4-11-2019

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Recommended Citation

Phillips, C. B., Hurley, J. C., Angadi, S. S., Todd, M., Berardi, V., Hovell, M., & Adams, M. A. (2019). Delay discount rate moderates a physical activity intervention testing immediate rewards. *Behavioral Medicine*. https://doi.org/10.1080/08964289.2019.1570071

Delay Discount Rate Moderates a Physical Activity Intervention Testing Immediate Rewards

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ABSTRACT

Financial incentives can increase physical activity (PA), but differences in the immediacy of reward delivery and individual differences in delay discount rates (i.e., higher discount values associated with less tolerance for delayed rewards) may explain differential responding. The current study tested whether delay discount rate moderated the relative effectiveness of immediate financial rewards on increasing daily PA. Inactive, overweight adults (ages 18-60, N=96) were randomized to receive either smaller, immediate goal-contingent rewards or larger, delayed rewards for participation. Delay discount rates were derived for those who completed the Monetary Choice Questionnaire (N=85). Linear mixed models tested interactions between discount rate and intervention arm on changes in mean daily Fitbit-measured steps from baseline to intervention phases, and rates of change during the intervention phase. Across all groups, participants increased by 2258 steps/day on average from baseline to intervention and declined by 9 steps/day across the 4-month intervention phase. The mean increase in daily steps was greater for immediate reward-arm participants across all discount rates. Descriptive exploration of reward effects by delay discount rate suggested that the magnitude of reward effects decreased at higher discount rates. During the 4-month intervention phase, rates of decline in daily steps were similar in both reward arms, but declines became more pronounced at higher discount rates. Overall, intervention efficacy decreased with less tolerance for delays. The importance of financial reward immediacy for increasing PA appears to increase with greater delay discount rates.

Key Words: physical activity, delay discounting, financial incentives, reward schedule, intervention, impulsive behavior

INTRODUCTION

Physical activity (PA) is widely recognized as one of the most important behaviors for preventing chronic disease and all-cause mortality, yet fewer than half of U.S. adults engage in sufficient PA to meet current guidelines,[1,2] and nearly a quarter do not engage in any leisure time PA.[1] Delay discounting has been largely overlooked for the incongruity between benefits and engagement in physical activity. Delay discounting, also known as temporal or time discounting, refers to the shrinking value or effectiveness of a reward as the time delay to receipt increases.[3] Due to the higher relative value of immediate reinforcers in choice situations, many individuals match their behaviors to attain near-term reinforcers, even when in conflict with long-term aspirations.[4] Many well-documented benefits of PA (e.g., improved functional capacity, weight maintenance, reduced morbidity) are not immediately realized likely because most inherent benefits of PA are delayed and potentially valued less relative to other alternative sedentary behaviors which tend to have less near-term aversive or more immediately rewarding consequences.

Delay discounting has been observed across species and is considered a universally-observed behavioral phenomenon.[5] However, behavioral economic research with humans reveals individual differences in the degree that people tolerate delays in reward immediacy given options with different reward timings.[3,6] Individuals with higher discount rates are more sensitive to immediate reinforcers and devalue delayed rewards more rapidly compared to individuals with lower discount rates. Consequently, higher discounters are likely to favor ‘smaller sooner’ rewards, whereas lower discounters are able to forego immediate reinforcers in favor of receiving ‘larger later’ rewards. Higher discount rates have been associated with unhealthy behaviors such as smoking, excessive alcohol and substance use, high-risk sexual practices, maladaptive food consumption and obesity.[7] Lower discount rates have been associated with a number of positive outcomes, including lower BMI,[8-13] higher education[12-14] and academic performance,[15,16] and higher income.[12] Compared to maladaptive health behaviors, a considerably smaller body of work has examined associations between discount rates and health-promoting behaviors,[7] including PA.[8,17,18] Several studies have found that discount rates are inversely related to self-reported PA.[8,18] However, evidence is sparse and prospective studies have not examined how delay discounting may relate to objectively-measured PA adoption or maintenance.

Increasing PA has been a goal for a number of behavioral interventions, which have achieved varying degrees of success.[19] One strategy is to use financial incentives to reward PA engagement, thereby providing more immediately rewarding consequences than occur naturally. Findings indicate that financial incentives can influence behavior change,[20,21] but effect sizes have been inconsistent across studies. Although multiple individual factors, along with incentive design features (type, amount, schedule), have been proposed to explain effect size heterogeneity,[20,21] individual differences in delay discount rates have not been examined. Tailoring interventions to participants' preferences and behavioral characteristics is thought to enhance intervention efficacy.[22,23] The temporal distribution of benefits vs. costs of PA may predict a participants' willingness to initiate and maintain PA.[24] Thus, the potency of financial incentives may be increased by matching immediacy of reward delivery with a participant's sensitivity to smaller immediate rewards vs. tolerance to larger delayed rewards (i.e., delay discount rate). A smaller, immediate monetary reward, for example, may be a potent incentive among higher discounters, who are apt to favor immediate reinforcement from competing behaviors (e.g., TV watching) over delayed benefits of PA. Conversely, the immediacy of a financial reward may have little impact on the reward's effectiveness for lower discounters, or these individuals may actually favor larger delayed rewards due to a history of earning larger delayed rewards for other behaviors. The impact of matching reward immediacy with an individual's level of delay discounting has not been examined in PA intervention studies.

The current study aimed to address this gap in the literature via secondary analyses of the Walking Interventions through Texting (WalkIT) trial. The WalkIT trial investigated the effects of financial rewards and goal setting on Fitbit-measured PA over a 4-month study period. [25,26] The primary study hypothesized[26] that participants randomized into the immediate reward-arm would increase their PA more than participants assigned into the delayed, non-contingent reward-arm regardless of goal setting or discounting rate. Main outcomes have been reported previously, but briefly, the immediate reward arm increased by 746 steps/day more than the delayed reward arm.[26] For the current secondary analyses, we asked whether group status interacted with participants' measured delay discount rate to affect PA. Participants with higher discount rates who were coincidentally randomized into the immediate reward arm were hypothesized to have greater increases in PA than high discounters randomized to the delayed reward arm.

METHODS

Participants

Inclusion criteria for study participation were as follows: (a) age 18-60, (b) self-reported BMI between 25 and 55 kg/m^2, (c) daily access to computer, Internet, email, and text message-enabled mobile phone, and (d) willing to send/receive several text messages/day and attend two office visits. Exclusionary conditions were as follows: (a) any contraindications to unsupervised exercise or submaximal exercise testing as reported on the Physical Activity Readiness Questionnaire plus (PAR-Q+), (b) currently pregnant or planned to become pregnant during study period, (c) planned to leave the study area for more than 10 days during the study period, or (d) actively participating in another PA, diet, or weight loss program. The current analytic sample included randomized participants who completed the delay discounting measure at the post-intervention office visit (N = 85).

Study Design and Procedures

The 2 x 2 factorial design tested the main and interactive effects of financial rewards (smaller, immediate goal-contingent vs. larger, delayed participation-contingent) and goal setting (adaptive vs. static goals) to increase PA among generally healthy, overweight/obese, and inactive adults (N = 96) (ClinicalTrials.gov ID NCT02053259). Briefly, study activities consisted of an online screening survey, baseline assessment visit, 10-days of baseline activity monitoring, a 4-month intervention phase and a post-intervention assessment visit. At the baseline visit, participants reviewed and signed Arizona State University Institutional Review Board approved consent forms and completed additional screening, demographic, and psychosocial questionnaires. Participants were then supplied with a blinded Fitbit Zip (Fitbit Inc, San Francisco, CA, USA), trained on proper use of the Fitbit and text system, and instructed to wear the Fitbit while maintaining their usual daily routines throughout a 10-day baseline period. No step feedback was provided to participants during the baseline phase. Participants deemed insufficiently active (i.e., $\leq$ 10,000 steps/ day on $\geq$ 5 days/week) with at least 9 valid days of wear (valid day required $\geq$ 500 steps) and those who successfully synced their device during baseline phase were immediately randomized into one of four intervention arms: immediate rewards/adaptive goals, immediate rewards/static goals, delayed rewards/adaptive goals, or delayed rewards/static goals. During the intervention phase, participants were asked to continue wearing and syncing an unblinded Fitbit Zip, as well as manually report daily Fitbit step totals to the study team via text message. Standardized educational emails and daily prompt-to-action texts were provided to participants in all groups. An automated system designed by software engineering staff delivered intervention components that varied by group assignment (i.e., reward delivery and goal setting, as described in the interventions section below). Participants in all groups sent and received approximately 2-3 daily text messages. At the 4-month post-intervention assessment, participants completed the delay discounting measure, returned the Fitbit Zip, and were debriefed about the study purpose.

Interventions

Reward arms. Participants in the immediate, smaller reward arm were informed at randomization that they could earn one point for each daily step goal met (i.e., continuous, fixed magnitude reinforcement); one point equaled $1.00. When a goal was met, participants received a text with a praise message, updated point balance, and next goal (e.g., “Well done, Mary! You have 4 points! Goal for 9/15 is *6948* steps.”). When a goal was not met, participants received a text confirmation of the step report and the next goal (e.g., “Steps received. Goal for 9/15 is *6948* steps”). Each time 5 points were accumulated, points were automatically exchanged by the automated system for a $5 gift card which was delivered by email.

Participants in the delayed, larger reward arm were told at randomization they would earn progressively larger monthly incentives (i.e., $5, $10, $10, $20) for wearing their Fitbit Zip, syncing regularly, and participating in the study. A text confirmation of step reports and the next goal were provided to participants of the delayed reward arm, but no praise messages or points were sent. Non-contingent, participation-only rewards were used for the delayed arm to match total amounts (magnitude) between reward conditions on average and because offering incentives for participation is commonly used in physical activity trials.[20]

Financial incentives were structured so that the amounts provided across reward arms would be roughly equivalent during the intervention phase (i.e., $44-$45) and for the entire study period (i.e., $69-$70).[26] Participants were allowed at baseline to select a preferred incentive type from a list of available retail options and were allowed to change their preferred option via text or email at any time during the study. Additional details of the intervention can be found in Hurley et al. [25]

Goal arms. Because the intervention was a factorial design (i.e., all participants were assigned to a reward condition and a goal condition), models were statistically adjusted for goal arm assignment (i.e., adaptive vs. static). Each daily goal for the adaptive goal arm was determined using a rank-ordered percentile algorithm using the previous nine days of non-missing activity data.[26] Adaptive goals were designed to increase, decrease or remain the same based on an individual's performance. Static goal arm participants were issued the same daily goal based on current PA recommendations (10,000 steps/day for $\geq$ 5 days/week). Automatic delivery of the next day's goal was prompted by the previous day's step report regardless of goal condition.

Measures

Delay discount rate. Delay discount rate was measured using the 27-item Monetary Choice Questionnaire (MCQ)[27] and scored using the Kaplan et al. automated scorer.[28] The MCQ yields delay discount (k) values for small, medium, and large reward magnitudes. An overall delay discounting composite score was created for each participant by calculating the geometric mean (geomean k) of the three reward magnitude values. Because raw geomean k scores were positively skewed, scores were natural log transformed (ln geomean k) for analyses.

Physical activity outcome. The PA outcome of interest was total daily steps, objectively-measured using the Fitbit Zip, a commercially-available hip-worn tri-axial accelerometer with excellent reliability (ICC=0.90) and validity (ICC=0.99) for steps.[29] Participants were asked to wear the device during all waking hours (i.e., $\geq$ 10 hours/day) during the baseline and intervention phases, removing it only for sleep and to avoid submerging in water. Participants were instructed to sync daily, using their personal computers equipped with a USB sync dongle and connected to the Internet. With each sync, PA data were transmitted to the study team.

Covariates. Previous studies have found inverse associations between delay discount rates and age,[12,30] income and education,[12,14,31] cigarette smoking,[8,12] and BMI.[8,12] Gender[31,32] has also been related to delay discounting, though inconsistent in direction. We adjusted for these variables in all models. Additional candidate covariates were assessed for inclusion during the base model building process, including employment status (currently employed or not), race (White, Black, American Indian, Asian, multiple races, refused to answer), ethnicity (Hispanic or non-Hispanic), marital status (married or living with partner vs. other), parental status (any children vs. none), and student status (currently enrolled or not).

Analytic Approach

Daily steps was modeled as a continuous outcome using linear mixed models (LMM) with repeated measures of steps (Level 1) nested within individual participants (Level 2). Time was scaled in days and centered at the first day of the intervention period. Statistical analyses were conducted using SAS 9.4 PROC MIXED.

Model building. Model fitting began with a base LMM that included fixed effects for study day (centered at the first intervention day), 11 indicator variables for calendar month, an effects-coded variable for the intervention component of goal arm assignment (static = -1, adaptive = 1), age (centered at sample mean), gender (female or male), household income (four levels from < \$25,000 to ≥ \$75,000), highest educational level attained (three levels from < high school diploma to ≥ 4-year college degree), smoking status (currently smoke or not), and BMI (kg/m^2, calculated from self-reported weight and height), random person-level intercept and study day parameters, and a parameter specifying a first-order autoregressive moving average (ARMA(1,1)) covariance structure among repeated (day-level) residuals. Additional person-level covariate selection was based on improvement in model fit relative to the base model. Separate models were estimated for each person-level covariate using maximum likelihood method and assessed for fit using -2 log likelihood tests (at $p \leq .10$). Parental status significantly improved model fit and was retained for subsequent analyses. The level 2 covariates plus a phase indicator (baseline = 0, intervention = 1) and intervention day variable (all baseline days = 0, first post-randomization day = 1, final study day = 109) were added to the base model to form an adjusted base model for hypothesis testing.

Testing Interactions between Delay Discount Classification and Reward Arm. LMMs were conducted to test the interactive effects of reward preference and reward arm on daily steps. Building on the adjusted base model, the interactive effects of discount rate and reward arm on mean changes in steps/day upon transitioning from baseline to intervention phase were addressed by adding a Delay Discount Rate x Reward Arm x Phase interaction term for (Model 1). Model 2 tested the interactive effects of discount rate and reward arm on rates of change in steps/day across the intervention period by adding a Delay Discount Rate x Reward Arm x Intervention Day interaction term to Model 1. For Model 2 analyses, intervention day was grouped into 9-10-day time increments, coded 0-11 (baseline = intervention time 0, intervention days 1-9 = time 1, …intervention days 100-109 = intervention time 11). Because we hypothesized that the effectiveness of reward arms may only differ at a certain unknown threshold value of delay discount rate, least squared means were estimated for the fixed effects of Reward Arm x Phase and Reward Arm x Intervention Day at delay discount rates (ln geomean k) corresponding to -8.14, -7.34, -6.54, -5.73, -4.93, -4.13, -3.33, -2.53, and -1.73 to conduct post-hoc comparisons. These delay discount values approximated the sample mean and +/- 0.5, 1.0, 1.5, and 2.0 standard deviations (SDs) from the sample mean. Therefore, post-hoc test results are reported as standardized z-scores (DDz) ranging from -2.0 (lowest discounting value; highest tolerance for reward delays) to 2.0 (highest discounting value; lowest tolerance for reward delays). Model 2-estimated mean daily steps during intervention phase time periods were used to calculate the percent decline in daily steps from the time period in which peak step attainment was achieved (time period 1 or 2) to end of the intervention phase (time period 11).

RESULTS

Table 1 displays descriptive characteristics of the analytic sample (N = 85) by reward arm. The majority were female (79%), white (81%), employed (98%), and non-smoking (91%). Participants ranged in age from 19 to 60 years (M = 41.4, SD = 9.5), with self-reported BMIs ranging from 25.1 to 49.8 (M = 33.8, SD = 6.1). Natural log-transformed geomean k values ranged from -8.75 to -1.39 (M = -4.93, SD = 1.60) and median = -4.91. Consistency scores for small, medium, and large calculated geomean k values for the sample ranged from 85% to 100% (M = 98.2%, SD = 3.1%). No individual participant consistency score for calculated small, medium, and large k values fell below 75%, the threshold suggested for identifying problematic response patterns.[28] Table 2 presents mean daily steps during baseline and intervention phases by reward arm and quartile of delay discount rate for the sample. Eleven participants randomized to a study arm were excluded from current analyses due to missing MCQ data. Excluded participants did not differ statistically from the analytic sample on demographic factors, smoking status or BMI (*p*s > .05), and in the analytic sample, delayed reward participants did not differ from immediate reward participants on these factors or on total rewards earned (*p*s > .05).

Delay Discount Rate and Intervention Arm Interactions: Mean Changes in Daily Steps

Model-estimated mean daily steps for the pooled sample increased, on average, by 2258 steps from baseline to intervention phase (b = 2258, 95% CI [1750, 2766], $p < .001$), and declined by an average of 9 steps per day during the intervention phase (b = -31, 95% CI [-107, 45], $p = .427$).

Figure 1 shows Model 1 estimates of mean daily step changes from baseline to intervention phase for each reward arm at all estimated discount rates. Results from Model 1 indicated no interaction among reward arm, delay discount rate, and phase (b = 92, 95% CI [-319, -503], $p = .660$; reference category: delayed reward arm at baseline). Immediate rewards were more effective than delayed rewards for increasing daily steps across all delay discount rates. However, descriptive exploration of reward effects across discount rates suggested that the *magnitude* of both immediate and delayed reward effects decreased at higher discount rates. For example, at a low discount rate (DDz = -2.0), the estimated effect of immediate vs. delayed rewards from baseline to intervention phase was 3105 steps (b = 3105 95% CI [1035, 4733, p = .004]. In contrast, at a high discount rate (DDz = 2.0), the estimated effect of immediate vs. delayed rewards from baseline to intervention phase was 2698 steps (b = 2698, 95% CI [620, 4776 p = .012].

Delay Discount Rate and Intervention Arm Interactions: Rates of Change in Daily Steps During the Intervention Phase

Estimated mean daily steps from Model 2 from the intervention phase are presented by reward arm for selected levels of delay discount in Figure 2. No interaction was found between reward arm, delay discount rate, and intervention time period (b = 3.16, 95% CI [-68, 74], p = .931), suggesting rates of decline were similar in both reward arms at all estimated discount rates. Descriptive exploration of model-estimated daily steps across the intervention period suggested patterns of peak daily step attainment and subsequent declines varied by delay discount rates. At DDz $\leq$ -1.0, model-estimated mean daily steps reached peak values for immediate arm participants in time period 1 (intervention days 1-9) and for delayed arm participants in time period 2 (intervention days 10-19). At a DDz = -0.5, model-estimated mean daily steps peaked in time period 1 for immediate and delayed arm participants. At or above the sample mean discount rate (DDz $\geq$ 0), immediate arm participants reached peak model-estimated daily steps in time period 2 and delayed arm participants peaked in time period 1.

Declines in model-estimated daily steps, expressed as the percent decrease from peak step attainment to end of the intervention are presented in Figure 3. At DDz $\leq$ -0.5, decreases were slightly greater for immediate vs. delayed arm participants. In contrast, at DDz $\geq$ 0.5, declines in mean daily steps from peak to end of the intervention were greater for delayed arm, and these declines were more pronounced at higher discount rates (Figure 3).

DISCUSSION

The current study tested whether delay discount rate moderated the relative effectiveness of immediate financial rewards for increasing daily PA in a mobile health intervention. As hypothesized, immediate rewards were more effective than delayed rewards for increasing mean daily steps, but those with higher discounting rates showed more pronounced decreases in intervention response than those with lower discounting rates, regardless of reward arm. Overall, results showed that participants with the highest discount rates randomized to delayed rewards had the poorest average intervention response and participants with the lowest discount rates randomized to immediate rewards had the strongest intervention response.

The rate of decline in model-estimated mean daily steps during the intervention was similar for both reward arms, but the decline from peak step attainment to intervention end differed across reward arm and discount rates. At DDz $\leq$ -0.5, the percent decrease was greater for immediate reward arm participants compared to delayed arm participants. At DDz $\geq$ 0.5, delayed arm participants generally had greater declines. Results suggest that participants with higher discount rates were more susceptible to degradation of financial incentives over time regardless of reward timing and declines from peak step attainment were greatest when reward preference was mismatched to reward group assignment (Figures 2 and 3).

Current findings may be explained when considered from a behavioral economics perspective[33], whereby engaging in PA involves actual and perceived costs versus the actual and perceived benefits of PA and competing sedentary options[34]. Within the context of the current intervention, use of immediate financial incentives was intended to increase PA among insufficiently active adults by augmenting typically delayed natural benefits, or offsetting natural aversive aspects, of PA adoption and ongoing engagement with temporary, artificial rewards. Present results suggest smaller, immediate financial rewards more effectively increased mean levels of PA and reinforced behavior change more than larger, delayed non-contingent rewards for participation only, and these effects were more pronounced at higher discount rates. These results, consistent with previously-reported main outcomes for WalkIT which did not intervene on delay discounting rate,[26] were expected among participants with higher discount rates.

Prior observational research has suggested that individuals with higher delay discount rates devalue the health benefits of PA more steeply than lower discounters.[8,18] Thus, holding financial rewards constant across delay discount rates, the value of, and likelihood of engaging in, PA for health benefits should decrease at higher discount rates. Consistent with this reasoning, participants with higher discount rates had faster declines in Fitbit-measured PA across the intervention period than their more delay tolerant counterparts assigned to the same reward arm. Taken together these results suggest that higher discounters devalued the benefits of PA (and possibly financial rewards) to a greater extent than lower discounters, resulting in differential intervention potency over time. These results were somewhat unexpected within the immediate arm of the current study. We hypothesized that immediate financial rewards would be more effective than delayed financial rewards at mitigating declines in PA across the intervention period. However, participants assigned to the immediate reward arm had rates of decline in steps that were similar to delayed reward arm participants. In other words, although immediate rewards were more effective at increasing PA among higher discounters, the potency of immediate and delayed rewards waned similarly, and to a greater extent at higher discount rates. This is difficult to explain, but the impact of the immediate reward appears to have resulted in an initial rapid change in overall level of PA that persisted across the 4-month intervention period. For high discounters the benefits of exercise appeared to diminish at a greater rate regardless of group status.

One possible explanation for the observed difference in overall PA that persisted is related to the implemented goals and contingencies of the immediate reward arm. Because immediate rewards were contingent on a participant meeting their daily goals, a participant who missed several step goals experienced longer delays to the next successive reward. Principles of operant conditioning suggest that desired behaviors may not be properly supported when participants do not frequently interact with the designed consequences and thereby do not experience continuous reinforcement to increase deficit behaviors.[35] It is possible that at progressively higher discount rates, physical activity goals were too high for some individuals and resulted in less interaction with the financial contingencies and thereby some participants failed to experience the rewarding consequences of PA or experienced more benefit from competing inactivity behaviors. Combined with a steeper devaluation of reinforcing consequences for PA behaviors (1 point = $1), this delay may have contributed to a faster rate of PA decline due to a decrease in the time adjusted rate of return[24] among higher discounters. This raises the question of whether lower goals, larger magnitude rewards, variable magnitude rewards, or schedules that are unpredictably timed (variable probability)[36] should be introduced at some point during the intervention phase to help mitigate declines in the potency of continuous, fixed rewards among individuals with higher discounting rates.[37] Future work can test whether the effectiveness of variable reward magnitudes or variable reward probabilities differ by delay discount rates for PA.

One limitation of the current study is that the delay discount measure was administered at the end of the intervention period. Thus, it is possible that discount rates were modified by the intervention itself. Although individuals' delay discount rates are generally considered to be stable over time, evidence suggests they may also be altered by personal experiences or environmental circumstances.[38,39] Recently Sofis & Jarmolowicz[40] found reductions in delay discount rates in a small sample of women after participating in a 7-week structured exercise program. Whether or not the changes were attributable to the effort-paced component vs. the PA component of the intervention was unclear but they raise a potential alternate explanation for the current results. If sensitivity to delay can be altered by participation in a 4-month reward-based PA intervention, it would also be important to determine if causality is uni- or bi-directional, and the extent to which changes in delay discounting rates are sustained, or simply reflective of a temporary change in behavioral consequences during the intervention period. Future studies can address these questions empirically by replicating this study and measuring discounting rates pre- and post-intervention, and at post-intervention follow-ups. In addition, examining other behavioral (e.g., establishing operations), physiological, and/or neural correlates of change may provide information about the underlying mechanisms.

Higher discount rates have been associated with higher BMIs[8-12] and less self-reported PA.[8,18] Thus, limiting the study sample to overweight sedentary individuals could have resulted in a range of delay discount rates that are not reflective of insufficiently active populations with normal weight BMIs, and results may not generalize to other populations. Future work could explore BMI as a potential modifier or as a mediator/causal variable, influencing the effectiveness of financial rewards through differences in the perceived value and/or the perceived cost of PA at different BMIs.

Despite the stated limitations, the present study had several important strengths, including a prospective design, age-diverse adult community sample, objectively measured PA, tangible financial incentives delivered in near real time and the use of advanced technology to optimize intervention delivery. Unlike previous animal and human lab-based studies that systematically control environmental conditions by eliminating noise and potential confounding and moderating variables, this prospective study of adults operated in the free-living world and used a randomized factorial design to systematically control for a myriad of environmental conditions. Thus, results observed by reward schedule and by discounting rate for PA have greater ecological validity than previous ones. The current analyses also contributes new hypothesis-generating information about financial incentives to increase PA and provide a novel explanation for variability in their effectiveness found across intervention studies. Understanding how the potency of rewards over time may be modified by individuals' delay discount rates can enable better tailoring of interventions to increase their long-term effectiveness. Based on current results, smaller, immediate fixed financial rewards delivered on a continuous schedule effectively induced PA behaviors among both higher and lower discounters. However, reward potency waned over the intervention period and became more pronounced at higher rates of delay discounting. This result may be explained by differential changes in time adjusted rates of return during the intervention, whereby briefly disengaging in PA and reducing the frequency of reinforcing consequences resulted in lower time adjusted rates of return for future PA[24] among higher discounters. Future work can test the effects of varying reward schedules and magnitudes on the effectiveness of rewards across a range of discount rates over time. If there are differential effects across discounting rates, researchers could individualize reward magnitudes and delivery schedules to optimize long-term effectiveness.

Another possible option is incorporating just-in-time adaptive interventions (JITAIs)[41] to provide behavioral support for participants classified as high risk (i.e., high discounting rates) at baseline. For example, participants with high baseline delay discount rates may benefit from frequent monitoring to identify situations with a higher likelihood of lapse in PA, such as those in which more immediate consequences for engaging in a competing sedentary behavior are likely to be more potent than the longer-term health or social benefits of PA. Once these critical time points are identified, additional micro-interventions or short-term intervention strategies could be implemented to promote continued PA engagement.

Future research can also address questions about causation, and if and where the threshold is for behavior change, with respect to delay discount rate and reward magnitude and schedule. In other words, does the magnitude or delivery schedule of rewards needed to evoke PA adoption and maintenance vary by delay discount rate? Whether or not delay discount rate can be modified by PA or financial rewards for PA can also be tested, as can whether any intervention-induced changes remain when rewards are removed. Answering these questions may facilitate more precise designs of PA interventions that optimize their cost-effectiveness and desired behavioral outcomes.

CONCLUSIONS

To the authors' knowledge, this study was the first to examine whether the effectiveness of financial incentives to increase PA varies by the individuals' sensitivity to immediate rewards or conversely ability to tolerate delayed, non-contingent rewards. Current results support smaller immediate rewards over larger delayed rewards, regardless of delay discount rate. Results suggest that at higher delay discount rates (less tolerant of reward delay), intervention responsiveness generally decreases, and the immediacy of rewards becomes an important factor in initiating PA behavior change. Additionally, reward effectiveness may wane more rapidly over time at higher delay discount rates, particularly when there are delays to rewards. This is particularly noteworthy in light of promising, but inconsistent, behavior change effects found for financial incentives, and the need to understand how to more effectively target interventions to participant needs. In practical application, the modest investment of time needed to assess delay discount rates could enable identification of individuals at risk for reduced intervention effectiveness or rapid waning of effectiveness, thereby enabling reward structures tailored to mitigate risk and result in more potent behavior change interventions.

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Table 1. Sample characteristics by reward arm

	Total (N = 85)	Immediate Reward Arm (n = 45)	Delayed Reward Arm (n = 40)
Age, mean (SD)	41.4 (9.5)	40.0 (9.3)	42.0 (9.5)
BMI, mean (SD)	33.8 (6.1)	33.9 (5.7)	33.6 (6.5)
Female (%)	78.8	84.4	72.5
Race and Ethnicity*			
White (%)	81.2	75.6	87.5
Black (%)	9.4	13.3	5.0
American Indian (%)	4.7	6.7	2.5
Asian (%)	4.7	2.2	7.5
Hispanic (%)	20.0	24.4	15.0
Mixed Race/Ethnicity (%)	21.4	25.0	17.5
Refuse to answer (%)	2.4	4.4	0.0
Smokers (%)	9.4	6.7	12.5
In School (%)	11.8	13.3	10.0
Married/Cohabitating (%)	54.1	51.1	57.5
Employed (%)	97.6	97.8	97.5
Has children (%)	65.5	66.7	64.1
Household income, median	$50,000-74,999	$50,000-74,999	$50,000-74,999
Education, median	College graduate	College graduate	College graduate
Total rewards, mean dollars (SD)	71.23 (21.63)	73.11 (29.47)	69.13 (4.37)

*Race/ethnicity total is > 100%. Participants were allowed to select "all that apply". SD = Standard deviation.

Table 2. Mean daily steps and rewards earned by delay discounting quartile

	Delayed Reward Arm (n = 40)		Immediate reward Arm (n = 45)	
Delay Discount Rate Quartile[§]	Baseline Daily Steps[*]	Intervention Daily Steps[*]	Baseline Daily Steps[*]	Intervention Daily Steps[*]
Quartile 1 (more tolerant of delay)	5362 (2539)	6975 (3404)	5436 (2531)	8171 (3538)
Quartile 2	5194 (2487)	7775 (5076)	5441 (2704)	8301 (4594)
Quartile 3	5279 (2943)	6459 (2990)	6084 (2705)	8351 (4039)
Quartile 4 (less tolerant of delay)	5131 (2559)	6173 (3145)	4819 (2530)	6795 (3554)

[*]Mean (SD) of raw daily steps, unadjusted for goal group and other covariates. [§]Delay discount rates are expressed as the natural log transformed geometric mean of the calculated k values for small, medium and large reward magnitudes (ln Geomean k). Quartile 1 = ln Geomean k -8.7515 - -5.9969; Quartile 2 = ln Geomean k -5.9970 - -4.9121; Quartile 3 = ln Geomean k = -4.9121 - -3.9940; Quartile 4 = ln Geomean k = -3.9941 - -1.3922.

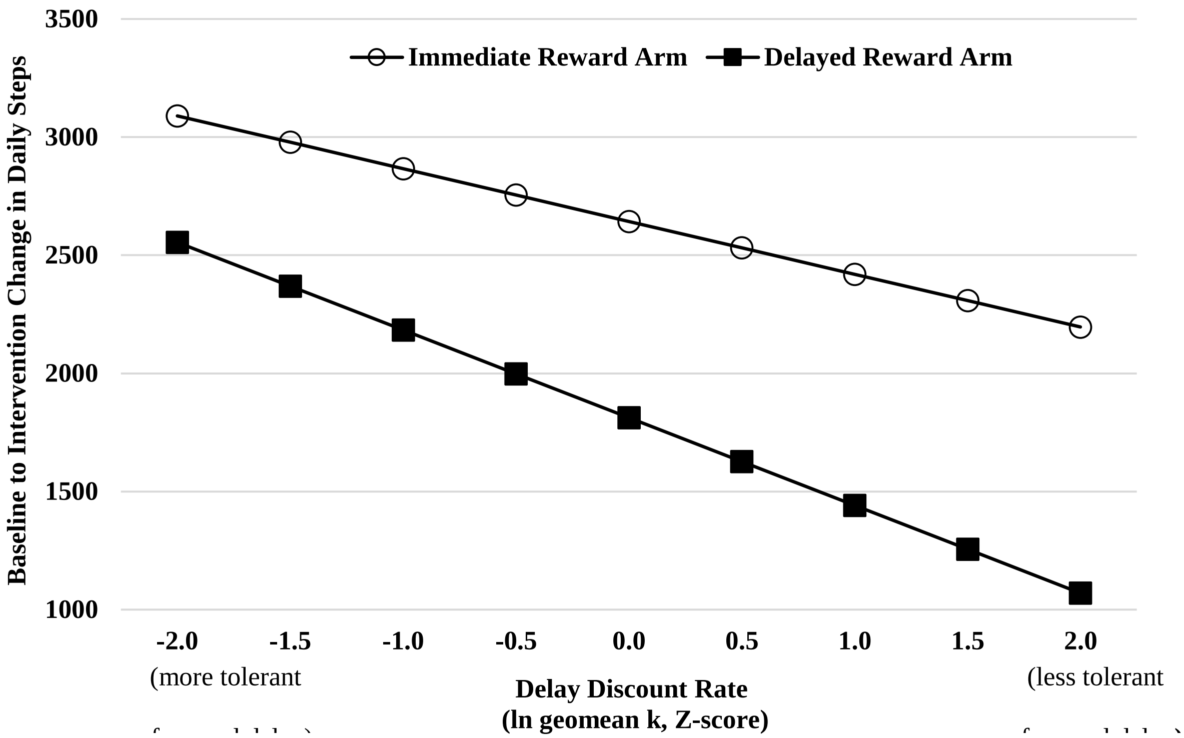

Figure 1. Model-estimated mean daily steps by reward arm and delay discount rate

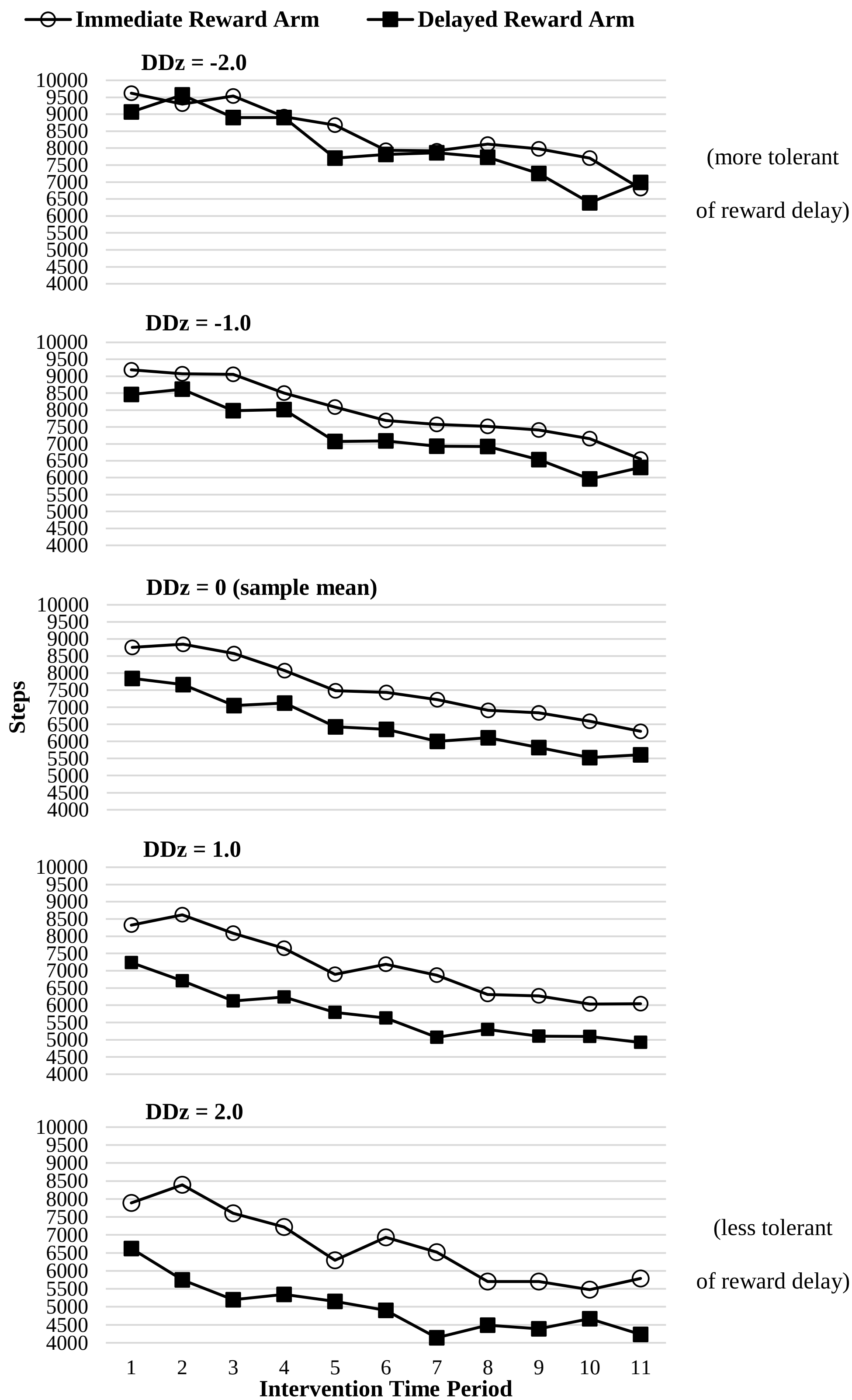

Figure 2. Model-estimated daily steps across the intervention phase by reward arm at delay discount rates = -2.0, -1.0, 0, 1.0, and 2.0. DDz = delay discount rate (ln geomean k) Z-scores. Higher delay discount rate values indicate lower tolerance for delayed rewards.

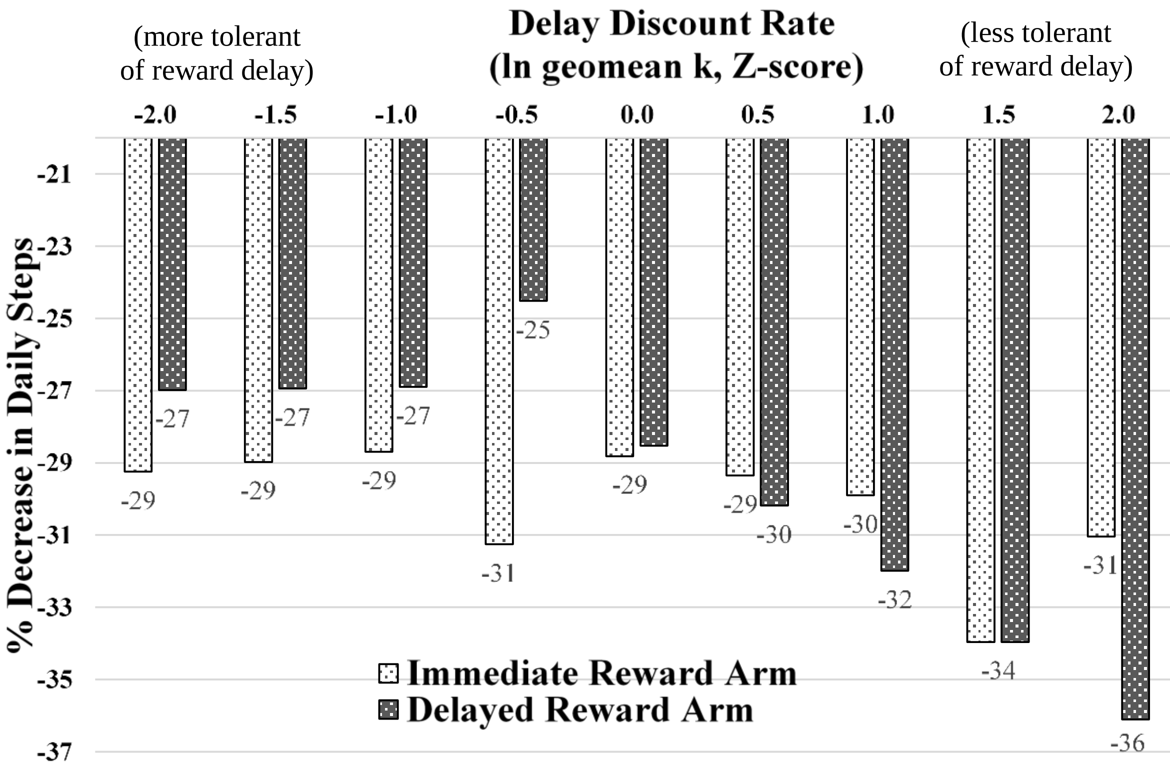

Figure 3. Percent decrease in model-estimated mean daily steps from peak attainment to end of intervention phase by reward arm at all estimated delay discount rates