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Evaluation of the Effectiveness of Behavioral Economic Incentive Programs for Goal Achievement on Healthy Diet, Weight Control and Physical Activity: A Systematic Review and Network Meta-analysis

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Abstract

Background Healthy diet, weight control and physical activity to reduce obesity can be motivated by financial incentives (FI). Behavioral-economic approaches may improve the incentivization effectiveness. This study compares and ranks the effectiveness of standard and behavioral incentivization for healthy diet, weight control, and physical activity promotion.

Purpose To investigate whether behavioral-economic insights improve incentivization effectiveness.

Methods A systematic search of Medline and Scopus was performed from database inception to December 2020. Study characteristics, program designs, and risk ratio (RR) were extracted. A two-stage network meta-analysis pooled and ranked intervention effects.

Results There were 35 eligible RCTs. For diet-weight control, standard FI, deposit contract (deposit), lottery-based incentive (lottery), and standard-FI + lottery increased goal achievement compared to no-FI but only deposit was statistically significant with pooled RRs and 95% confidence intervals (CI) of 1.21 (0.94, 1.56), 1.79 (1.04, 3.05), 1.45 (0.99, 2.13), and 1.73 (0.83, 3.63). For physical activity, standard-FI, deposit, and lottery significantly increased goal achievement compared to no-FI, with pooled RRs of 1.38 (1.13, 1.68), 1.63 (1.24, 2.14) and 1.43 (1.14, 1.80), respectively. In a follow-up period for physical activity, only deposit significantly increased goal achievement compared to no-FI, with pooled RRs of 1.39 (1.11, 1.73).

Conclusion Deposit, followed by lottery, were best for motivating healthy diet, weight control and physical activity at program end. Post-intervention, deposit then standard-FI were best for motivating physical activity. Behavioral insights can improve incentivization effectiveness, although lottery-based approaches may offer only short-term benefit regarding physical activity. However, the imprecise intervention effects were major concerns.

Lay summary

Healthy diet, weight control and physical activity to reduce obesity can be motivated by financial incentives (FI). Behavioral-economic approaches may improve the effectiveness of FI programs. This study aims to investigate whether behavioral-economic insights improve incentivization effectiveness for healthy diet, weight control, and physical activity promotion. We conducted a systematic review of published randomized controlled trials (RCTs), then pooled the interested results, compared and ranked the effectiveness of standard and behavioral incentivization programs by a two-stage network meta-analysis. There were 35 eligible RCTs. For diet-weight control, standard FI, deposit contract (deposit), lottery-based incentive (lottery), and standard-FI + lottery increased goal achievement compared to no-FI but only deposit was statistically significant. For physical activity, standard-FI, deposit, and lottery significantly increased goal achievement compared to no-FI. In a follow-up period for physical activity, only deposit significantly increased goal achievement compared to no-FI. In conclusion, deposit, followed by lottery, were best for motivating healthy diet, weight control and physical activity at program end. Post-intervention, deposit then standard-FI were best for motivating physical activity. This shows that behavioral insights can improve incentivization effectiveness, although lottery-based approaches may offer only short-term benefit regarding physical activity.

Keywords behavioral economic · healthy diet · incentive · network meta-analysis · physical activity · weight control

Introduction

Obesity and overweight represent a substantial health burden that leads to the development of metabolic syndrome [1, 2] and non-communicable diseases, e.g., diabetes, hypertension and cardiovascular diseases [3, 4]. Obesity and overweight are preventable through healthy diet and regular physical activity [3]. However, unhealthy dietary behaviors [5] and insufficient physical activity are omnipresent [6] despite conventional interventions which have mostly focused on legislation (e.g., banning partially hydrogenated oils), taxes (e.g., sweetened beverage tax) and subsidies (e.g., fruit and vegetables), and information provision [7–10]. In addition, financial incentives (FI) [11, 12] have also been used to improve the effectiveness of promotions of healthy diet and physical activity. However, their effectiveness is largely dependent on their design [7, 11, 12]. As such, FI programs informed by behavioral economics [13, 14] may represent a more efficacious approach than a standard FI program to promote healthy diet and physical activity.

Behavioral economics combines insights from economics and psychology to understand particular heuristics that human brain uses to cope with the large burden of complex choices, which lead to predictable systematic biases and errors. Such better understanding of human decision-making provides opportunities for influencing choices that take better account of how people actually respond [15] because the predictable biases can be used to help or nudge people make better choices. Such interventions involving FI include such as deposit contracts (participants risk losing money if they do not meet goals which is effective because people dislike losses more than we like gains of an equivalent amount), lottery-based incentive (meeting goals makes participants eligible for a lottery prize which is effective because people overweight small probabilities), regret lottery (all participants eligible for a lottery ticket but only those meeting goals are eligible to receive the prize which is effective because seen one's ticket drawn and not being eligible for the prize creates an intense regret feeling), and other types of incentive schemes.

A previous meta-analysis [16] was published in 2015 and included seven studies to compare the effectiveness of weight loss between standard FIs, deposit contracts and regret lotteries. We described a protocol for a systematic review and network meta-analysis (NMA) [17] to consider these interventions with additional FIs including price incentives, lottery-based incentives, and group-based payments for several outcomes. The current study focused solely on goal achievement outcomes in healthy diet, weight control, and physical activity by comparison of standard and behavioral economic FIs; the probabilities of being the best interventions for these outcomes were estimated and ranked.

Methods and Analysis

This systematic review and NMA was conducted following the PRISMA guidelines [18] and registered at PROSPERO (CRD42020198024). Review methods were described in the published protocol [17] but are summarized briefly below:

Studies were identified from Medline via PubMed and Scopus databases up to December 2020. Two reviewers (SB and OP) independently selected studies, disagreement was resolved by consensus with a third reviewer (AT).

Search terms were constructed based on interventions and outcomes (more details in Supplementary Table 1 and published protocol [17]). A two-step study selection was performed: First, individual studies from the systematic reviews with or without meta-analysis (SRs/MAs) were selected. Second, relevant individual studies published since the previous SR/MA were selected from the searches.

Systematic reviews were selected if they compared behavioral economic incentive programs with any FI program comparisons (e.g., standard monetary (or equivalent) rewards, price incentives, deposit contract, lottery-based incentive, regret lottery, group-based payment or no incentive), and had any outcome of improvement of healthy diet, weight control, and/or physical activity. Selection of individual studies were based on the following criteria: compared any pair of interventions defined above; interventions were directly implemented on cluster/subject levels; assessed any outcome of improved healthy diet, weight control, and/or physical activity including actual weight, weight change, and others; and published in English or other languages amenable to Google translate.

Given the significant number of studies identified, this report focused on randomized control trials (RCTs) with outcomes of goal achievement on healthy diet, weight control and physical activity (Fig. 1).

Interventions and Outcomes

The primary outcome for this study was goal achievement (success/failure) in healthy diet, weight control and physical activity (gym visits, steps) evaluated at the end of the intervention program and at follow-up period (if available).

Interventions of interest initially stated in the review protocol [17] were standard FI, deposit contract, and lottery (i.e., lottery-based incentive, regret lottery), group-based payment, or no incentive. None of the RCTs included reported group-based payments, only a small number considered lottery-based incentives and regret lottery, which therefore necessitated amalgamation into a single outcome referred to as lottery. As such, four interventions were considered including no FI, standard FI, deposit contract (called deposit), and lottery.

Data extraction and risk of bias assessment

Data extractions and assessment of the risk of bias (RoB) were independently performed by two reviewers (SB and OP). The following data were extracted: setting, study design, FI interventions (i.e., type, goal criteria, target at process or outcome, incentive size, duration, frequency, setting), characteristics of study population (i.e., having non-communicable diseases (NCDs), percentage female, mean age), type of supplementary components (i.e., text reminder, feedback, education classes, self-monitoring), follow-up time during and after incentives, outcomes, and data for pooling (ln risk ratio (RR)).

Incentive per day was calculated to standardize the amount of incentive by dividing the maximum amount of FI rewarded by the program duration (in days). Inflation rates for each country [19] with an exchange rate for purchasing power in US dollars (USD PPP) [20] were calculated for 2020.

RoB for randomized trials was assessed using the Cochrane risk-of-bias tool for randomized trials (RoB2) [21], with disagreement resolved by consensus with a third reviewer (AT).
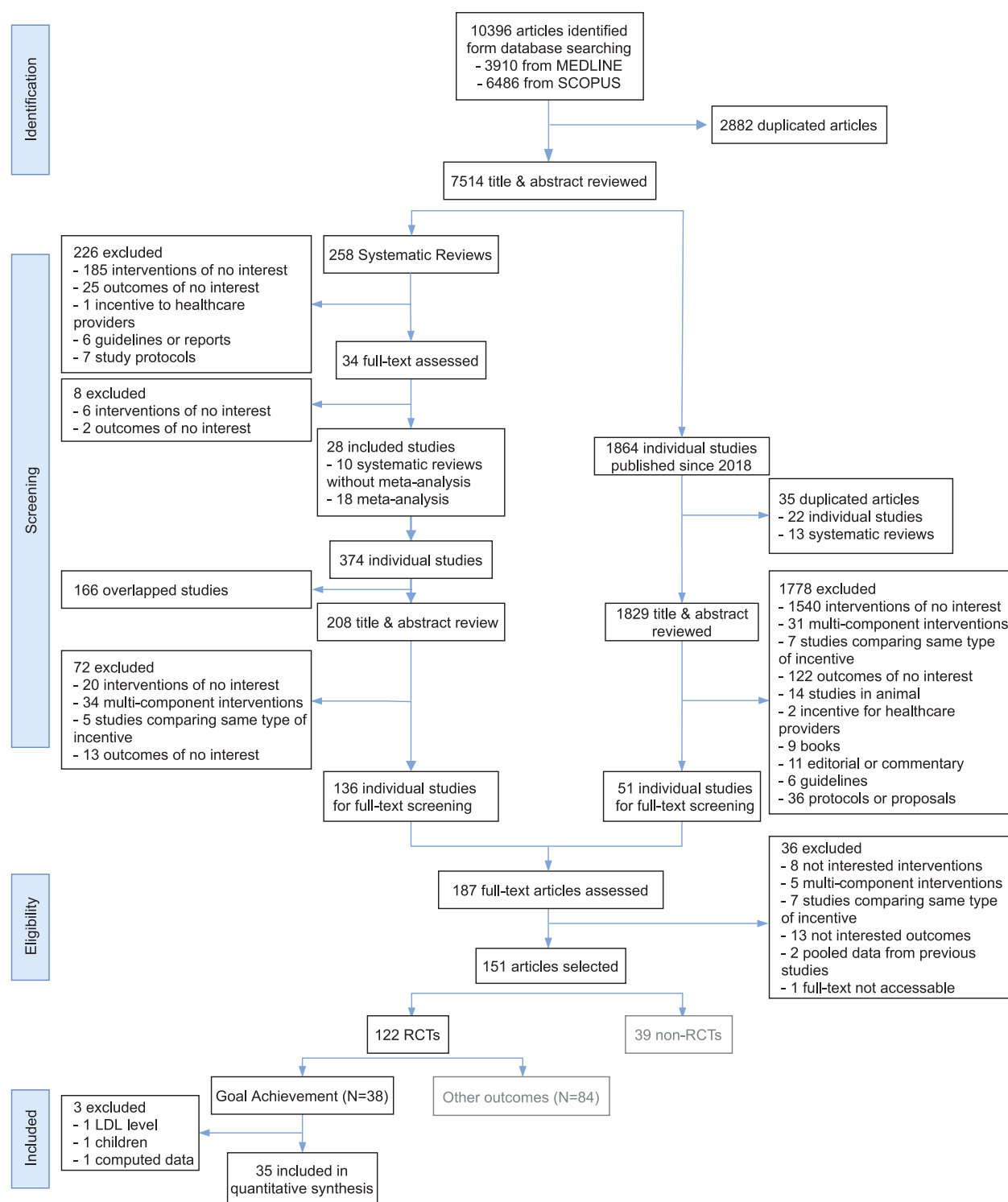
Identification

10396 articles identified form database searching
- 3910 from MEDLINE
- 6486 from SCOPUS

2882 duplicated articles

7514 title & abstract reviewed

Screening

258 Systematic Reviews

226 excluded
- 185 interventions of no interest
- 25 outcomes of no interest
- 1 incentive to healthcare providers
- 6 guidelines or reports
- 7 study protocols

34 full-text assessed

8 excluded
- 6 interventions of no interest
- 2 outcomes of no interest

28 included studies
- 10 systematic reviews without meta-analysis
- 18 meta-analysis

1864 individual studies published since 2018

35 duplicated articles
- 22 individual studies
- 13 systematic reviews

374 individual studies

166 overlapped studies

208 title & abstract review

1829 title & abstract reviewed

1778 excluded
- 1540 interventions of no interest
- 31 multi-component interventions
- 7 studies comparing same type of incentive
- 122 outcomes of no interest
- 14 studies in animal
- 2 incentive for healthcare providers
- 9 books
- 11 editorial or commentary
- 6 guidelines
- 36 protocols or proposals

72 excluded
- 20 interventions of no interest
- 34 multi-component interventions
- 5 studies comparing same type of incentive
- 13 outcomes of no interest

136 individual studies for full-text screening

51 individual studies for full-text screening

Eligibility

187 full-text articles assessed

36 excluded
- 8 not interested interventions
- 5 multi-component interventions
- 7 studies comparing same type of incentive
- 13 not interested outcomes
- 2 pooled data from previous studies
- 1 full-text not accessable

151 articles selected

122 RCTs

39 non-RCTs

Included

Goal Achievement (N=38)

Other outcomes (N=84)

3 excluded
- 1 LDL level
- 1 children
- 1 computed data

35 included in quantitative synthesis

Fig. 1: Flow diagram of selection of studies. .

Statistical Analysis

Direct meta-analysis

Effect sizes (RRs) for goal achievement outcome were estimated and pooled across studies using a random-effect model if heterogeneity was present (Q test p-value $< .10$ or $I^2 \geq 25\%$), otherwise a fixed-effect model was applied. Heterogeneity was assessed using Cochrane's Q test and I^2 statistics [22–24].

Pre-specified subgroup analysis was performed by criteria of goal achievement (e.g., percentage or absolute weight control or number of gym visits), target (on process/outcome/both), size, frequency and duration of incentive, setting (clinic/non-clinic or gym/non-gym) and participant characteristics (female proportion, having NCDs, mean age). Publication bias was assessed using a funnel plot and Egger's test. If asymmetry

was present, a contour-enhanced funnel plot was constructed to identify the cause of publication bias.

Network meta-analysis

A network meta-analysis approach was applied to indirectly estimate mixed relative treatment effects where none or only a few direct comparisons were available by borrowing data from a common comparator [25]. As such, relative treatment effects for all possible pairwise comparisons were estimated beyond what would normally be possible through conventional direct meta-analyses approaches. A two-stage network meta-analysis was applied to assess relative treatment effects using a consistency model with common between-study variance [25]. Interventions were coded as 1, 2, 3, 4 for no FI, standard FI, deposit, and lottery, respectively. Mixed relative treatment comparisons between all FIs were then estimated accordingly. The probability of being the best FI program for goal achievement (i.e., highest RR) was estimated using surface under the cumulative ranking curve (SUCRA) method. The probability of goal achievement for each treatment was estimated with 1000-replications and an average probability estimated ranging between 0 and 100%, with a greater value reflecting a higher rank [26]. Inconsistency assumptions were evaluated by a design-treatment interaction model [25]. All analyses were performed using STATA software V.17.1; a p-value<0.05 was considered statistically significant.

Results

Characteristics of Selected Studies

A total of 7,514 studies were identified (Fig. 1), 122 were RCTs, of which 38 reported defined goal achievement in contrast to the remainder which reported other outcomes, see Fig. 1. Three RCTs [27–29] were further excluded leaving 35 RCTs [30–64] (16 and 19 RCTs for diet-weight control and physical activity, respectively) for further details, see Supplementary Fig. 1. Only inclusion of two studies [31, 32] was questioned by both reviewers (SB and OP), and this was solved by discussion and consensus. Comparison pairs (i.e., intervention vs comparator) of goal achievement in diet-weight control and physical activity are described in Table 1 and Supplementary Fig. 2.

All studies were conducted in high-income countries: 26 (74.3%) in the USA, 7 (19.4%) in Europe and 2 (5.9%) in Asia. Study participants from 16 studies had metabolic syndrome including overweight, obesity, prediabetes, diabetes, and hypertension (45.7%). Mean age ranged from 18 to 80.4 with median of 45.1 years; percentage of female ranged from 5.3% to 91.5% with a median of 69.5% (Supplementary Table 2).

Criteria of goal achievement included percentage weight loss (N = 9), absolute weight loss/control (N = 5), choosing healthy snack (N =1), and self-weighing (N = 1) for diet-weight controls; steps (N = 12) and gym visits (N =7) for physical activity. Incentives were paid for process (N = 23), outcome (N = 10), and both (N = 6). The size of financial incentive per day in USD PPP ranged from 0.03 to 38.5 with a median of 1.5. The maximum size of lottery prize ranged from 51 to 356.8 with a median of 103.6 USD PPP. Program duration ranged from 7 days to 1 year with a median of 3 months and payment frequency ranged from daily to every 3 months with a median of every week. Supplementary components included knowledge provision in the form of a booklet/ brochure (N = 2), one-time education class (N = 3) and repeated classes (N = 4); counselling (N = 5); feedback (N = 24); self-monitoring (N = 14) (Supplementary Table 2).

Risk of Bias

Of 35 RCTs, 91%, 100%, 97%, 100%, 49% were judged as low RoB for randomization, protocol deviations, missing outcome data, outcome measurement, and reporting bias, respectively (Supplementary Figure 3). Consequently, 54% and 43% of all RCTs were rated as "some concerns" and "low concern" of RoB, respectively, with only a single study identified as high RoB. A RoB assessment was questioned by both reviewers in only a single study [34] and this was resolved by discussion.

Direct meta-analysis

Sixteen RCTs [30–45] compared effects of interventions on goal achievement in diet-weight control including standard FI (N = 8, 12 interventions), deposit (N = 3), lottery (N = 5) and standard FI+lottery (N = 2) versus no FI (Supplementary Figure 2). A meta-analysis was applied (Supplementary Figure 4) indicating deposit and lottery significantly led to goal achievement more often than no FI with pooled RRs [95% confidence interval (95%CI)] of 1.99 (1.36, 2.92) and 1.34 (1.01, 1.80), respectively. In addition, standard FI and standard FI+lottery also performed better than no FI but this was not significantly, with pooled RRs of 1.20 (0.93, 1.53) and 2.22 (0.58, 8.49), respectively.

Nineteen RCTs [46–64] compared effects of interventions on achievement of physical activity goals (Supplementary Figure 2). These effect sizes were pooled across studies indicating standard FI, deposit and lottery were significantly more likely to achieve goal than no FI (1.46 (1.18, 1.79), 1.63 (1.31, 2.03) and 1.44 (1.20, 1.73) respectively, Supplementary Figure 5). In addition, deposit was 1.16 (0.98, 1.38) times more likely to achieve goal than standard FI but this was non-significant.

Degree of heterogeneity (I^2) of pooling was estimated, see Supplementary Table 3. For diet-weight control, the I^2 values were high (78.66%) in standard FI, moderate (53.69% and 60.05%) in standard FI+lottery and lottery. For physical activity, heterogeneity was high (I^2 = 71.31%) in only standard FI vs no-FI but none for the remaining. None of heterogeneity sources could be identified by a meta-regression (Supplementary Table 4). However, subgroup analysis by size of FI per day showed that higher median FI provided greater effect than lower median FI (Supplementary Figure 6), suggesting that as expected, higher financial incentives are more likely to provide a stronger effect than lower financial incentives on goal outcomes for both diet and physical activity. Likewise, additional subgroup analysis showed that the effect of lottery was higher if incentive duration was <180 days, knowledge was provided, and performed in a clinic.

A small study effect was evaluated by Egger's test (Supplementary Table 3) and funnel plots (Supplementary Figure 7 and 9) indicating asymmetry of the funnel on pooling of lottery vs no-FI (p = .03) for diet-weight control and standard FI vs no-FI (p < .001) for physical activity. Contour-enhanced funnel plots (Supplementary Figure 8 and 10) were then constructed for both comparisons indicating that asymmetry was likely due to genuine heterogeneity not just to study size.

Table 1: Characteristics of Included Studies

Study	Country	Intervention	Incentive to process/outcome	FI per day (USD PPP)	Duration (days)	Frequency (days)	Setting	NCDs	Age (mean)	Follow up day post-program
Goal type: diet										
Achtziger, 2019	Switzerland	no FI standard FI	process	0.64	7	7	non-clinic	No	35.42	N/A
Goal type: weight control										
Colvin, 1983	USA	no FI standard FI	outcome	3.32	77	7	non-clinic	No	NR	182.625
Volpp, 2008	USA	no FI deposit lottery (regret)	outcome	3.35	112	1	clinic	Yes	NR	N/A
Petry, 2011	USA	no FI lottery	outcome	0.03	84	84	clinic	Yes	45.65	N/A
Kullgren, 2013	USA	no FI standard FI	outcome	3.43	168	30	clinic	Yes	45.30	N/A
Leahey, 2015	USA	no FI standard FI + lottery	combined	0.52	91.3125	91.3125	non-clinic	No	45.69	318.9375
Patel, 2016a	USA	no FI lottery (regret)	outcome	1.57	365.25	14	non-clinic	Yes	44.89	N/A
Finkelstein, 2017	Singapore	no FI deposit	outcome	1.32	112	14	clinic	Yes	44.34	121.75
Yancy, 2018	USA	no FI standard FI lottery	outcome	2.90	182.625	1	non-clinic	No	48.99	182.625
VanEpps, 2019	USA	no FI standard FI	process, outcome, combined	2.22	112	7	clinic	Yes	48.79	N/A
Yancy, 2019	USA	no FI lottery	process	0.65	182.625	7	non-clinic	Yes	48.06	182.625
Chin, 2020	USA	no FI standard FI	process, outcome, combined	2.22	112	7	clinic	Yes	NR	N/A
Cleveland, 2020	USA	no FI deposit	outcome	1.47	350	7	non-clinic	No	48.13	N/A
Desai, 2020	USA	no FI standard FI	combined	38.48	365.25	14	clinic	Yes	48.33	N/A
LaRose, 2020	USA	no FI standard FI + lottery	combined	0.54	84	84	non-clinic	Yes	NR	N/A
West, 2020	USA	no FI standard FI	combined	2.20	182.625	7	non-clinic	Yes	48.99	N/A
Goal type: steps										
Petry, 2013	USA	no FI lottery	process	0.03	84	84	non-gym	Yes	63.20	N/A
Kullgren, 2014	USA	no FI lottery	process	3.09	112	7	non-gym	No	71.90	56

Table 1. Continued

Study	Country	Intervention	Incentive to process/outcome	FI per day (USD PPP)	Duration (days)	Frequency (days)	Setting	NCDs	Age (mean)	Follow up day post-program
Patel, 2016b	USA	no FI lottery (regret)	process	0.64	91	2	non-gym	NR	40.52	91
Patel, 2016c	USA	no FI standard FI deposit lottery	process	1.43	91	1	non-gym	Yes	39.68	91
Patel, 2016d	USA	no FI lottery (regret)	process	0.20	91	7	non-gym	NR	41.32	91
Harkins, 2017	USA	no FI standard FI	process	3.00	112	7	non-gym	NR	80.35	28
Burns, 2018	USA	no FI standard FI deposit	process	1.47	35	7	non-gym	No	19	14
Patel, 2018	USA	no FI lottery (regret)	process	1.32	91	1	non-gym	Yes	41.02	91
Budworth, 2019	UK	no FI standard FI deposit	process	1.58	14	14	non-gym	No	33.78	N/A
Kramer, 2019	Switzerland	no FI standard FI	process	0.30	91.3125	30	non-gym	NR	45.39	N/A
Kramer, 2020	Switzerland	no FI standard FI	process	0.91	42	1	non-gym	NR	41.73	N/A
Tanji, 2020	Japan	no FI standard FI	process	0.48	21	21	non-gym	Yes	61.20	N/A
Goal type: gym visits										
Courneya, 1997	USA	no FI standard FI	process	2.47	31	31	gym	No	36	N/A
Pope, 2013	USA	no FI standard FI	process	5.70	84	7	gym	No	NR	N/A
Pope, 2014	USA	no FI standard FI	process	2.88	168	7	gym	Yes	18	N/A
Royer, 2015	USA	no FI standard FI deposit	process	5.62	28	7	gym	No	39.50	84
Rohde, 2017	The Netherlands	no FI standard FI	process	0.87	197.84	91.25	gym	No	33.28	182.625
Fricke, 2018	Switzerland	no FI standard FI	process	1.32	140	3.5	gym	No	39.14	N/A
van der Swaluw, 2018	The Netherlands	no FI lottery (regret)	process	0.37	91	7	gym	Yes	49.61	91

NR: not reported; N/A: not available; FI: financial incentive; deposit: deposit contract, lottery: lottery-based incentive; USD PPP with 2020 as a base year

a   Diet and weight control goal achievement
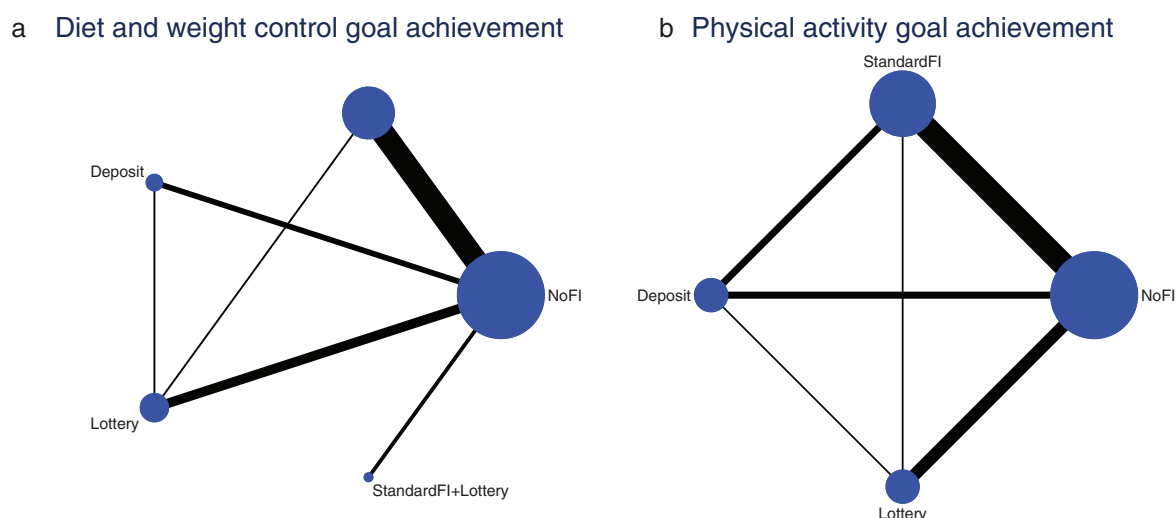
b   Physical activity goal achievement

Fig. 2: Network map of different types of financial incentive program on a) diet- weight control goal achievement b) physical activity goal achievement. Size of nodes was weighted by numbers of studies/comparisons. Size of edges was weighted by numbers of subjects in each comparison. Each number on plots represents numbers of studies/comparisons and subjects contributing to the corresponding comparison.

Network meta-analysis

Data used for NMA of goal achievement in diet-weight control and physical activity are provided (Supplementary Table 5-6). For diet-weight control goal achievement, 16 RCTs [30–45] were included consisting of standard FI, deposit, lottery, standard FI+lottery, and no FI (Fig. 2a). All FIs increased the chance of goal achievement compared to no-FI, but only deposit was significant with pooled RR (95%CI) of 1.79 (1.04, 3.05) (Table 2 and Supplementary Figure 11). In addition, deposit was also more likely to lead to goal achievement compared to standard FI and lottery, with lottery more likely than standard FI, although all RRs failed to meet the significance threshold (Fig. 3a and Table 2).

Nineteen RCTs [46–64] were included in the NMA of physical activity (Fig. 2b). Standard FI, deposit, and lottery significantly increased the chances of goal achievement compared to no-FI with pooled RRs (95%CI) of 1.38 (1.13, 1.68), 1.63 (1.24, 2.14) and 1.43 (1.14, 1.80), respectively (Table 2 and Supplementary Figure 12). Furthermore, among FIs, deposit was superior, followed by lottery and then standard FI, however, these differences were non-significant (Fig. 3b and Table 2).

SUCRA was applied to rank probabilities of being the best intervention (Supplementary Table 7). For diet-weight control goal achievement, deposit was ranked first followed by standard FI+lottery, lottery, standard FI, and no FI. Similarly, for physical activity goal achievement deposit was top-ranked, followed by lottery, standard FI and no FI.

Consistency assumption and publication bias

Inconsistency assumptions were checked, indicating no evidence of inconsistency for both diet-weight control (Chi-square = 2.52, p = .64) and physical activity (Chi-square = 0.33, p = 0.99). Comparison-adjusted funnel plots were created for both outcomes (Supplementary Figure 13-14) and showed asymmetry for physical activity goal achievement (Egger test, p = .01). This asymmetry resulted from the comparison of standard FI with no-FI (Egger test, p = .001), and was mainly due to heterogeneity rather than small-study

effects as the contour-enhanced funnel plot identified studies within areas of different significance levels (Supplementary Figure 15).

Follow-up period

Five [32, 35, 37, 38, 40] and 10 studies [47–53, 61, 62, 64] followed up participants after the end of intervention for weight control and physical activity goal achievement (Supplementary Figure 16), respectively. Median follow-up time was 6 (range: 4–10.5) and 4.3 months (range: 2 weeks - 6 months), respectively (Table 1).

Direct meta-analysis showed a non-significant difference in goal achievement on weight control between standard FI and lottery relative to no FI with pooled RRs (95%CI) of 1.07 (0.78, 1.47) and 0.91 (0.62, 1.36), respectively (Supplementary Figure 17). For physical activity, standard FI, deposit and lottery showed better goal achievement than no FI, but only deposit was significant with a pooled RR of 1.44 (1.11, 1.87) (Supplementary Figure 18). Egger's test (Supplementary Table 8) and funnel plots (Supplementary Figure 19-20) identified no asymmetry on pooling.

NMA was performed for physical activity goal achievement (Supplementary Table 6) indicating significant effects of deposit compared to no FI and standard FI with pooled RRs (95%CI) of 1.39 (1.11, 1.73) and 1.25 (1.01, 1.55), respectively (Table 2 and Supplementary Figure 21). SUCRA ranking suggested that deposit was the best option followed by standard FI and lottery in achievement of physical activity (Supplementary Table 7). There was no evidence of inconsistency (Chi-square = 1.38, p = .85). Comparison-adjusted funnel plots and Egger's test (p = .40) identified no asymmetry (Supplementary Figure 22).

Confidence in Network Meta-Analysis

The Confidence In Network Meta-Analysis (CINeMA) [65, 66] approach was applied to assess confidence in the results of our NMAs based on six domains, i.e., within-study bias, reporting bias, indirectness, imprecision, heterogeneity, and incoherence. Each domain was rated as no concerns, some concerns, or major concerns; the overall assessment

Table 2: Estimation of Relative Intervention Effects on Goal Achievements: A Network Meta-analysis

Intervention	Comparator	Diet-Weight control Endline	Physical activity Endline	Physical activity Follow-up
Standard FI	No FI	1.21 (0.94, 1.56)	**1.38 (1.13, 1.68)**	1.11 (0.94, 1.30)
	Deposit	0.68 (0.38, 1.22)	0.85 (0.66, 1.09)	0.80 (0.64, 0.99)
	Lottery	0.84 (0.54, 1.28)	0.96(0.72, 1.28)	1.06 (0.81, 1.38)
	Standard FI + lottery	0.70 (0.32, 1.52)	N/A	N/A
Deposit	No FI	**1.79 (1.04, 3.05)**	**1.63 (1.24, 2.14)**	**1.39 (1.11, 1.73)**
	Standard FI	1.47 (0.82, 2.64)	1.18 (0.92, 1.52)	**1.25 (1.01, 1.55)**
	Lottery	1.23 (0.68,2.22)	1.13 (0.81, 1.58)	1.32 (0.98, 1.79)
	Standard FI + lottery	1.03 (0.42,2.56)	N/A	N/A
Lottery	No FI	1.45 (0.99,2.13)	**1.43 (1.14, 1.80)**	1.05 (0.83, 1.32)
	Standard FI	1.20 (0.78,1.84)	1.04 (0.78, 1.39)	0.95 (0.72, 1.24)
	Deposit	0.81 (0.45,1.47)	0.88 (0.63, 1.23)	0.76 (0.56, 1.02)
	Standard FI + lottery	0.84 (0.37,1.91)	N/A	N/A
Standard FI + lottery	No FI	1.73 (0.83,3.63)	N/A	N/A
	Standard FI	1.43 (0.66,3.10)	N/A	N/A
	Deposit	0.97 (0.39,2.40)	N/A	N/A
	Lottery	1.19 (0.52,2.71)	N/A	N/A

FI, financial incentive;deposit, deposit contract; lottery, lottery-based incentive; and N/A, not available. Bold indicates statistical significance of the results.
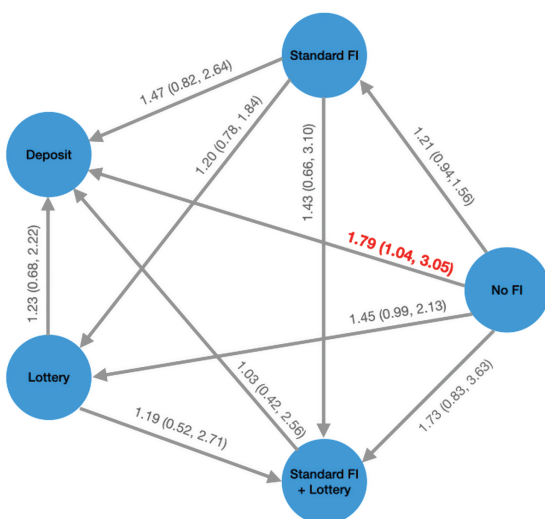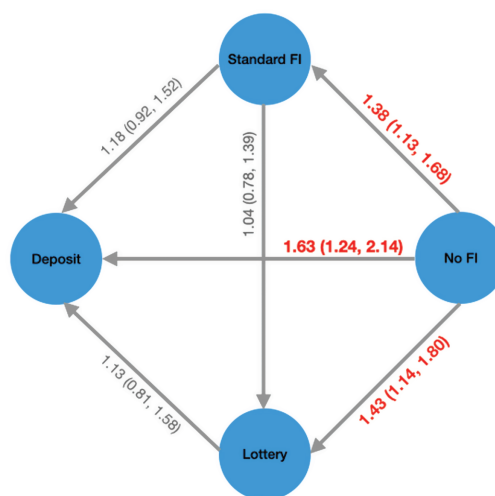

Fig. 3: Pooled effect sizes with 95% confidence interval in parenthesis for each comparison in the network for a) diet-weight control goal achievement b) physical activity goal achievement. Arrows point to the best in each comparison. Bold indicates statistical significance of the results.

was determined by incorporating all domains as very low, low, moderate, or high evidence. For goal achievement in diet-weight control and physical activity during and after implementation of interventions, there were 10, 6, and 6 comparisons, out of which 40%, 50%, and 50% were judged as low confidence, respectively (Supplementary Table 9-11); while the remainder were considered as moderate confidence.

Discussion

We performed a NMA to assess the effects of FIs on goal achievement for diet-weight control and physical activity

using data from 35 RCTs. Findings suggested that the best interventions for diet-weight control goal achievement at the end of the program were deposit, followed by standard FI+lottery, lottery, and standard FI (compared to no FI). These interventions, with the exception of standard FI+lottery, were also best for physical activity goal achievement. In addition, the benefits of deposit persisted for 2 weeks to 6 months beyond the end of the intervention.

In general, goal achievement for healthy diet, weight control, and physical activity is dependent not only on type of FI but also on the time period beyond the intervention ends. For instance, deposit, lottery, and standard FI were best for

physical activity goal achievement during intervention implementation but only the effect of deposit persisted 4 months after the program had ended, suggesting integrating behavioral insight regarding loss aversion can improve incentive program effectiveness [16, 67, 68]. In addition, deposit increased goal achievement by 47% compared to standard FI; this would have been a clinically significant effect but it did not reach statistical significance. Although lottery represented the second-best option at program end, its effect diminished thereafter suggesting that while lottery generated some short-term benefits, these were less sustainable in the longer term. At the beginning of a lottery program, participants may have overestimated the probability of winning the prize and therefore were highly motivated. When people realize the true expected value of the prize over time, the motivating effect then faded out [53].

Our findings were consistent with those from a previous meta-analysis which found that deposit had the best effect, followed by lottery and standard FI compared to no FI in healthy goal achievement [16]. Although deposit represented the most effective FI, it may face uptake problems given that participants risk losing money if they do not meet goals [61, 69]. Allowing participants to set their own deposit amount aligned with their income may resolve this issue. Nevertheless, deposit is considered fairer and less controversial as individuals finance their own healthy behaviors [67].

According to the self-determination theory, both intrinsically (e.g., pleasure, interest, or challenges) and/or extrinsically motivations (e.g., rewards, commands, or legally restrictions) determine health behaviors [70]. The effect of financial reward, which acts as an external motivation, depends on how the rewards are perceived, e.g., either as supportive, informational, or controlling [71, 72]. If it is perceived as controlling, it might undermine intrinsic motivation leading to unsustainable health behavior change. On the contrary, if it supports or reinforces intrinsic motivation, its effect can last beyond the program end. Financial incentive program, which contains supportive communication and allows participants to have their autonomy on the implementation, might have long-term effect on health behaviors [71].

Previous meta-analysis evidence [73] for traditional interventions such as media campaigns for behavioral change showed only very small effects on diet and exercise (pooled coefficients of 0.05), which was substantially lower than clinically-based interventions of education and counselling (weighted average effect size of 0.51 for diet-weight control) [74]. Other behavioral economic interventions may also prove efficacious as suggested through another recent meta-analysis [75] demonstrating the effectiveness of nudges in both health and food domains with average standardized effects of 0.34 and 0.65, respectively. These interventions provided positive effects similar to deposit contracts in our study, although these could not be directly compared.

Our findings were based on RCT data conducted in developed countries, so application of this evidence in developing countries should be considered with caution. Previous evidence shown that people with low incomes tend to favor lottery compared to those on higher income [76, 77]. Therefore, lottery programs may represent a more feasible option in middle-/low-income countries. Furthermore, RCTs are needed to compare the effectiveness of different types of FIs in middle-/low-income countries, given the current paucity of studies available.

Our study has several strengths. To our knowledge, this is the first NMA synthesizing evidence from all available standard and behavioral FI programs (deposit and lottery including regret lottery) for goal achievement on healthy diet, weight control, and physical activity. FI effects were also assessed beyond the program conclusion, where information was available. However, some limitations could not be avoided. First, some comparisons in NMA were based on only small number of both RCTs and included subjects that met the inclusion criteria, particularly for three of the six comparisons for diet-weight control (number of subjects of 38 to 208) and two of the six comparisons for physical activity (number of subjects of 41 to 139) which were based on data from two studies or less that contributed to the NMA. As a result, estimates of intervention effects were imprecise leading to major concerns for suggestion of deposit and standard FI versus lottery. This lessens the confidence in conclusion for these particular comparisons. However, the conclusion for the other comparisons is not affected as the results from the pairwise direct meta-analysis and NMA are quite similar. Second, the effects of FI programs were subject to low/moderate heterogeneity and the small number of RCTs included were not amenable to sub-group analysis to identify and reduce heterogeneity. Third, approximately 50% of the intervention effects estimated from our NMA had moderate levels of confidence while the remainder had low levels in line with the CINeMA reporting protocols. Our results should therefore be updated when further RCTs have been published.

Conclusions

Behavioral FIs, namely deposit, followed by lottery approaches, represented the best incentives for goal achievement in healthy diet, weight control, and physical activity on program completion. In the longer term, deposit, followed by standard FI, provided the best options for goal achievement for physical activity beyond the intervention timeframe. However, these intervention effects are major concerns due to imprecision. Further update NMA should be performed. Behavioral insight about loss aversion may improve the effectiveness of incentive programs for healthy diet, weight control and physical activity. While lottery-based approaches may provide only potential short-term benefits in the context of physical activity.

Compliance with Ethical Standards

Author contributions: Suparee Boonmanunt: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing – Original Draft, Visualization

Oraluck Pattanaprateep: Methodology, Investigation, Writing – Original Draft

Boonsong Ongphiphadhanakul: Conceptualization

Gareth McKay: Writing - Review & Editing

John Attia: Writing - Review & Editing

Ivo Vlaev: Writing - Review & Editing

Ammarin Thakkinstian: Conceptualization, Methodology, Formal analysis, Investigation, Writing – Review & Editing, Supervision, Funding acquisition

Transparency statements: Study and analytic plan pre-registration: The study including the analysis plan was pre-registered at PROSPERO (CRD42020198024). Link: https://www.crd.york.ac.uk/prospero/

Data availability: De-identified data from this study are not available in a public archive. De-identified data from this study will be made available (as allowable according to institutional IRB standards) by emailing the corresponding author.

Analytic code availability: Analytic code used to conduct the analyses presented in this study are not available in a public archive. They may be available by emailing the corresponding author.

Materials availability: Materials used to conduct the study are not publicly available.

Supplementary Material

Supplementary material is available at *Annals of Behavioral Medicine* online.

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