# Effective Strategy of Financial Incentive for Exercise Adherence

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## Abstract

Financial incentive is a popular intervention approach to motivating individuals to engage in health behaviors such as physical activity. Traditional strategies of financial incentive include to offer constant, decreasing, and increasing rewards over time conditioned on achieving a daily or weekly behavior goal. But such simple strategies could take a wasted shot of incentive at those who are temporally highly-motivated, or fail to offer incentives enough to motivate inactive individuals. Therefore, much remains to be explored to find sophisticated incentive strategies for exercise adherence. In this paper, by focusing on a psychological determinant called self-efficacy, we investigate cost-effective incentive strategies for maintaining a recommended level of physical activity. We analyze a field experiment data of 9-week walking program, and propose a probabilistic model that mimics a participant's behavior in the walking program. Through a simulation study with the proposed model, we show that a more effective incentive strategy than conventional approaches could be found.

*keyword*: Self-efficacy, Financial incentive, Exercise adherence, Behavior model, Statistical Analysis

## 1 Introduction

Physical inactivity is a major risk factor for noncommunicable diseases such as heart disease, stroke, diabetes and breast and colon cancer. It also provokes hypertension, overweight and obesity and could deteriorate mental health, quality of life and well-being. WHO estimated the global cost of physical inactivity as INT$ 54 billion per year in direct health care, in 2013, with an additional INT$ 14 billion attributable to lost productivity [15], highlighting the great benefits of encouraging and increasing individuals' physical activities.

Financial incentive is a popular intervention tool for motivating individuals to engage in health behaviors such as weight loss [14, 13], smoking cessation [12], and physical activity [9]. Compared to other types of interventions such as text message, financial incentive is subjected to a severe trade-off between financial feasibility and performance, and thus is required to be cost-effective: larger incentive is highly likely to change individuals' behaviors, while being a financial burden for health care services. The simplest strategy of financial incentive is to hang a constant reward conditioned on performing a pre-defined behavior for each period (e.g., $0.1 for one-hour walking per day), which has been widely adopted by various health care services that promote physical activity. Some non-static strategies, which include decreasing and increasing rewards over time, have recently been investigated [1], but much remains to be explored to find sophisticated incentive strategies for exercise adherence.

In this paper, by focusing on a psychological determinant called *self-efficacy*, we investigate cost-effective and dynamical incentive strategies for maintaining a recommended level of physical activ-

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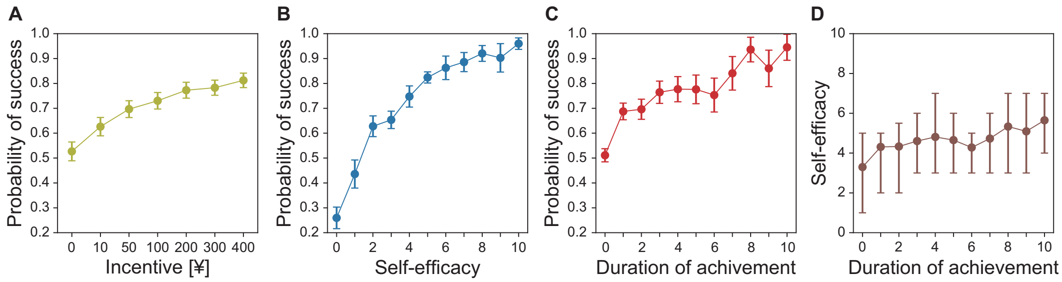


Figure 1: Results on a field experiment data. (A) The probabilities of achievement conditioned on the offered incentives. (B) The probabilities of achievement conditioned on the self-efficacy scores. (C) The probabilities of achievement conditioned on the durations of the most recent consecutive goal achievements (abbreviated as "duration of achievement"). (D) The self-efficacy scores as function of the durations of the most recent consecutive goal achievements.

ity. Self-efficacy is defined as perceived capability to perform a target behavior [2], and social cognitive theory predicts that self-efficacy has a reciprocal relationship with achievements of the target behavior [2–4]: higher self-efficacy causes higher achievement, and vice versa. First, we analyze a real-world data obtained through a 9-week walking program with daily step goals, and confirm the reciprocal relationship between walking-related self-efficacy and step achievement. Then we construct a probabilistic behavior model that mimics the reciprocal dynamics, based on which we show that a more effective incentive strategy could be found than conventional approaches through a simulation study.

## 2 Study Design and Participants

We conducted a field experiment of 9-week walking program with a daily goal of 8,000 steps. Participants were instructed to wear wireless activity trackers (Fitbit Inspire 2) and install Slack app on their own smartphones to receive messages and respond to surveys. At the end of each day, the participants received a notification of success/fail along with the earned reward, and a questionnaire form to measure self-efficacy, followed by the next-day incentive offered for the step goal, which was assigned randomly from {¥0, ¥10, ¥50, ¥100, ¥200, ¥300, ¥400} each day. The purpose of the experiment was to investigate the causal relationships between financial incentive, self-efficacy, and step goal achievement.

Self-efficacy (SE) is the confidence in one's ability to perform a target behavior [2]. According to a guide for constructing self-efficacy scales developed by Bandura (2006) [5], the participants rated their ability to achieve the step goal the next day on a 10-point scale from 0 = "cannot do at all" to 10 = "can do very well" to measure their level of self-efficacy.

Participants were 88 Japanese adults recruited by a survey company in Japan. To be eligible, participants had to be aged 20-60 years, non-pregnant, inactive but willing to increase physical activity within half a year. Participant activity/inactivity was assessed by the Japanese version of International Physical Activity Questionnaire (IPAQ) short form [6, 10], where "low" level of physical activity was recruited as a participant.

## 3 Statistical Analyses

We examined the causal relationships between financial incentive, self-efficacy, and step goal achievement based on the field experiment data. The data consists of a sequence of offered incentives, reported scores of self-efficacy, and binary results (1 = success, and 0 = failure) of the step goal for each participant $u \in \{1, \ldots, U\}$, denoted by $\{f_t^u\}_{t=1}^T$, $\{s_t^u\}_{t=1}^T$, and $\{y_t^u\}_{t=1}^T$, respectively. The duration of time step, $T$, is 9 × 7 = 63 days, and the number of participants, $U$, is 88.

Figure 1A, 1B, and 1C display the conditional probabilities for a participant to achieve the daily step goal (8,000 steps) as functions of the offered incentives, the scores of self-efficacy, and the

Table 1: Estimated parameters of behavior model. # represents the index of 11 sub-groups, and the bottom low is the mean and the standard deviation of estimated parameters.

| # | $\hat{\alpha}_s$ | $\hat{\alpha}_f$ | $\hat{\beta}$ | $\hat{v}_0$ | $\hat{v}_1$ |
|---|---|---|---|---|---|
| 1 | 0.592 | 0.005 | 0.313 | 0.279 | 0.980 |
| 2 | 0.449 | 0.001 | 0.195 | 0.385 | 0.980 |
| 3 | 0.649 | 0.003 | 0.268 | 0.274 | 0.984 |
| 4 | 0.330 | 0.011 | 0.930 | 0.480 | 0.777 |
| 5 | 0.139 | 0.097 | 0.106 | 0.435 | 0.810 |
| 6 | 1.448 | 0.070 | 0.027 | 0.544 | 0.885 |
| 7 | 0.018 | 0.023 | 0.816 | 0.422 | 0.850 |
| 8 | 1.284 | 0.094 | 0.017 | 0.158 | 0.871 |
| 9 | 0.344 | 0.004 | 0.205 | 0.395 | 0.885 |
| 10 | 0.233 | 0.097 | 0.090 | 0.581 | 0.971 |
| 11 | 0.032 | 0.016 | 0.441 | 0.385 | 0.657 |
| | 0.502 ± 0.452 | 0.038 ± 0.040 | 0.310 ± 0.292 | 0.394 ± 0.117 | 0.877 ± 0.098 |

durations of the most recent consecutive goal achievements, $d_t^u$, respectively, where the conditional probabilities given $x$, denoted by $\hat{p}(x)$, were estimated as follows:

$$\hat{p}(x) = \sum_{(t,u)\in\mathcal{A}_x} y_t^u \Big/ \sum_{(t,u)\in\mathcal{A}_x} 1, \quad \mathcal{A}_x = \{(t,u)|x_t^u = x\}, \quad x \in \{f, s, d\}. \tag{1}$$

The sample means (1) correspond to the maximum likelihood estimators of the success probability parameter for the Bernoulli distribution, and the error bars were provided by the 0.05 significance levels of the binomial proportion confidence intervals. Figure 1D displays the self-efficacy scores as function of the durations of the most recent consecutive goal achievements, where the self-efficacy scores given duration $d$, denoted by $\hat{s}(d)$, were estimated as follows:

$$\hat{s}(d) = \sum_{(t,u)\in\mathcal{B}_d} s_t^u \Big/ \sum_{(t,u)\in\mathcal{B}_d} 1, \quad \mathcal{B}_d = \{(t,u)|d_t^u = d\}, \tag{2}$$

and the error bars were provided by the 0.5 significance levels of confidence intervals. Figure 1A shows that the probability for a participant to succeed in the daily step goal was positively correlated with the offered amount of incentive, which suggests that the financial incentive is an effective intervention tool for promoting daily walking. Figure 1B and 1D show that higher self-efficacy caused higher probability of success, and longer duration of consecutive successes caused higher self-efficacy, which is consistent with the reciprocal relationship between self-efficacy and health behavior that the social cognitive theory predicts [2–4]. The reciprocal relationship can yield a self-exciting dynamics of health behavior, which was confirmed by Figure 1C.

## 4 Simulation Study

*Behavior Model*

Based on the result of statistical analyses, we propose a simple probabilistic model that mimics the participant's behavior in the walking program. Let $f_t$, $s_t$, and $y_t$ be the offered financial incentive, the self-efficacy, and the goal achievement (1/0 = success/failure) at time step $t \in \{1, \ldots, T\}$, respectively. Then we assume that $y_t$ is generated from a Bernoulli distribution with success probability parameter, $\eta_t$, which depends on $f_t$ and $s_t$:

$$p(y_t|\eta_t) = \eta_t^{y_t}(1-\eta_t)^{1-y_t}, \quad \eta_t = \sigma(\alpha_s s_t + \alpha_f f_t), \tag{3}$$

where $\alpha_s$ and $\alpha_f$ represent the sensitivities of self-efficacy and financial incentive to participant's motivation, and $\sigma(z)$ represents a sigmoid function that has the lower and the upper bounds as $v_0$ and $v_1$ for $z >= 0$:

$$\sigma(z) = \frac{v_1 v_0}{(v_1 - v_0)\exp(-z) + v_0}. \tag{4}$$

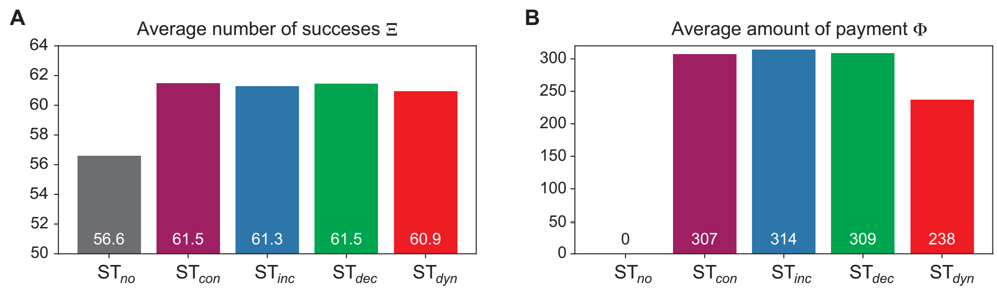


Figure 2: Results on simulation study. (A) The average number of successes. The higher, the better. (B) The average financial cost. The lower, the better.

We further assume that the self-efficacy $s_t$ has a linear dynamical system as follows:

$$s_{t+1} = (1-\beta)s_t + \beta y_t, \tag{5}$$

where the self-efficacy $s_t$ takes a value between 0 and 1, and the effect of a goal achievement $y_t$ on $s_t$ decays by a factor $(1-\beta)$. The proposed behavior model has a five-dimensional parameter, $\boldsymbol{\theta} = (\alpha_s, \alpha_f, \beta, v_0, v_1)$.

*Model Fitting*

Based on the field experiment data, $\{f_t^u, s_t^u, y_t^u\}_{t,u}$, we fitted the behavior model by the maximum likelihood method with a popular gradient descent algorithm, *Adam* [7]:

$$\hat{\boldsymbol{\theta}} = \arg\max_{\boldsymbol{\theta}} \sum_{u=1}^{U}\sum_{t=1}^{T}\Big[y_t^u \log(\eta_t^u) + (1-y_t^u)\log(1-\eta_t^u)\Big], \tag{6}$$

where

$$\eta_t^u = \sigma(\alpha_s s_t^u + \alpha_f f_t^u), \quad s_{t+1}^u = (1-\beta)s_t^u + \beta y_t^u. \tag{7}$$

We split randomly the $U$ = 88 participants into 11 sub-groups, and estimated a model parameter based on each of the sub-group's data. Table 1 shows the mean and standard deviation over the 11 estimated model parameters, where the value of model parameter differs largely between participants. It suggests that the strategy of financial incentive should be optimized for each individual.

*Cost-Effective Incentive Strategy*

The reciprocal relationship between self-efficacy and goal achievement implies that a small incentive could be enough to motivate a participant to engage in the goal while the level of self-efficacy is high. Thus, we examined a dynamic incentive strategy, denoted by ST$_{dyn}$, that the offered incentive, $f_t$, depends on the level of self-efficacy, $s_t$, at each time step $t$:

$$\mathrm{ST}_{dyn}: f_t = \begin{cases} c_1 & s_t <= s_{th} \\ c_0 & s_t > s_{th} \end{cases}, \qquad t \in \{1, \ldots, T\}, \tag{8}$$

where $s_{th}$ and $T$ represent the threshold level of self-efficacy and the duration of observation, respectively, and $c_1 > c_0$. We compared the performance of the dynamic strategy (ST$_{dyn}$) with those of conventional strategies, which consist of constant (ST$_{con}$), increasing (ST$_{inc}$), decreasing (ST$_{dec}$), and no (ST$_{no}$) rewards over time:

$$\mathrm{ST}_{con}: f_t = \frac{B}{T}, \quad \mathrm{ST}_{inc}: f_t = \frac{2Bt}{T(T+1)}, \quad \mathrm{ST}_{dec}: f_t = \frac{2B(T-t+1)}{T(T+1)}, \quad \mathrm{ST}_{no}: f_t = 0, \tag{9}$$

where $B$ represents the budget of financial incentive. Here, we set ($c_0$, $c_1$, $s_{th}$, $T$, $B$) as (15, 1, 0.4, 100, 500).

Under each of the strategies, we simulated the behavior model with model parameter in Table 1 $N$ times, and evaluated the performance based on the average number of successes and the average amount of payment, denoted by $\Xi$ and $\Phi$, respectively:

$$\Xi = \frac{1}{N}\sum_{n=1}^{N}\sum_{t=1}^{T} y_{n,t}, \quad \Phi = \frac{1}{N}\sum_{n=1}^{N}\sum_{t=1}^{T} f_{n,t} \cdot y_{n,t}, \tag{10}$$

where $y_{n,t}$ and $f_{n,t}$ represent the result of success/failure and the amount of incentive offered at time step $t$ of the $n$-th trial, respectively. $N$ was set as $10^4$. Figure 2 displays the result of simulation study, which shows that the dynamic strategy, $\mathrm{ST}_{dyn}$, achieved comparable successes of goal while being substantially cheaper than the conventional strategies. Because the dynamic strategy (8) is not mathematically optimized, it is possible to find a more sophisticated strategy with the help of techniques such as reinforcement learning [11] and optimal control theory [8].

## 5 Conclusion

We focused on a psychological determinant called *self-efficacy*, and investigated cost-effective incentive strategies for maintaining a recommended level of physical activity. First, we analyzed a field data obtained through a 9-week walking program of a daily step goal, and confirmed the reciprocal relationship between walking-related self-efficacy and step achievement that the social cognitive theory predicts. Next, we proposed a simple probabilistic behavior model that incorporated the reciprocal relationship, and fitted the model to the field data. Finally, through a simulation study based on the behavior model, we showed that a more effective incentive strategy can be found than conventional approaches which include constant, increasing, and decreasing rewards over time.

## Conflict of Interest

The authors declare that there are no conflicts of interest.

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