RESEARCH ARTICLE

Financial incentives for objectively-measured physical activity or weight loss in adults with chronic health conditions: A meta-analysis

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Abstract

Objective

We conducted a meta-analysis and systematic review of published randomized controlled trials (RCTs) to evaluate the impact of financial incentives (FI) on objectively-measured physical activity (PA) and weight loss (WL) in adults with sedentary behavior or chronic health conditions.

Evidence review

We performed a systematic search for RCTs published in English indexed in PubMed, Embase, or Web of Science through July 27, 2017. We limited our search to RCTs that involved an FI intervention with a monetary component, objectively-measured PA or WL outcomes, samples with either sedentary lifestyles or chronic health conditions, and a comparator group that did not receive performance-contingent FI. We calculated the mean difference and standardized mean difference (SMD) for each study and used a random effects model to summarize intervention efficacy. We used the Jadad scoring tool to assess the quality of the identified articles.

Results

We abstracted data from 11 RCTs. Two of the 11 included studies focused on PA, totaling 126 intervention and 116 control subjects. Nine RCTs evaluated the effect of FI on WL, totaling 1,799 intervention and 1,483 control subjects. The combined estimate for change in daily steps was 940 (95%CI [306–1,574]) more in PA intervention groups than in control groups and 2.36 (95%CI [1.80–2.93]) more kilograms lost by WL intervention groups.
compared to control groups. The overall estimated SMD for both outcomes combined was 0.395 (95%CI [0.243–0.546; p<0.001]), favoring FI interventions.

**Conclusion**

FI interventions are efficacious in increasing PA and WL in adults with chronic conditions or sedentary adults. Public health programs to increase PA or prevent chronic disease should consider incorporating FI to improve outcomes.

**Introduction**

The prevalence of chronic health conditions and sedentary behavior is rising: over a third of US adults are obese,[1, 2] and between 5% and 13% of adults meet the recommended physical activity (PA) guidelines.[3–5] Limited PA and chronic conditions reduce quality of life,[6, 7] are predictors of increased morbidity and mortality,[8, 9] and are costly.[10, 11] PA and weight loss (WL) are associated with reduced risk of comorbidity incidence and progression.[12–14] This highlights the need for interventions to increase PA and promote WL.

When making decisions pertaining to long-term health, people disproportionately choose immediate gratification from unhealthy activities over rewards with delayed and uncertain outcomes, such as reduced disease risk.[15–19] Delay discounting is a risk factor for physical inactivity and obesity.[20, 21] Financial incentive (FI) interventions draw from behavioral economic theory, which aims to understand economic principles in the context of psychological and social influences.[15, 22] FI interventions provide immediate rewards contingent on engaging in healthful behaviors and offer extrinsic motivation for developing healthy habits.[23]

FI have been used in studies to promote behaviors such as smoking cessation, medication adherence, PA, and WL.[23–28] Successful FI interventions incorporate actuarial amounts, or the raw monetary values, of incentives that are valued high enough to be motivating.[29] Intervention duration is another important parameter in determining habit formation and successful achievement of behavioral goals. For many adults, successful habit formation develops over at least two months of engaging in the behavior.[30] Further, interventions that employ principles of loss aversion, the notion that the magnitude in dissatisfaction associated with losing acquisitions is greater than the satisfaction associated with actuarial equivalent gains, are often more successful than those that utilize gain incentive schemes.[17, 31]

Previous systematic reviews have evaluated the effects of FI for PA or WL,[23, 24, 26, 31, 32] but these reviews have included self-reported data, which may overestimate outcomes.[33] Further, those with chronic conditions may have different health behaviors and perceptions compared to an ostensibly healthy population,[34] which may result in different responses to financial incentives for PA or WL. We aim to use evidence from randomized controlled trials (RCTs) to determine the efficacy of FI for objectively-measured PA and WL in persons with chronic conditions or sedentary lifestyles and determine whether specific components of intervention design make FI interventions more efficacious.

**Methods**

This study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol[35] and was registered in the PROSPERO International Prospective Register of Systematic Reviews (2017:CRD42017058063).
Identification of studies

We performed a systematic search of PubMed, Embase, and Web of Science for peer-reviewed articles published from database inception through July 27, 2017 that were available in English. [36] Included studies met search criteria in three categories: (1) FI or behavioral economics, (2) PA or WL outcomes, and (3) presence of a chronic condition or sedentary lifestyle. The search strings used in each database are provided in the Supporting Information (Appendix in S1 File).

Inclusion and exclusion criteria

Two reviewers (YG and TPT) screened the titles and abstracts of the studies and excluded those failing to meet inclusion criteria. The inclusion criteria were: (1) subjects at least eighteen years of age; (2) RCT; (3) at least one intervention arm eligible for PA or WL performance-contingent FI independent of additional interventions; (4) sample had a chronic health condition or sedentary lifestyle; (5) study reported objective PA or WL measures at baseline and either the change in outcome or the outcome at follow-up; (6) intervention lasted at least 12 weeks; (7) intervention designed to promote PA or WL; and (8) study included a control arm that did not receive performance-contingent FI.

After the title and abstract screens, two reviewers (YG and TPT) independently reviewed the full text of articles to confirm that the studies met the inclusion criteria. The reviewers discussed and came to consensus on any discrepancies. The reviewers referenced the literature cited in each included study to identify any additional papers not captured with the original searches.

Data abstraction

YG and TPT independently abstracted data from the eligible manuscripts and entered data in a Research Electronic Data Capture (REDCap) database.[37] We abstracted participant demographics and clinical characteristics; characteristics of the control arm; FI scheme, distribution, and amount; primary follow-up time point; and primary outcome data. For studies that included more than one FI or comparator arm, we abstracted data from all intervention arms.

YG and TPT compared the data abstracted from each study in REDCap, resolved discrepancies via discussion, and consulted two adjudicators (EL and JEC) to clarify study inclusion or data abstraction protocols. For each study, we calculated the maximum possible actuarial amounts of performance-contingent incentives that subjects could earn until the primary outcome timepoint. Foreign currencies were first converted to US dollars using IRS yearly average currency exchange rates.[38] We adjusted FI amounts to 2016 US dollars using the US Bureau of Labor Statistics Consumer Price Index.[39] We divided by study duration to calculate weekly maximum possible actuarial FI amounts to compare time-adjusted FI amounts between studies of different durations.

If data were not available in tables or within the text, we abstracted data from published figures using ImageJ.[40] We contacted authors via e-mail up to two times if numerical outcome data were not published (Table A in S1 File). If we were unable to obtain the data necessary to compute SMD, the study was excluded.

We evaluated the articles that met the inclusion criteria for quality using the Jadad assessment tool, a five-point scoring system that assesses RCTs based on appropriate methods of randomization, blinding, and withdrawal reporting.[41] Because of the nature of a FI intervention, participants and certain study staff could not be blinded to the arm assignment. Therefore, in accordance with guidelines, we evaluated whether data analysts and investigators were blinded to arm assignment in the studies.[42, 43]
Statistical analysis

We abstracted the primary outcome—objectively-measured average daily steps or weight—from each study at baseline and at end-of-intervention follow-up. We calculated the mean difference, or the difference in change in outcome from baseline to follow-up between control and intervention groups, for each intervention arm. To standardize the results measured on disparate scales to a uniform outcome unit, we calculated the standardized mean difference (SMD) for each study. The SMD is calculated by dividing the mean difference by the standard deviation (SD) of the outcome. For a study that reported the SD of change in the intervention and control groups separately, we pooled the SDs and used this as the denominator to divide the mean difference to create SMD. This study did not report the SD of change from baseline to final time point for each group, so we imputed these values by calculating the correlation between baseline, final, and change SDs from studies that reported all three values. We assumed that correlations derived from studies that reported SDs for all three values would apply to the remaining studies. Using the properties of variances, namely that the variance of the sum of two distributions is the sum of the variances of the distributions plus twice their covariance, we calculated the SD of change for the study that did not explicitly report it.

In one study with a factorial design, two arms received an FI intervention and two did not. For the intervention group, we report the outcome as the weighted mean of the primary outcomes from arms receiving the FI intervention. For the control group, we report the weighted mean of the primary outcome from the two arms that did not receive the FI intervention. The SDs for each group were pooled using the appropriate arms.

We assessed heterogeneity between the studies using the Cochrane’s Q, $I^2$, and H statistics. We assessed the contribution of each study arm to the overall heterogeneity using the influence and the Q-term, which is the contribution of the study to Cochrane’s Q-statistic. We computed the influence for each study arm by comparing the overall pooled estimate with and without including the arm. In a sensitivity analysis, we excluded study arms with large contributions to heterogeneity based on these measures.

We used a random effects model using maximum likelihood to calculate the final combined estimate of SMD across study arms overall and within each outcome type (PA and WL) separately. For studies that reported more than one intervention meeting our inclusion criteria, we included both arms and compared each arm to the control group. We included a random effect for study to account for the correlation between multiple arms coming from the same study and having the same comparator group, and split the sample size of the control group equally among intervention arms, as recommended by the Cochrane Handbook. We used meta-regression to determine the contributions of study characteristics to treatment effect. Study characteristics included study setting (workplace vs. non-workplace); type of outcome (WL vs. PA); incentive characteristics: the financial incentive schema (deposit contract, lottery, loss incentive, gain incentive), weekly maximum possible actuarial amount of FI, intervention duration, and the incentive distribution schedule; control arm characteristics: frequency of counseling in the control arm and frequency that the study followed-up with the control arm about the primary outcome. First, each characteristic was evaluated separately in a univariate regression model in order to estimate stratified effect estimates for each level of the predictor variable. Then, we selected variables with p-values less than 0.05 from univariate meta-regression to include in the multivariable meta-regression. To control for potential differences in outcome depending on outcome type (WL vs. PA) we ran an additional meta-regression including the covariates selected from univariate meta-regression and outcome type.
Results

Studies identified

A total of 4,303 citations met the search criteria, yielding 3,677 titles after removing duplicates and patents. From these, we identified 412 titles meeting search criteria and screened abstracts for inclusion criteria. Forty-four abstracts were eligible, which we considered in full-text review. Ultimately, 15 trials fulfilled all inclusion criteria. Four studies did not provide sufficient information to calculate SMD; thus, we included 11 papers containing 20 total intervention arms in the initial analysis. Fig 1 presents the PRISMA flow diagram.[35]

Heterogeneity assessment

Quantitative measures indicated considerable heterogeneity between the 11 studies ($I^2 = 0.62$, 95% CI [0.38–0.77]; $H = 1.63$, 95% CI [1.27–2.09]). One study, Almeida (2015), had high weight (weight = 441.2, Q-term = 16.63), contributing substantially to heterogeneity.[45] In our sensitivity analysis, we excluded this study,[45] resulting in 10 included studies with 18 intervention arms. After removing Almeida (2015), heterogeneity was reduced considerably ($I^2 = -0.46$, 95% CI [-1.92–0.27]; $H = 0.83$, 95% CI [0.59–1.17]). Publication bias was assessed graphically with funnel plots. The funnel plot without Almeida (2015) showed symmetry around the peak, failing to suggest publication bias. The funnel plots with and without the excluded studies are shown in Fig 2.

Participant and trial characteristics

Among the 11 included studies, there were 11 control and 19 intervention arms for a total of 1,599 control and 1,925 intervention subjects, or 3,524 participants in total. In the two papers evaluating FI for PA,[47, 50] there were a total of 126 treatment subjects and 116 control subjects. Among the nine papers evaluating FI for WL,[45, 51–58] there were a total of 1,799 treatment subjects and 1,483 control subjects. The median sample size of all included studies was 132 participants (25th–75th percentile: 68–201.5) and ranged from 40 to 1790. Nine trials recruited overweight or obese subjects,[51–58] one recruited patients with sedentary lifestyles,[50] and one recruited subjects with osteoarthritis.[47] Four trials recruited participants from a workplace,[45, 53, 54, 56] three from hospitals,[47, 52, 58] two from the community,[50, 51] and one each from a rehabilitation clinic[55] and university.[57] Table 1 describes study characteristics (see Table B in S1 File for a more comprehensive summary of study details).

Quality assessment. We present the methodological quality and reporting of the 11 included trials as assessed using Jadad score in the Supporting Information (Table C in S1 File).[41] The median Jadad score was 4, ranging from 3 to 5 out of 5.

Intervention characteristics. Of the 11 included studies (19 intervention arms), two studies (two intervention arms) intended to increase PA,[47, 50] while nine studies (17 intervention arms) intended to promote WL.[45, 51–57] Of 19 FI intervention arms in 11 studies, eight had gain incentive schemes,[45, 47, 50, 51, 55, 56] two implemented loss incentive schemes,[53] six utilized deposit contracts,[52, 54, 58] two used lottery schemes,[56, 58] and one used a combination of gain incentive and lottery.[51] The derivation of the total amount of FI a subject could earn, adjusted to 2016 USD, is described in the Supporting Information (Table D in S1 File). The median of the possible FI amount per week or the expected value per week for lottery incentive arms, in 2016 inflation-adjusted USD, was $22.41 (25th–75th percentile: $12.36–$36.37), ranging from $10.72 to $76.54. Almeida (2015) did not report the actuarial amount of FI offered to participants. The mean primary follow-up time point was at 24.7 (SD: 10.6) weeks, ranging from 12 to 52 weeks.
4303 titles met search criteria
   PubMed: 808
   EMBASE: 721
   Web of Science: 2774

- Duplicates: 605
- Patents: 21

3677 titles screened
- Excluded: 3265

412 abstracts reviewed
- Non-RCT: 226
- Intervention lacked FI component: 107
- Study lacked PA or weight loss intervention: 12
- Intervention duration less than 12 weeks: 5
- No objectively-measured PA or weight loss outcome: 4
- Study sample included minors: 4
- Unavailable in English: 3
- Evaluation of surgical or pharmaceutical therapy outcomes: 3
- Intervention arm(s) received additional intervention (other than FI): 3
- Non-human study: 1

44 articles reviewed
- Intervention lacked FI component: 8
- FI arm(s) received additional, non-FI intervention: 5
- No objectively-measured PA or weight loss outcome: 5
- Non-RCT: 3
- FI arm did not have a monetary component: 2
- Intervention duration less than 12 weeks: 2
- Study did not provide baseline data: 1
- Study lacked PA or weight loss intervention: 1
- Study sample did not have chronic health condition or sedentary lifestyle: 1
- Study sample included minors: 1

15 articles met inclusion criteria

11 articles eligible
- Insufficient information reported: 4

*Fig 1. PRISMA flow consort diagram.*[35].

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Effect of financial incentives on physical activity and weight loss

In the two studies measuring PA outcomes, the pooled mean difference in steps per day was 940 (95%CI [306–1574]) steps (S1 Fig), translating to a pooled SMD of 0.392 (95%CI [-0.027–0.811]). In the nine studies measuring WL outcomes, the pooled mean difference in kilograms lost was 2.32 (95%CI [1.76–2.88]), translating to a pooled SMD of 0.395 (95%CI [0.209–0.581]) (S2 Fig). Both outcomes favored FI interventions over control (Fig 3). The pooled SMD of all outcomes for treatment compared to control was 0.395 (95%CI [0.243–0.546]; p<0.001), indicating a moderate, statistically significant effect on PA and WL in those who received performance-contingent FI compared to control participants.

In a sensitivity analysis excluding the study with high contribution to overall heterogeneity, the pooled mean difference for the eight studies measuring WL outcomes was 2.36 kg (95% CI [1.80–2.93]), translating to a pooled SMD of 0.562 (95% CI [0.296–0.827]). The pooled SMD of all outcomes for treatment compared to control was 0.452 (95%CI [0.351–0.554]; p<0.001).

Longer interventions appeared to be associated with lower SMD: a 10-week increase in intervention duration was associated with a 0.177 decrease in SMD (p = 0.011; Fig 4). We did not find significant associations between the outcome and any other covariate.

Differences between control arm designs significantly contributed to the outcome. The frequency of interaction with a health counselor (p<0.001) and the frequency of following up with control arm participants (p = 0.005) affected the difference in outcomes between the control arm and the intervention arms. We used a multivariate meta-regression to determine the effect of both the control arm characteristics. The effects of both the frequency of counseling and the follow-up frequency of the control arm remained significant (p = 0.001 and 0.04, respectively); regular counseling and less than monthly follow-up in the control arm was associated with the lowest SMD. These results were similar in a model additionally adjusting for outcome type (PA vs. WL). In sensitivity analysis excluding Almeida (2015),[45] which had high weight and contributed significantly to heterogeneity, the frequency in which the control arm receiving coaching or were followed up by the study were not associated with effect (p = 0.533 and 0.402, respectively).

Discussion

To our knowledge, this is the first meta analysis evaluating the impact of FI on objectively-measured PA and WL outcomes. Our results suggest that FI are moderately effective in improving PA and WL in adults with sedentary lifestyles or comorbidities, increasing steps per day by 940 steps and weight loss by 2.3 kilograms compared to control participants. We found that greater weekly actuarial FI and shorter interventions were positively associated with favorable outcomes.

Several meta-analyses on FI for a range of health behavior changes have been conducted and have varied conclusions. One evaluated the effect of FI on PA found that incentives increased exercise attendance by 11.6% when compared to control.[32] In a meta-analysis on FI for behavioral obesity treatments, there were no significant effects of FI compared to control.[24] For PA, FI was effective if dispersed conditionally upon meeting goals, but not when given unconditionally, such as a gym membership.[26] Another meta-analysis found that FI for smoking cessation, vaccination or screening attendance, and physical activity was more effective than usual care or no intervention, with an effect size of 1.62 for all health-related outcomes.[23] Additionally, these studies included self-reported outcomes, which may bias results in trials[33, 59] because people tend to over-report PA levels.[39, 60] Ours was the first meta-
A

Weight (1/Variance)

Standardized Mean Difference

B

Weight (1/Variance)

Standardized Mean Difference
Table 1. Study characteristics, baseline measures, and change in outcome measures.

| Study       | Chronic condition   | Site               | N     | Mean age (SD) | Change (SD) | Mean age (SD) | Change (SD) | N     | Mean age (SD) | Change (SD) |
|-------------|---------------------|--------------------|-------|---------------|-------------|---------------|-------------|-------|---------------|-------------|
| **Physical Activity (steps/day)** |                     |                    |       |               |             |               |             |       |               |             |
| [50]Harkins 2017 | Sedentary lifestyle | Community          | 16    | 4851 (2500)   | 1624 (1133) | 24            | 4794 (2826) | 2769 (2108) | 80    | 6 (16)        | Gain incentive $330 |
| [47]Losina 2017 | OA                  | Hospital           | 100   | 5578 (2984)   | 481 (2747)  | 102           | 5142 (3069) | 1327 (2804) | 65    | 8 (24)        | Gain incentive $305 |
| **Weight Loss (kg)**   |                     |                    |       |               |             |               |             |       |               |             |
| [51]Finkelstein 2017 | Obesity             | Community          | 54    | 80.5 (13.1)   | 1.8 (3.7)   | 107           | 81.3 (12.1) | 3.3 (3.7)   | 44    | 10 (32)       | Gain incentive/Lottery $385 |
| [52]John 2011a | Obesity             | Hospital           | 11    | 105.0 (10.9)  | 0.5 (6.3)   | 22            | 103.5 (10.6) | 4.4 (6.2)   | Notreported | 32 (32)       | Deposit contract $1,645 |
| [52]John 2011b | Obesity             | Hospital           | 11    | 105.0 (10.9)  | 0.5 (6.3)   | 22            | 105.1 (14.5) | 3.5 (5.8)   | Notreported | 32 (32)       | Deposit contract $1,645 |
| [53]Kullgren 2013a | Obesity             | Workplace          | 17    | 94.1 (14.0)   | 0.5 (5.1)   | 35            | 94.6 (12.0)  | 1.7 (4.8)   | 45    | 10 (24)       | Loss incentive $640 |
| [53]Kullgren 2013b | Obesity             | Workplace          | 18    | 94.1 (14.0)   | 0.5 (5.1)   | 35            | 98.0 (15.0)  | 4.8 (4.8)   | 45    | 10 (24)       | Loss incentive $640 |
| [54]Kullgren 2016a | Obesity             | Workplace          | 11    | 100.1 (15.6)  | -0.5 (3.5)  | 33            | 100.7 (16.6) | 2.0 (4.0)   | 44    | 10 (24)       | Deposit contract $538 |
| [54]Kullgren 2016b | Obesity             | Workplace          | 11    | 100.1 (15.6)  | -0.5 (3.5)  | 33            | 97.1 (18.3)  | 2.4 (4.6)   | 44    | 10 (24)       | Deposit contract $1,076 |
| [55]Kullgren 2016c | Obesity             | Workplace          | 11    | 100.1 (15.6)  | -0.5 (3.5)  | 33            | 108.2 (22.3) | 1.0 (4.5)   | 44    | 10 (24)       | Deposit contract $1,613 |
| [55]Paloyo 2015a | Obesity             | Rehabilitation clinic | 117  | 11.1 (20.0)   | 1.8 (4.9)   | 237           | 114.0 (23.0) | 4.0 (5.2)   | 48    | 9 (16)        | Gain incentive $214 |
| [55]Paloyo 2015b | Obesity             | Rehabilitation clinic | 117  | 111.0 (20.0)  | 1.8 (4.9)   | 229           | 114.0 (23.0) | 4.9 (6.4)   | 48    | 9 (16)        | Gain incentive $428 |
| [56]Patel 2016a | Obesity             | Workplace          | 17    | 103.3 (18.5)  | 0.0 (6.5)   | 51            | 102.0 (16.2) | 0.5 (5.5)   | 45    | 10 (52)       | Gain incentive $558 |
| [56]Patel 2016b | Obesity             | Workplace          | 17    | 103.3 (18.5)  | 0.0 (6.5)   | 50            | 103.7 (17.1) | 0.6 (5.7)   | 45    | 10 (52)       | Gain incentive $558 |
| [56]Patel 2016c | Obesity             | Workplace          | 16    | 103.3 (18.5)  | 0.0 (6.5)   | 50            | 103.9 (17.2) | 0.5 (1.0)   | 45    | 10 (52)       | Lottery $558 |
| [57]Shin 2017   | Obesity             | University         | 35    | 91.6 (9.8)    | 1.1 (2.9)   | 35            | 92.7 (12.2)  | 3.1 (3.7)   | 28    | 5 (12)        | Gain incentive $172 |
| [58]Volpp 2008a | Obesity             | Hospital           | 10    | 104.8 (14.3)  | 1.8 (4.1)   | 19            | 110.0 (13.7) | 6.0 (5.7)   | Notreported | 16 (16)       | Lottery $447 |
| [58]Volpp 2008b | Obesity             | Hospital           | 9     | 104.8 (14.3)  | 1.8 (4.1)   | 19            | 109.5 (11.3) | 6.4 (4.6)   | Notreported | 16 (16)       | Deposit contract $1,225 |

* N reflects splitting of control group sample size across multiple arms from the same trial, where applicable
** Outlying study excluded from sensitivity analysis.

FI: financial incentives; OA: osteoarthritis; SD: standard deviation

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analysis to look at objectively-measured PA and WL outcomes exclusive of other health-related measures.

The SMD for WL that we report in the current analysis is 0.395, which is in line with the effect size of 0.47 reported in a meta-analysis of motivational interviewing (MI), another behavioral intervention, for WL.\[61\] For PA, we calculated an effect size of 0.392, which is higher than that found in meta-analyses of other behavioral interventions; these meta-analyses reported effect sizes between 0.07 and 0.27 and included studies that included both self-reported and objective outcomes.\[61–63\] Extrinsic motivators, such as FI, may be more effective than intrinsic motivators when an individual has limited initial interest in pursuing an activity because extrinsic motivators offer rewards associated with an independent outcome;\[64\] this may explain the increased effectiveness of FI compared to MI in the short-term.

**Fig 3. Forest plot of standardized mean differences (SMDs) (n = 11 studies, 19 study arms).** Each study arm is listed on the y-axis. Study arms are grouped by outcome type (PA or WL). The SMD is along the x-axis with a vertical line at zero representing the null value. Squares represent study arm-specific SMDs. Diamonds represent combined estimates from the random effects meta-analysis. The small diamonds represent the combined estimates for each outcome type (PA or WL) separately. The large diamond represents the overall combined estimate of all study arms for both outcomes. Bars are 95% confidence intervals.

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We found a smaller difference between the control arm and the intervention arm when the control group had more frequent interactions with a health coach. Control participants who receive coaching may be more motivated to participate in healthy behaviors, likely causing a smaller difference seen between control and intervention groups in those studies. Another meta-analysis found that in WL studies, control groups receiving no intervention lost less weight compared to groups that received usual care for WL, which generally includes health coaching.[65] We also found a smaller difference between the control arm and the intervention arm when the control group had less frequent follow-up about their objective outcomes; however, in the sensitivity analysis excluding Almeida (2015), the study that contributed significantly to heterogeneity due to high weight, both these control arm characteristics were not associated with intervention effect.

We found that longer intervention duration is associated with an attenuated intervention effect. This may be due to external rewards providing diminishing motivation over time as an
individual’s focus shifts from executing activities to earning rewards.[64] When designing FI interventions, habit formation should be emphasized over rewards. Our analysis did not evaluate sustainability of interventions due to the heterogeneity of secondary follow-up time points across studies. Maintenance of the favored behavior is a crucial goal of any intervention, and this underscores the need to evaluate intervention sustainability in future FI studies.

Limitations
The results of this analysis should be viewed considering several limitations. Trials of FI to improve PA or WL reported dissimilar outcomes, such as steps per day and WL in kilograms or pounds. In addition to considering PA and WL outcomes separately, we compared data across both outcomes. While we attempted to do this by using SMDs,[46] it is possible that the outcome measures may be associated with different underlying constructs. The SMD for overall effect allows for comparison across multiple measurement scales but does not capture potential differences in study populations, such as variation in participant characteristics for those engaging in PA versus WL studies.

While we assessed study quality with the Jadad score, we did not exclude studies based on quality. Further, a challenge in interpreting FI intervention outcomes is that the comparator arms often received heterogeneous treatments. We found significant associations between characteristics of the control arm and treatment effect, whereby less intensive control arms (less frequent coaching and follow-up) were associated with higher treatment effect. Further, while we did not find significant associations between many FI characteristics and outcome, there was heterogeneity within scheme types; for example, of the six intervention arms using deposit contracts, only one was unmatched[54] and the other five increased possible rewards with 1:1 or 2:1 matching.[52, 54, 58] These differences in implementation may influence intervention effects. While meta-analyses can be conducted on as few as two studies, our sample size had 11 studies with 19 intervention arms, limiting our ability to conduct subgroup analyses, thus our analyses were likely underpowered to detect differences in effect by study characteristics.[66] Finally, previous works have suggested that individual- or population-level demographic characteristics may affect the efficacy of FI interventions,[29, 55, 67] and this should be examined in future studies on FI.

Conclusions
We found a statistically significant estimate that subjects in groups receiving FI averaged 940 (95% CI [306–1,574]) more steps after PA interventions and lost on average 2.32 (95% CI [1.76–2.88]) more kilograms after WL interventions. Overall, we found a combined SMD of 0.395 (95%CI [0.243–0.546]; p<0.001) favoring FI over control for improving PA and WL outcomes. This meta-analytic review supports the use of FI in interventions to improve PA or WL. This analysis underscores the need for further studies to determine the sustainability of FI interventions; which subgroups, if any, benefit the most from FI; and which FI designs are most effective. These results may be useful for informing targeted interventions and policy decisions. Lifestyle improvement and public health programs should consider incorporating FI or pairing FI with other behavioral interventions invoking intrinsic motivation to improve PA or WL outcomes.

Supporting information
S1 Checklist. PRISMA checklist. (DOC)
S1 File. Appendix with search strings run in PubMed, Embase, and Web of Science; Table A with list of authors consults and data included in analysis; Table B with detailed summaries of included papers; Table C with methodological quality assessment: Jadad scores.[41]; Table D with derivation of maximum weekly possible financial incentives values.

S1 Fig. Forest plot of primary meta-analysis of steps per day. (TIF)

S2 Fig. Forest plot of primary meta-analysis of weight loss. (TIF)

Author Contributions

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References

1. Ogden CL, Carroll MD, Fryar CD, Flegal KM. Prevalence of obesity among adults and youth: United States, 2011–2014. NCHS Data Brief. 2015(219):1–8.

2. Selvin E, Parrinello CM, Sacks DB, Coresh J. Trends in prevalence and control of diabetes in the United States, 1988–1994 and 1999–2010. Ann Intern Med. 2014; 160(8):517–25. https://doi.org/10.7326/M13-2411 PMID: 24733192

3. Shiroma EJ, Cook NR, Manson JE, Buring JE, Rimm EB, Lee IM. Comparison of self-reported and accelerometer-assessed physical activity in older women. PLoS One. 2015; 10(12):e0145950. https://doi.org/10.1371/journal.pone.0145950 PMID: 26713857

4. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc. 2008; 40(1):181–8. https://doi.org/10.1249/MS.0b013e31815a5163 PMID: 18091006

5. Dunlop DD, Song J, Semanik PA, Chiang RW, Sharma L, Bathon JM, et al. Objective physical activity measurement in the osteoarthritis initiative: Are guidelines being met? Arthritis Rheum. 2011; 63 (11):3372–82. https://doi.org/10.1002/art.30562 PMID: 21792835
6. Rubin RR, Peyrot M. Quality of life and diabetes. Diabetes Metab Res Rev. 1999; 15(3):205–18. PMID: 10441043

7. Soni RK, Porter AC, Lash JP, Unruh ML. Health-related quality of life in hypertension, chronic kidney disease, and coexistent chronic health conditions. Adv Chronic Kidney Dis. 2010; 17(4):e17–26. https://doi.org/10.1053/j.ackd.2010.04.002 PMID: 20610351

8. Huang ES, Laiteerapong N, Liu JY, John PM, Moffet HH, Karter AJ. Rates of complications and mortality in older patients with diabetes mellitus: the diabetes and aging study. JAMA Intern Med. 2014; 174(2):251–8. https://doi.org/10.1001/jamainternmed.2013.12956 PMID: 24322595

9. Young DR, Hivert MF, Alhassan S, Cambhi SM, Ferguson JF, Katzmarzyk PT, et al. Sedentary behavior and cardiovascular morbidity and mortality: a science advisory from the American Heart Association. Circulation. 2016; 134(13):e262–79. https://doi.org/10.1161/CIR.0000000000000440 PMID: 27528691

10. Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. Lancet. 2011; 378(9793):815–25. https://doi.org/10.1016/S0140-6736(11)60814-3 PMID: 21872750

11. Roehrig C, Miller G, Lake C, Bryant J. National health spending by medical condition, 1996–2005. Health Aff (Millwood). 2009; 28(2):w358–67.

12. Bijnen FC, Caspersen CJ, Mosterd WL. Physical inactivity as a risk factor for coronary heart disease: a WHO and International Society and Federation of Cardiology position statement. Bull World Health Organ. 1994; 72(1):1–4. PMID: 8131243

13. Fletcher GF, Balady G, Blair SN, Chaitman B, Caspersen C, Chaitman B, et al. Statement on exercise: benefits and recommendations for physical activity programs for all Americans. A statement for health professionals by the Committee on Exercise and Cardiac Rehabilitation of the Council on Clinical Cardiology, American Heart Association. Circulation. 1996; 94(4):857–62. PMID: 8772712

14. Thorgeirsson T, Kawachi I. Behavioral economics: merging psychology and economics for lifestyle interventions. Am J Prev Med. 2013; 44(2):185–9. https://doi.org/10.1016/j.amepre.2012.10.008 PMID: 23332337

15. Ainslie G. Derivation of "rational" economic behavior from hyperbolic discount curves. Am Econ Rev. 1991; 81(2):334–40.

16. Epstein LH, Salvy SJ, Carr KA, Dearing KK, Bickel WK. Food reinforcement, delay discounting and obesity. Physiol Behav. 2010; 100(5):438–45. https://doi.org/10.1016/j.physbeh.2010.04.029 PMID: 20435052

17. Thorgeirsson T, Kawachi I. Behavioral economics: merging psychology and economics for lifestyle interventions. Am J Prev Med. 2013; 44(2):185–9. https://doi.org/10.1016/j.amepre.2012.10.008 PMID: 23332337

18. Ainslie G. Derivation of "rational" economic behavior from hyperbolic discount curves. Am Econ Rev. 1991; 81(2):334–40.

19. Loewenstein G, Prelec D. Anomalies in intertemporal choice: evidence and an interpretation. Q J Econ. 1992; 107(2):573–97.

20. Tate LM, Tsai PF, Landes RD, Rettiganti M, Leffler LL. Temporal discounting rates and their relation to exercise behavior in older adults. Physiol Behav. 2015; 152(Pt A):295–9. https://doi.org/10.1016/j.physbeh.2015.10.003 PMID: 26440317

21. Barlow P, Reeves A, McKee M, Galea G, Stickler D. Unhealthy diets, obesity and time discounting: a systematic literature review and network analysis. Obes Rev. 2016; 17(8):109–9. https://doi.org/10.1111/obr.12431 PMID: 27256685

22. Hursh SR. Behavioral economics. J Exp Anal Behav. 1984; 42(3):435–52. https://doi.org/10.1901/jeab.1984.42-435 PMID: 16812401

23. Giles EL, Robalino S, McColloch E, Sniehotta FF, Adams J. The effectiveness of financial incentives for health behaviour change: systematic review and meta-analysis. PLoS One. 2014; 9(3):e90347. https://doi.org/10.1371/journal.pone.0090347 PMID: 24618584

24. Paul-Ebhohimhen V, Avenell A. Systematic review of the use of financial incentives in treatments for obesity and overweight. Obes Rev. 2008; 9(4):355–67. https://doi.org/10.1111/j.1467-789X.2007.00409.x PMID: 17956546

25. Noordraven EL, Audier CH, Staring AB, Wierdema AI, Blanken P, van der Hoom BE, et al. Money for medication: a randomized controlled study on the effectiveness of financial incentives to improve medication adherence in patients with psychotic disorders. BMC Psychiatry. 2014; 14:343. https://doi.org/10.1186/s12888-014-0343-3 PMID: 25438877

26. Barte JC, Wendel-Voss GC. A systematic review of financial incentives for physical activity: the effects on physical activity and related outcomes. Behav Med. 2017; 43(2):79–90. https://doi.org/10.1080/08964289.2015.1074880 PMID: 26431076
27. Volpp KG, Troxel AB, Pauly MV, Glick HA, Puig A, Asch DA, et al. A randomized, controlled trial of financial incentives for smoking cessation. N Engl J Med. 2009; 360(7):699–709. https://doi.org/10.1056/NEJMsa0806819 PMID: 19213683

28. Seal KH, Kral AH, Lorvick J, McNees A, Gee L, Edlin BR. A randomized controlled trial of monetary incentives vs. outreach to enhance adherence to the hepatitis B vaccine series among injection drug users. Drug Alcohol Depen. 2003; 71(2):127–31.

29. Ariely D, Gneezy U, Loewenstein G, Mazur N. Large stakes and big mistakes. Rev Econ Stud. 2009; 76:451–69.

30. Lally P, van Jaarsveld CH, Potts HW, Wardle J. How are habits formed: Modelling habit formation in the real world. Eur J Soc Psychol. 2009; 40(6):998–1009.

31. Paloyo AR, Reichert AR, Reinermann H, Tauchmann H. The causal link between financial incentives and weight loss: an evidence-based survey of the literature. J Econ Surv. 2014; 28(3):401–20.

32. Mitchell MS, Goodman JM, Alter DA, John LK, Oh PI, Pakosh MT, et al. Financial incentives for exercise adherence in adults: systematic review and meta-analysis. Am J Prev Med. 2013; 45(5):658–67. https://doi.org/10.1016/j.amepre.2013.06.017 PMID: 24139781

33. Villanueva EV. The validity of self-reported weight in US adults: a population based cross-sectional study. BMC Public Health. 2001; 1:11. https://doi.org/10.1186/1471-2458-1-11 PMID: 11716792

34. Barile JP, Mitchell SA, Thompson WW, Zack MM, Reive BB, Cella D, et al. Patterns of chronic conditions and their associations with behaviors and quality of life, 2010. Prev Chronic Dis. 2015; 12:E222. https://doi.org/10.5888/pch.12.150179 PMID: 26679491

35. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009; 339:b2535. https://doi.org/10.1136/bmj.b2535 PMID: 1962555

36. Morrison A, Polisena J, Husereau D, Moulton K, Clark M, Fidler M, et al. The effect of English-language restriction on systematic review-based meta-analyses: a systematic review of empirical studies. Int J Technol Assess Health Care. 2012; 28(2):138–44. https://doi.org/10.1017/S0266462312000086 PMID: 22559755

37. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009; 42(2):377–81. https://doi.org/10.1016/j.jbi.2008.08.010 PMID: 18929686

38. Internal Revenue Service. Yearly Average Currency Exchange Rates. [Web] Washington, D.C. 2017 [updated August 17, 2017; cited 2018 January 8]; Available from: www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates.

39. United States Department of Labor—U.S. Bureau of Labor Statistics. Consumer Price Index. 2017 [August 18, 2017]; Available from: www.bls.gov/cpi/#data.

40. Rasband WS. ImageJ. In: U.S. National Institutes of Health, editor. Bethesda, Maryland, USA1997-2016.

41. Jadad AR, Moore RA, Carroll D, Jenkinson C, Reynolds DJ, Gavaghan DJ, et al. Assessing the quality of reports of randomized clinical trials: is blinding necessary? Control Clin Trials. 1996; 17(1):1–12. PMID: 8721797

42. Boutron I, Guittet L, Estellat C, Moher D, Hrobjartsson A, Ravaud P. Reporting methods of blinding in randomized trials assessing nonpharmacological treatments. PLoS Med. 2007; 4(2):e61. https://doi.org/10.1371/journal.pmed.0040061 PMID: 17311468

43. Boutron I, Moher D, Altman DG, Schulz KF, Ravaud P. Extending the CONSORT statement to randomized trials of nonpharmacologic treatment: explanation and elaboration. Ann Intern Med. 2008; 148(4):295–309. PMID: 18283207

44. Normand SL. Meta-analysis: formulating, evaluating, combining, and reporting. Stat Med. 1999; 18(3):321–59. PMID: 10070677

45. Almeida FA, You W, Harden SM, Blackman KC, Davy BM, Glasgow RE, et al. Effectiveness of a worksite-based weight loss randomized controlled trial: the worksite study. Obesity (Silver Spring). 2015; 23(4):737–45.

46. Cochrane Handbook for Systematic Reviews of Interventions. www.cochrane-handbook.org: The Cochrane Collaboration; 2011. Available from: http://handbook-5-1.cochrane.org/.

47. Losina E, Collins JE, Deshpande BR, Smith SR, Michi GL, Usiskin IM, et al. Financial incentives and health coaching to improve physical activity following total knee replacement: a randomized controlled trial. Arthritis Care Res (Hoboken). 2017.

48. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ. 2003; 327(7414):557–60. https://doi.org/10.1136/bmj.327.7414.557 PMID: 12958120
49. Whitehead A. Meta-analysis of controlled clinical trials. Chichester, West Sussex, England: John Wiley & Sons, Ltd; 2002.

50. Harkins KA, Kullgren JT, Bellamy SL, Karlawish J, Glanz K. A trial of financial and social incentives to increase older adults’ walking. Am J Prev Med. 2017; 52(5):E123–E30. https://doi.org/10.1016/j.amepre.2016.11.011 PMID: 28062271

51. Finkelstein EA, Tham KW, Haaland BA, Sahasranaman A. Applying economic incentives to increase effectiveness of an outpatient weight loss program (TRIO)—a randomized controlled trial. Soc Sci Med. 2017; 185:63–70. https://doi.org/10.1016/j.socscimed.2017.05.030 PMID: 28554652

52. John LK, Loewenstein G, Troxel AB, Fassbender JE, Volpp KG. Financial incentives for extended weight loss: a randomized, controlled trial. J Gen Intern Med. 2011; 26(6):621–6. https://doi.org/10.1007/s11606-010-1628-y PMID: 21249462

53. Kullgren JT, Troxel AB, Loewenstein G, Norton LA, Gatto D, Tao Y, et al. A randomized controlled trial of employer matching of employees’ monetary contributions to deposit contracts to promote weight loss. Am J Health Promot. 2016; 30(6):441–52. https://doi.org/10.1177/0890117116658210 PMID: 27445325

54. Paloyo AR, Reichert AR, Reuss-Borst M, Tauchmann H. Who responds to financial incentives for weight loss? Evidence from a randomized controlled trial. Soc Sci Med. 2015; 145:44–52. https://doi.org/10.1016/j.socscimed.2015.09.034 PMID: 26448164

55. Patel MS, Asch DA, Troxel AB, Fletcher M, Osman-Koss R, Brady J, et al. Premium-based financial incentives did not promote workplace weight loss in a 2013–15 study. Health Aff (Millwood). 2016; 35(1):71–9.

56. Shin DW, Yun JM, Shin JH, Kwon H, Min HY, Joh HK, et al. Enhancing physical activity and reducing obesity through smartcare and financial incentives: a pilot randomized trial. Obesity (Silver Spring). 2017; 25(2):302–10.

57. Volpp KG, John LK, Troxel AB, Norton L, Fassbender J, Loewenstein G. Financial incentive-based approaches for weight loss: a randomized trial. JAMA. 2008; 300(22):2631–7. https://doi.org/10.1001/jama.2008.804 PMID: 19066383

58. Liu SH, Eaton CB, Driban JB, McAlindon TE, Lapane KL. Comparison of self-report and objective measures of physical activity in US adults with osteoarthritis. Rheumatol Int. 2016; 36(10):1355–64. https://doi.org/10.1007/s00296-016-3537-9 PMID: 27435920

59. Boyle T, Lynch BM, Courneya KS, Vallance JK. Agreement between accelerometer-assessed and self-reported physical activity and sedentary time in colon cancer survivors. Support Care Cancer. 2015; 23(4):1121–6. https://doi.org/10.1007/s00520-014-2453-3 PMID: 25301224

60. VanBuskirk KA, Wetherell JL. Motivational interviewing with primary care populations: a systematic review and meta-analysis. J Behav Med. 2014; 37(4):768–80. https://doi.org/10.1007/s10865-013-9527-4 PMID: 23934180

61. O’Halloran PD, Blackstock F, Shields N, Holland A, Iles R, Kingsley M, et al. Motivational interviewing to increase physical activity in people with chronic health conditions: a systematic review and meta-analysis. Clin Rehabil. 2014; 28(12):1159–71. https://doi.org/10.1177/0269215514536210 PMID: 24942478

62. Oliveira JS, Sherrington C, Amorim AB, Dario AB, Tiedemann A. What is the effect of health coaching on physical activity participation in people aged 60 years and over? A systematic review of randomised controlled trials. Br J Sports Med. 2017.

63. Ryan RM, Deci EL. Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. Contemp Educ Psychol. 2000; 25:54–67. https://doi.org/10.1006/ceps.1999.1020 PMID: 10620381

64. Waters L, George AS, Chey T, Bauman A. Weight change in control group participants in behavioural weight loss interventions: a systematic review and meta-regression study. BMC Med Res Methodol. 2012; 12:120. https://doi.org/10.1186/1471-2288-12-120 PMID: 22873682

65. Valentine J, Pigott TD, Rothstein HR. How Many Studies Do You Need?: A Primer on Statistical Power for Meta-Analysis. Journal of Educational and Behavioral Statistics. 2010; 35(2):215–47.

66. Haff N, Patel MS, Lim R, Zhu J, Troxel AB, Asch DA, et al. The role of behavioral economic incentive design and demographic characteristics in financial incentive-based approaches to changing health behaviors: a meta-analysis. Am J Health Promot. 2015; 29(5):314–23. https://doi.org/10.4278/ajhp.140714-LIT-333 PMID: 25928816