [20] and reported according to PRISMA guidelines[21], following a registered protocol (PROSPERO, CRD42019111019).

Eligibility criteria

Studies were included if they were peer reviewed randomised controlled trials (RCTs) or quasi-randomised control trial (quasi-RCTs) published in English including adult participants (≥18 years) with an average body mass index (BMI) of ≥25 kg/m^2. Interventions had to be delivered via automated text messages (i.e. SMS) to a mobile phone as the primary component of the intervention. Text message delivery could be standard SMS or messaging apps such as WhatsApp[22].

Outcomes measure

The outcome of interest in this systematic review was weight change, measured in kilograms, from baseline to the end of the intervention and post intervention follow-up period.

Search strategy

An electronic database search was conducted from 1990 to July 2018 using a comprehensive search strategy developed in Ovid MEDLINE (Table S1) and modified for other databases: Scopus, PsycINFO, and CINAHL.

Study selection

One reviewer (VG) screened the titles and abstracts of all records. A second reviewer (RS) independently screened a random 10% (n=119). Interrater agreement for study selection was Cohen's kappa (κ)= 1. All records identified as potentially relevant were examined as full text. Full texts of potentially eligible RCTs were obtained (n=92) and independently appraised for inclusion by two reviewers (RS, VG). Where queries arose, they were resolved through discussion with a third reviewer (SUD). Two reviewers (RS, SUD) verified study inclusion based on eligibility.

Data extraction

Two reviewers (RS, VG) independently extracted relevant population and intervention characteristic from eligible papers. Any disagreements were resolved by a third reviewer (SUD). Extracted data included year and country of study, study design, participant characteristics including average age, gender split, average BMI, inclusion and exclusion criteria, description of intervention and control conditions, duration of intervention, changes in measurements and duration of follow-up.

Risk of bias assessment

Two reviewer (RS, VG) assessed risk of bias of each study independently. Disagreements were resolved by consensus or by consultation with a third reviewer (SUD). Risk of bias was assessed as ‘low risk’, ‘high risk’ or ‘unclear risk’ and individual risk of bias items were evaluated [20]. For quasi-RCTs, the Cochrane handbook guidance on cluster RCTs risk of bias assessment were followed[23]. There was satisfactory inter-rater agreement for risk of bias indicators (κ= 0.63).

Data Analysis

Studies reporting sufficient data to calculate mean differences in weight change in kg at intervention end and post intervention follow up, were meta-analysed using RevMan (version 5.3). Meta-analyses were conducted to examine the difference between intervention and control groups for weight change at the end of the active intervention period, or the reported measurement time point closest to the end of the intervention. When studies tested multiple versions of the intervention against a comparison condition, then the interventions were treated as separate studies, with control participants divided by the number of interventions in the meta-analysis. When a choice of weight outcomes was available (e.g. measurement vs self-report), the more objective measure was chosen. When a choice of weight change analysis was available (e.g. completers vs intention-to-treat analysis), the outcome that took account of missing data was chosen. When studies reported average weights at baseline and follow-up, weight change was calculated by subtracting the baseline weight from the final weight. When standard deviations for weight change in kg were not reported and could not be converted using the guidelines from the Cochrane handbook[23], the formula provided by Avenell et al.,[24] was used. Effect sizes were calculated separately for weight loss and weight loss maintenance studies. All pooled effects were calculated as mean difference in weight change using a random effects model (inverse-variance approach). The I^2 statistic was used to quantify degree of inconsistency between studies[25]. I^2 levels of ≥25% and ≥50% were interpreted as an indicator for moderate and substantial heterogeneity respectively. The test for subgroup differences available in RevMan 5.3 was used to examine subgroup differences. Subgroup analyses were conducted for the weight loss interventions only, due to an insufficient number of weight

loss maintenance studies. One weight loss study was excluded from the tailoring subgroup analysis due to a high degree of tailoring seen in other aspects of the intervention[26]. Inter-rater agreement for key risk of bias indicators was calculated using the kappa statistic[27].

Subgroup analysis

Comparisons were made for the following intervention characteristics in weight loss studies where at least two studies could be included within a specific category. Intervention duration (<6 months vs 6 months vs 12 months), defined as the length of time participants received text messages. Frequency of SMS delivery (daily vs weekly/bi-weekly vs personalised), defined as how often text messages were sent. Use of theory (theory base mentioned vs no theory base mentioned), defined as whether the study explicitly reported the intervention as being based on a specific theory or theories. SMS interactivity (interactive vs not interactive), defined as intervention messages requiring a response from participants. SMS tailoring (tailored vs generic), tailored SMS were defined as uniquely individualised messages to each participant based on their individual assessment at baseline. These could for example include stage of change, personal goals and barriers, or sub-groups of participants e.g. based on smoking status, diet, or sex. Generic SMS were defined as delivering the same content to each participant, including personalisation e.g. using participants' name.

Sensitivity analysis

To examine the robustness of the findings, the following studies were omitted from the sensitivity analysis if they used self-report measures of weight, incomplete data was supplemented by inputted based on statistical assumptions (when SD were estimated based

on weight change[28]), and where relevant information to conduct meta-analyses accounting for a quasi-RCT/ cluster-RCT design was not available.

RESULTS

The search identified 1,188 potentially relevant records, of which 92 were selected as potentially eligible; 15 RCTs met inclusion criteria (Figure 1, see Table S2 and S3 for included and excluded studies d). Details of the included studies are presented in Table 1.

--- Figure 1 ---

--- Table 1 ---

Fifteen studies were included[26,29-42]of which 12 focused on weight loss[26,29-33,35-38,41,42] and three on weight loss maintenance[34,39,40]. The studies were published between 2009-2017. In these 15 studies, 1,380 participants were allocated to an intervention arm and 1,336 participants to a control arm. Studies were conducted in the USA (n=7); Australia (n=3), Europe (n=3) and Asia (n=2).

Fourteen studies were individual randomised controlled trials (RCTs), one was a quasi-RCT[32]. Most studies (n=14) were two-armed trials comparing an intervention to a control group. One study had three-arms, comparing two SMS interventions to the control group[39]. Weight change was the primary outcome in all studies but one[31] which reported weight change as a secondary outcome. Sample sizes ranged from 30[30] to 710 participants[31]. Five studies included fewer than 100 participants [29,30,32,41,42], six included between 100 and 200 participants [26,33,35,36,38,39] , three between 200-500 participants[34,37,40] and over 500 participants[22]. The median number of participants per study was 125 [IQR 90 to 107.75]. Participant dropout ranged from 2%[22] to 50%[37]. Weighted average drop out was 17%, of which 20% dropped out of an intervention arm and 17% dropped out of a control arm. Loss

to follow up demographic details were reported in one study[40]: participants lost were more likely to be younger (42.8 vs 50.5 years), female, white British, previously part of a commercial weight loss group and had a higher BMI at the start of the intervention.

For the 2,716 participants in the 15 studies, the weighted average age was 47.6 years. Two studies included women only[32,41]. The remaining 13 studies contained both men and women. The weighted average of the proportion of men across all participants was 41% [IQR 17.7 to 42.95%]. The weighted average BMI before weight loss was 31.3 kg/m^2 [IQR 28.6 to 34.1kg/m^2] and weighted average of participant's baseline reported weight was 88.0kg [IQR 82.4 to 97.1kg] (Table 1).

The duration of weight loss interventions ranged from 2 months[32] to 12 months[26,35,38], the mean and median duration was 6 months.

The duration of weight loss maintenance interventions ranged from 1 to 3 months; the mean and median duration was 2 months. The weighted average participant baseline weight was 93.2kg [IQR 88.2 to 104.2kg].

Cost of intervention delivery was reported in two studies[33,34]. A 12 month weight loss intervention reported a total cost, including operational costs and personnel hours, of $21,113.61 for 163 randomised participants which equated to approximately $130 per participant[33]. A 6 month weight loss maintenance study reported an overall delivery cost per participant of approximate AU$80.00[34].

Six studies reported using theory to develop their interventions[26,35-39] (self efficacy theory[43], health belief model[36], transtheoretical model[36,37], self-regulation theory[36], social-cognitive theory[26], planned behavioural theory[26], regulatory focus theory , contingency model in mobile phone weight loss[43]). Three studies reported using one theory[37-39] (the

transtheoretical model[37], social cognitive theory[38], regulatory focus theory[39]). Three studies reported using multiple theories[26,35,36]. Nine studies did not mention theory[29-34,40-42].

The frequency of SMS delivery to participants ranged from messages 3-4 times a day[36,38] to once every 2 weeks[26], with a median of one SMS per day. Two studies tailored frequency to participant's preference[34,42].

SMS interactivity was reported in nine studies[30,32,33,35,36,38,40-42]. This included replying to messages with weekly weight (n=7)[32,33,35,38,40,42]; questions about diet (n=2)[36,41]; or responding to educational questions (n=1)[30]. Six studies sent automated feedback response based on computer algorithms[30,35,36,38,40-42], two studies did not respond to replies[33,37] and one study responded with customised researcher feedback[32].

Studies used a range of modes of SMS communication, including generic (n=3)[29,32,33] and tailored (n=6)[30,31,36-38,41-43].

Assessment of risk of bias

Nine studies were judged to have low risk of bias[26,30,31,33,35,36,38,40-42] and five studies to have high risk of bias[29,32,34,37,39]. High risk of bias rating was due to the quasi-RCT design, self-report outcome weight measures and high risk of attrition (Figure 2). Justifications for judgements are provided in the supplementary material (Table S4).

--- Figure 2---

Nine studies were judged to either have an unclear or high risk of detection bias based on reports of blinding of outcome assessment for group allocation [26,29,32-34,38,39,41,42]. However, as the primary outcome assessment (weight in kg) is an objective measurement, the risk of influencing the data recorded was inferred to be minimal under the assumption researchers conducted themselves in an ethical manner determined by research standards. Outcome

assessment was deemed a high risk of bias if self-reported weight measurements were taken.

Meta-analyses - intervention effectiveness

For weight loss interventions, the mean difference in weight change after the active intervention period was -2.28kg (95% CI, -3.17 to -1.39kg, I^2=70%) (Figure 3). For weight loss maintenance interventions, the mean difference in weight change was -0.68kg (95% CI, -1.31 to -0.05kg, I^2=0%) (Figure 4). Of the weight loss studies, none reported post-intervention follow up results. One study attempted six month post-weight loss intervention follow-up. Due to insufficient data no statistical analysis was undertaken and data was not reported[36]. Two weight loss maintenance studies reported post-intervention follow up (2 months[39] and 6 months[40]) with a mean difference in weight change of -0.57kg (95% CI -1.67 to 0.53kg, I^2= 0%) (see Fig S1).

--- Figure 3 ---

--- Figure 4 ---

Sensitivity analysis

Seven studies were included in the sensitivity analysis and showed a mean difference in weight change after the active intervention period of -1.90kg (95% CI, -2.74 to -1.06kg, I^2=31%) (see Fig S2)

Sub-group analysis

Subgroup analyses are shown in Table 2. No significant subgroup differences emerged for: intervention duration; frequency of SMS delivery; use of theory; SMS interactivity and SMS tailoring (see Fig S3-S7).

--- Table 2 ---

DISCUSSION

Principle Findings

SMS-based behaviour change interventions for weight loss showed significant small to medium weight loss effects at the end of the active intervention (-2.28kg, 95% CI -3.17, -1.39kg), but long-term post-intervention effects are unknown. A small number of behaviour change interventions targeting maintenance after weight loss showed significant small effects after the active intervention (-0.68kg, 95% CI -1.31, -0.05kg) which was non-significant six months post-intervention (-0.57kg, 95% CI -1.67, 0.53kg). Variation in weight loss effects could not be explained by differences in intervention features including intervention duration, SMS-frequency, use of theory, SMS interactivity and SMS tailoring.

Strength and weaknesses

This review specifically examined SMS as the primary delivery route of behaviour change interventions for weight management, thereby allowing conclusions to be drawn about this particular form of delivery. Previous reviews confounded SMS with a variety of other delivery components. Some of the included studies included delivery components other than SMS, such as websites or social media platforms[18]. However, all included studies used SMS as the primary delivery route making it unlikely that obtained effects are driven by other delivery components. The lack of subgroup differences for weight loss studies might be due to a lack of power as only twelve studies met inclusion criteria. In addition, some of the subgroups might have been too broad to detect more subtle differences. For example, interventions categorised as generic rather than tailored differed to some extent, with some personalising SMS (e.g. by using participant names) and others sending the same SMS to each participant. Descriptions of delivery aspects of interventions were not always fully

clear to facilitate coding. Some of the interventions were short term (i.e. between 3-6 months), limiting generalisability of SMS effects in the longer term. However, no difference between subgroups emerged on the basis of intervention timing. Subgroup analyses focused on form of delivery aspects of the SMS interventions, and did not examine intervention content such as behaviour change techniques. The majority of studies were conducted in western countries, however, preliminary evidence suggests that SMS-delivered weight loss interventions may also apply to non-western countries, including research from Korea[29] and Iran[32].

Relation to other studies

The findings of this review underline evidence suggesting that SMS-delivered behaviour change interventions can support significant small to medium weight loss[19]. Weight loss effects reported here are comparable in magnitude to other reviews that include a SMS within multicomponent mHealth interventions[15,17,18]. For example, a systematic review examining mobile health interventions including SMS for adults with obesity reported a weight effect of -2.35kg (95% CI, -2.84 to -1.87kg)[15], similar to -2.28kg (95% CI -3.17, -1.39kg) found in the current review.

Small to medium effects of SMS-delivered weight loss interventions have the potential to translate into clinical impact[6,44], particularly given the scalability and reach of this automated delivery format. Aveyard et al.,[45] for example found that primary care patients referred to a commercial weight loss intervention by their general practitioner lost -2.43kg compared to -1.18kg for patients provided with brief general practitioner advice. Results of this review suggest that referral to SMS-delivered weight management interventions has the potential to boost weight loss effects over and above standard treatments and advice.

SMS-delivered weight management interventions may provide a potentially effective alternative for those unable or unwilling to engage in group-based weight loss interventions. This review did not find differences in weight loss effects on the basis of intervention duration, SMS-frequency, use of theory, SMS interactivity and SMS tailoring. A previous systematic review of mobile health interventions found highest weight loss effects at six months with a reduction in effects sizes at 12 months, which remained statistically significant[15]. The current review found a similar pattern of effects sizes, typical for weight loss results over time[46]. Three studies showed significant weight effects at 12 months (-2.03kg, 95% CI -3.66,-0.40kg), suggesting that significant long-term net weight loss is possible despite some likely weight regain. Moreover, similar to a previous review[19], SMS were found to have small effects on weight loss maintenance following weight loss induced through non SMS-delivered interventions, but this effect did not last.

No significant association between frequency and weight change effects were found, in contrast to a review of weight loss interventions delivered via mobile phones who report an association between frequent interactions (1-4 interactions per day) and greater weight reduction[18]. This review found a trend that less frequent weekly or bi-weekly SMS interactions were associated with greater weight effects (-2.88kg, 95% CI -4.56, -1.21kg) compared to daily interactions (-1.56kg, 95% CI -2.26, -0.86).

Mechanisms and implications

The mechanisms through which SMS weight loss interventions lead to effects remain largely unclear. This requires further investigation particularly in light of the lack of associations between delivery features and weight effects found in this review. Although theory use was not found to be associated with more effective interventions, in line with previous

evidence[47], a better understanding of the mechanisms through which SMS work is critical to optimise SMS effectiveness, including form of delivery and SMS content features. Limited information on how SMS interventions were developed was reported. Optimisation of SMS content and delivery may benefit from more rapid and iterative experimental developments, prior to testing intervention content in a randomised controlled trial[48,49]. Regardless of the lack of evidence on the mechanisms, the effectiveness of SMS-delivered weight loss interventions suggests that these should be considered as a potentially effective public health tool to treat overweight and obesity, in those interested in receiving such support.

Unanswered questions and future research

This review was unable to examine the populations for whom SMS-delivered weight loss interventions might be most beneficial. For example, evidence suggests that men and women differ in their preferences and needs for weight loss treatment[50], but currently no gender-based analyses are reported for SMS-delivered interventions to determine any differences. The current review showed a greater proportion of men participating in included studies compared to other weight loss intervention studies[50,51], suggesting that SMS-delivered weight loss interventions may be engaging for men. Other key populations requiring further research are those from disadvantaged backgrounds, the elderly, ethnic minorities, as well as rural and remote populations.

Some studies included within trial costs of the intervention delivery.[33,34] However no full cost-effectiveness analysis of SMS-delivered weight management interventions were conducted. Given the relatively low resource costs of automated intervention delivery, cost

effectiveness could be implied. However, high quality evidence is required to examine and quantify cost-effectiveness of SMS delivered weight management interventions.

Future research might benefit from a better understanding of how different populations engage with and integrate SMS into their daily life. For instance, there might be age, sex or cultural difference in terms of the number, frequency, types and sources of messages individuals receive. Any SMS-delivered intervention needs to be meaningfully embedded within a pre-existing message context. Moreover, the way in which a participant integrates an SMS-delivered intervention into daily routines and social interactions requires further exploration.

CONCLUSION

SMS-delivered behaviour change interventions are effective to support weight loss and weight loss maintenance in the short term, leading to small to medium effects. Limited evidence exists for long-term post-intervention effects. Differences in weight loss effects could not be explained by examining intervention duration, SMS frequency, use of theory, SMS interactivity, and SMS tailoring. SMS-delivered weight management comprises an effective, potentially cost-effective and scalable intervention option to treat obesity.

References

1. World Health Organisation. http://apps.who.int/gho/data/node.main.A896?lang=en 2018. Accessed 6/2/19.
2. Health Survey of England. Overweight and obesity in adults and children. 2017.
3. Brown JD, Buscemi J, Milsom V, Malcolm R, O'Neil PM. Effects on cardiovascular risk factors of weight losses limited to 5–10%. *Translational behavioral medicine.* 2015;6(3):339-346.
4. Health NIf, Excellence C. Weight Management: Lifestyle Services for Overweight or Obese Adults (PH53). In: National Institute for Health and Care Excellence London; 2014.
5. Jensen MD, Ryan DH, Apovian CM, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and The Obesity Society. *Journal of the American college of cardiology.* 2014;63(25 Part B):2985-3023.
6. Bauer UE, Briss PA, Goodman RA, Bowman BA. Prevention of chronic disease in the 21st century: elimination of the leading preventable causes of premature death and disability in the USA. *The Lancet.* 2014;384(9937):45-52.
7. Dombrowski SU, Knittle K, Avenell A, Araujo-Soares V, Sniehotta FF. Long term maintenance of weight loss with non-surgical interventions in obese adults: systematic review and meta-analyses of randomised controlled trials. *Bmj.* 2014;348:g2646.
8. Wu T, Gao X, Chen M, Van Dam R. Long-term effectiveness of diet-plus-exercise interventions vs. diet-only interventions for weight loss: a meta-analysis. *Obesity reviews.* 2009;10(3):313-323.
9. Free C, Phillips G, Galli L, et al. The effectiveness of mobile-health technology-based health behaviour change or disease management interventions for health care consumers: a systematic review. *PLoS medicine.* 2013;10(1):e1001362.
10. Hall AK, Cole-Lewis H, Bernhardt JM. Mobile text messaging for health: a systematic review of reviews. *Annual review of public health.* 2015;36:393-415.
11. Newton S, Braithwaite D, Akinyemiju TF. Socio-economic status over the life course and obesity: Systematic review and meta-analysis. *PloS one.* 2017;12(5):e0177151.
12. Hardy L, Mihrshahi S, Gale J, Drayton B, Bauman A, Mitchell J. 30-year trends in overweight, obesity and waist-to-height ratio by socioeconomic status in Australian children, 1985 to 2015. *International Journal of Obesity.* 2017;41(1):76.
13. Free C, Phillips G, Watson L, et al. The effectiveness of mobile-health technologies to improve health care service delivery processes: a systematic review and meta-analysis. *PLoS medicine.* 2013;10(1):e1001363.
14. Armanasco AA, Miller YD, Fjeldsoe BS, Marshall AL. Preventive health behavior change text message interventions: a meta-analysis. *American journal of preventive medicine.* 2017;52(3):391-402.
15. Park S-H, Hwang J, Choi Y-K. Effect of Mobile Health on Obese Adults: A Systematic Review and Meta-Analysis. *Healthc Inform Res.* 2019;25(1):12-26.
16. Orr JA, King RJ. Mobile phone SMS messages can enhance healthy behaviour: a meta-analysis of randomised controlled trials. *Health psychology review.* 2015;9(4):397-416.
17. Siopis G, Chey T, Allman-Farinelli M. A systematic review and meta-analysis of interventions for weight management using text messaging. *Journal of human nutrition and dietetics.* 2015;28:1-15.
18. Schippers M, Adam P, Smolenski D, Wong H, de Wit J. A meta-analysis of overall effects of weight loss interventions delivered via mobile phones and effect size differences according to delivery mode, personal contact, and intervention intensity and duration. *Obesity reviews.* 2017;18(4):450-459.

19. Job J, Fjeldsoe B, Eakin E, Reeves M. Effectiveness of extended contact interventions for weight management delivered via text messaging: a systematic review and meta-analysis. *Obesity reviews.* 2018;19(4):538-549.
20. Higgins J. GSe. *Cochrane handbook for systematic reviews of interventions version.* 2011;5(0).
21. Liberati A, Altman D, Tetzlaff J, Mulrow C, Gøtzsche P, Ioannidis J. for the PRISMA 365 Group. The PRISMA statement for reporting systematic reviews and meta-analyses of 366 studies that evaluate healthcare interventions: explanation and elaboration. *BMJ.* 2009;339(367):b2700.
22. Chow CK, Islam SMS, Farmer A, et al. Text2PreventCVD: protocol for a systematic review and individual participant data meta-analysis of text message-based interventions for the prevention of cardiovascular diseases. *BMJ open.* 2016;6(10):e012723.
23. Green S, Higgins JP, Alderson P, Clarke M, Mulrow CD, Oxman AD. *Cochrane handbook for systematic reviews of interventions.* John Wiley & Sons Chichester, UK; 2008.
24. Avenell A, Broom J, Brown TJ, et al. Systematic review of the long-term effects and economic consequences of treatments for obesity and implications for health improvement. *Health technology assessment.* 2004.
25. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *Bmj.* 2003;327(7414):557-560.
26. Silina V, Tessma MK, Senkane S, Krievina G, Bahs G. Text messaging (SMS) as a tool to facilitate weight loss and prevent metabolic deterioration in clinically healthy overweight and obese subjects: a randomised controlled trial. *Scandinavian Journal of Primary Health Care.* 2017;35(3):262-270.
27. Cohen J. A coefficient of agreement for nominal scales. *Educational and psychological measurement.* 1960;20(1):37-46.
28. Avenell A, Broom J, Brown TJ, et al. Systematic review of the long-term effects and economic consequences of treatments for obesity and implications for health improvement. *Health technology assessment.* 2004;8(21).
29. Ahn A, Choi J. A one-way text messaging intervention for obesity. *Journal of telemedicine and telecare.* 2016;22(3):148-152.
30. Axley P, Kodali S, Kuo YF, et al. Text messaging approach improves weight loss in patients with nonalcoholic fatty liver disease: A randomized study. *Liver International.* 2018;38(5):924-931.
31. Chow CK, Redfern J, Hillis GS, et al. Effect of lifestyle-focused text messaging on risk factor modification in patients with coronary heart disease: a randomized clinical trial. *Jama.* 2015;314(12):1255-1263.
32. Faghanipour S, Hajikazemi E, Nikpour S, Shariatpanahi Sa-S, Hosseini AF. Mobile phone short message service (SMS) for weight management in Iranian overweight and obese women: a pilot study. *International journal of telemedicine and applications.* 2013;2013:5.
33. Fischer HH, Fischer IP, Pereira RI, et al. Text message support for weight loss in patients with prediabetes: a randomized clinical trial. *Diabetes care.* 2016;39(8):1364-1370.
34. Fjeldsoe BS, Goode AD, Phongsavan P, et al. Evaluating the maintenance of lifestyle changes in a randomized controlled trial of the 'Get Healthy, Stay Healthy'program. *JMIR mHealth and uHealth.* 2016;4(2):e42.
35. Haapala I, Barengo NC, Biggs S, Surakka L, Manninen P. Weight loss by mobile phone: a 1-year effectiveness study. *Public Health Nutr.* 2009;12(12):2382-2391.
36. Lin M, Mahmooth Z, Dedhia N, et al. Tailored, interactive text messages for enhancing weight loss among African American adults: the TRIMM randomized controlled trial. *The American journal of medicine.* 2015;128(8):896-904.

37. Partridge SR, McGeechan K, Hebden L, et al. Effectiveness of a mHealth lifestyle program with telephone support (TXT2BFiT) to prevent unhealthy weight gain in young adults: randomized controlled trial. *JMIR mHealth and uHealth.* 2015;3(2):e66.
38. Shapiro JR, Koro T, Doran N, et al. Text4Diet: A randomized controlled study using text messaging for weight loss behaviors. *Preventive Medicine.* 2012;55(5):412-417.
39. Shaw RJ, Bosworth HB, Silva SS, et al. Mobile health messages help sustain recent weight loss. *The American journal of medicine.* 2013;126(11):1002-1009.
40. Sidhu MS, Daley A, Jolly K. Evaluation of a text supported weight maintenance programme 'Lighten Up Plus' following a weight reduction programme: randomised controlled trial. *International Journal of Behavioral Nutrition and Physical Activity.* 2016;13(1):19.
41. Steinberg DM, Levine EL, Askew S, Foley P, Bennett GG. Daily text messaging for weight control among racial and ethnic minority women: randomized controlled pilot study. *Journal of medical Internet research.* 2013;15(11):e244.
42. Patrick K, Raab F, Adams M, et al. A text message-based intervention for weight loss: randomized controlled trial. *Journal of medical Internet research.* 2009;11(1):e1.
43. Haapala I, Barengo NC, Biggs S, Surakka L, Manninen P. Weight loss by mobile phone: A 1-year effectiveness study. *Public Health Nutrition.* 2009;12(12):2382-2391.
44. Excellence. NIfHaC. *Guidance on the prevention, identification, assessment and management of overweight and obesity in adults and children.* https://www.nice.org.uk/guidance/cg1892014.
45. Aveyard P, Lewis A, Tearne S, et al. Screening and brief intervention for obesity in primary care: a parallel, two-arm, randomised trial. *The Lancet.* 2016;388(10059):2492-2500.
46. Dombrowski SU, Avenell A, Sniehott FF. Behavioural interventions for obese adults with additional risk factors for morbidity: systematic review of effects on behaviour, weight and disease risk factors. *Obesity facts.* 2010;3(6):377-396.
47. Dalgetty R, Miller CB, Dombrowski SU. Examining the theory-effectiveness hypothesis: A systematic review of systematic reviews. *British journal of health psychology.* 2019;24(2):334-356.
48. Sheeran P, Klein WM, Rothman AJ. Health behavior change: Moving from observation to intervention. *Annual review of psychology.* 2017;68:573-600.
49. Peters G-JY, De Bruin M, Crutzen R. Everything should be as simple as possible, but no simpler: towards a protocol for accumulating evidence regarding the active content of health behaviour change interventions. *Health Psychology Review.* 2015;9(1):1-14.
50. Robertson C, Archibald D, Avenell A, et al. Systematic reviews of and integrated report on the quantitative, qualitative and economic evidence base for the management of obesity in men. *Health Technology Assessment (Winchester, England).* 2014;18(35):v.
51. Pagoto SL, Schneider KL, Oleski JL, Luciani JM, Bodenlos JS, Whited MC. Male inclusion in randomized controlled trials of lifestyle weight loss interventions. *Obesity.* 2012;20(6):1234-1239.

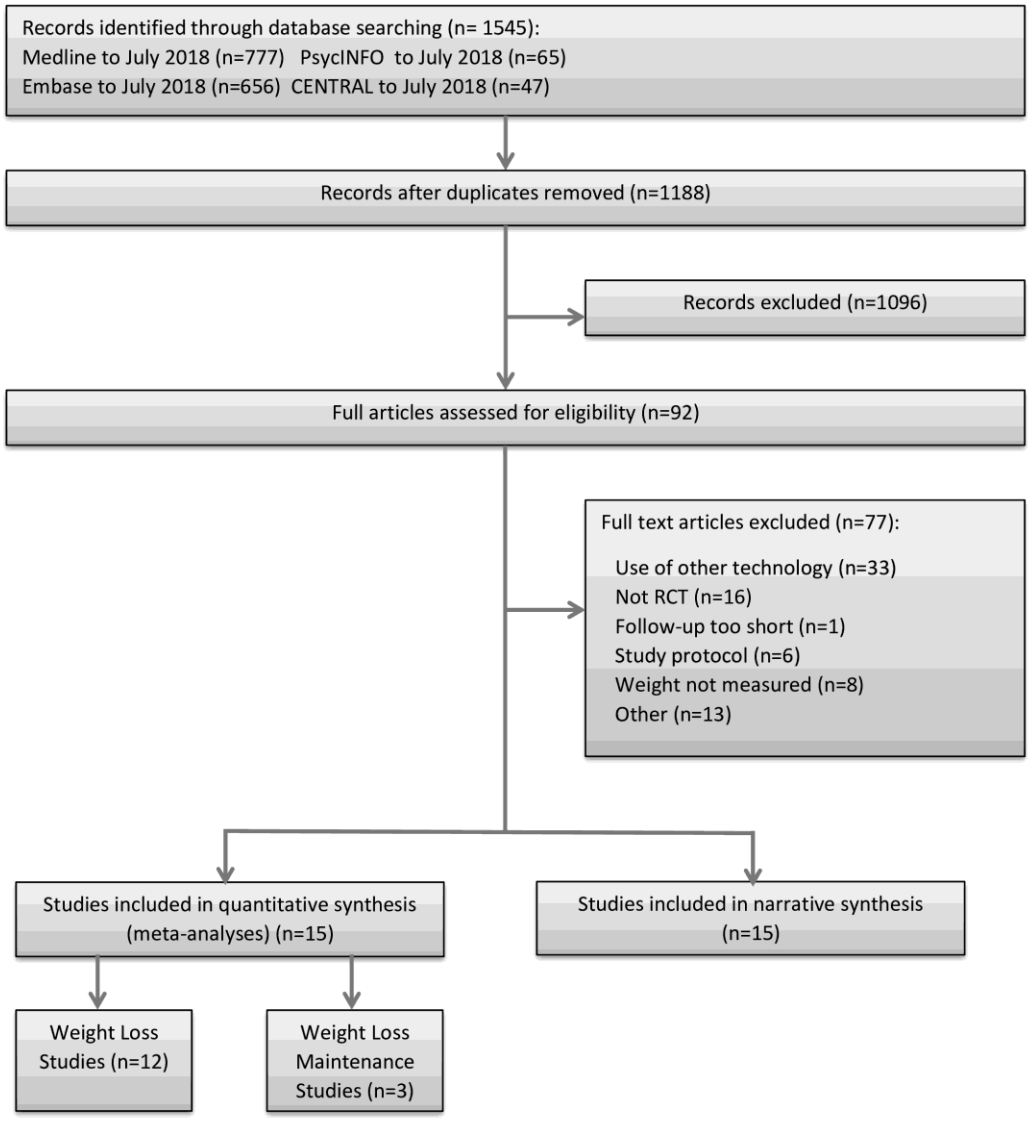

Figure 1: PRISMA diagram for systematic review inclusion and exclusion of studies.

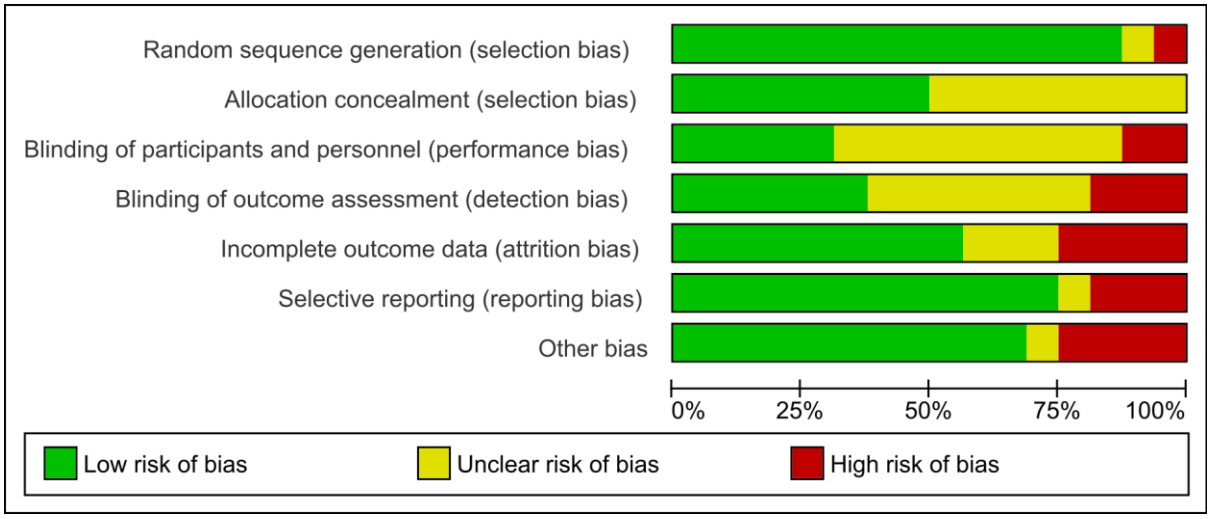

Figure 2: Cochrane risk of bias assessment for all included studies

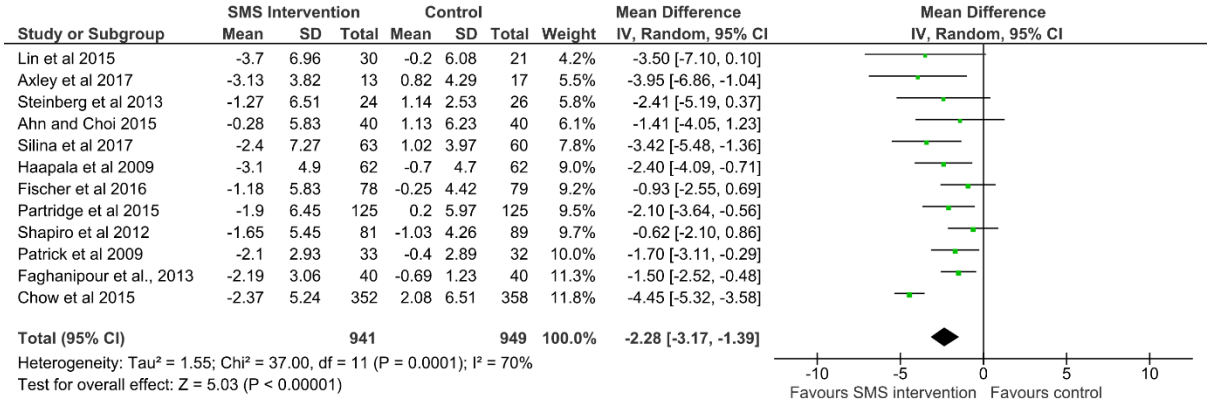

Figure 3: Forest plot of mean difference in weight change at end of active intervention period in SMS-delivered weight loss studies

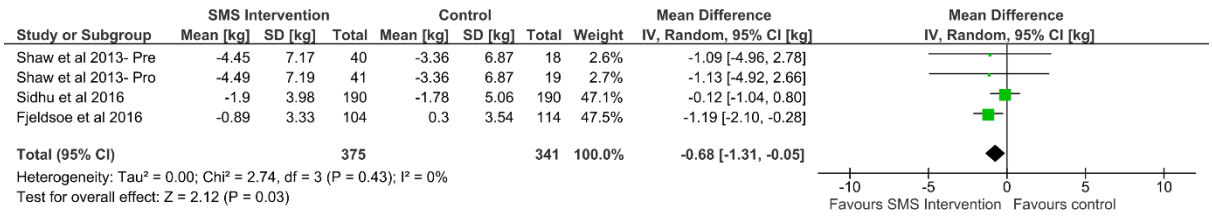

Figure 4: Forest plot of mean difference in weight change at end of active intervention period in SMS-delivered weight loss maintenance studies

Table 2: *Sub-group analysis of SMS intervention characteristics*

			Pooled effect size		
Subgroup Analysis	Studies (*k*)	Participants (*n*)	Mean Difference (*kg*)	95% CI	I^2
Intervention					
Duration					
< 6 months	4	475	-1.67	-2.37, -0.96	0%
6 months	5	998	-3.03	-4.79, -1.28	73%
12 months	3	417	-2.03	-3.66, -0.41	63%
SMS frequency					
Weekly/Bi-weekly	5	1092	-2.88	-4.56, -1.21	76%
Daily	5	554	-1.56	-2.26, -0.86	0%
Personalised	2	176	-1.99	-3.07, -0.90	0%
Theory-based mentioned					
Yes	5	718	-2.11	-3.14, -1.07	35%
No	7	1172	-2.33	-3.65, -1.00	80%
SMS interactivity					

Interactive	8	727	-1.63	-2.22, -1.04	2%
Not Interactive	4	1163	-3.06	-4.56, -1.57	70%
SMS tailoring					
Generic Communication	3	317	-1.34	-2.17, -0.52	0%
Tailored Communication	8	1450	-2.56	-3.75, -1.37	74%

Note. SMS= short message service