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Murray, J. M., French, D. P., Kee, F., Gough, A., Tang, J., & Hunter, R. F. (2020). Mechanisms of physical activity behavior change in an incentive-based intervention: mediation analysis. *Health Psychology*, *39*(4), 281-297. https://doi.org/10.1037/hea0000849

Published in:
Health Psychology

Document Version:
Peer reviewed version

Mechanisms of physical activity behavior change in an incentive-based intervention: Mediation analysis

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Abstract

Objective: The Physical Activity Loyalty (PAL) scheme was a cluster randomized controlled trial of a 6-month complex intervention targeting workplace physical activity. Financial incentives were incorporated in an evidence-based behavior change programme, including self-regulation techniques. This article examines short-term (<six months) and long-term (≥six months) mediation effects on physical activity.

Methods: Participants included 853 adults (457 intervention, 396 control). Physical activity was objectively-assessed using pedometers at baseline and at six and 12 months. Hypothesized short-term mediators (e.g. self-efficacy, intentions) were assessed at baseline and 4 weeks. Hypothesized long-term mediators (e.g. habit, intrinsic motivation) were assessed at baseline and 6 months. Mediation models employed the structural equation modelling product-of-coefficients approach.

Results: Intervention participants experienced significant decreases in 6-month pedometer steps/day versus controls (b = -336, p = 0.02), which were partially mitigated by positive indirect effects through 6-month *integrated regulation* (ab = 94.7, 95% CI: 18.7, 204.4), *intrinsic motivation* (ab = 59.0, 95% CI: 3.09, 154.5) and *habit* (ab = 198.7, 95% CI: 84.3, 369.9). There were no between-group differences in 12-month pedometer steps/day but positive indirect effects through 6-month *integrated regulation* (ab = 128.0, 95% CI: 27.3, 313.2), *planning* (ab = 115.0, 95% CI: 3.71, 285.5) and *habit* (ab = 153.3, 95% CI: 39.3, 333.1).

Conclusions: Most examined mediators were non-significant and mediation analyses did not explain decreases in physical activity for interventions versus controls. Results show that, contrary to self-determination theory hypotheses, *intrinsic motivation* is not necessarily adversely impacted if financial incentives are embedded in a complex intervention.

Keywords: Physical Activity, Randomized Controlled Trial, Behavior and Behavior Mechanisms, Motivation.

Trial registration: ISRCTN, ISRCTN17975376. Registered 19th September 2014, http://www.isrctn.com/ISRCTN17975376.

Background

Researchers are increasingly recognizing the need to harness insights from developments in the field of behavioral sciences to design innovative public health interventions that move beyond traditional efficacy trials and can answer the questions that ultimately improve public health (i.e. what intervention strategies are effective for promoting health behavior change, for whom, and in what context?) (Sheeran, Klein, & Rothman, 2017). Development of successful complex interventions relies on the testing and refinement of relevant behavior change theories to identify the underlying mechanisms (e.g. mediators) driving behavior and behavior change (Mackenzie & Blamey, 2005; Patrick & Williams, 2012). Research on mediators can reveal why some people change their physical activity behavior and which specific hypothesized mediators are associated with these changes (Bauman, Sallis, Dzewaltowski, & Owen, 2002). Thus, future interventions can be improved since they can be designed to target factors known to cause changes in physical activity behavior (Murray et al., 2018). Despite this, mediation analyses are not always conducted (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). Little is known about what triggers initiation and maintenance of physical activity behavior change and previous attempts at promoting physical activity have had limited success (Murray et al., 2017, 2018).

Studies of physical activity interventions have seldom conducted high quality formal mediation analyses (Murray et al., 2018; Rhodes & Pfaeffli, 2010; Teixeira et al., 2015). One systematic review investigated mediators of behavior change *maintenance*, defined as behavioral changes occurring at least six months post-baseline, in physical activity interventions and revealed severe methodological shortcomings in previous research in this area (Murray et al., 2018). For example, less than one-third of the included studies conducted formal mediation tests, mediation analyses were not pre-specified in published study protocols, and studies rarely measured mediating constructs prior to the physical activity outcome. Many of the tested interventions were not effective for changing the targeted mediators, suggesting that the selected behavior change techniques may not have been effective. Furthermore, increasing evidence that the determinants of behavior change initiation (i.e. constructs hypothesized to exhibit changes in the short-term, <six months) differ to those required for maintenance (i.e. constructs hypothesized to exhibit changes in the long-term, ≥six months) highlights the need for researchers to investigate these processes separately (Murray et al., 2017; Nigg, Borrelli, Maddock, & Dishman, 2008; Rothman, 2000; Schwarzer, 1992).

The current study aimed to address these gaps by investigating the pre-specified mechanisms (i.e. short- and long-term mediators) of behavior change in the Physical Activity Loyalty (PAL) scheme which was implemented in workplaces in Northern Ireland (NI) (Hunter et al., 2016). The PAL scheme was a complex, six-month multi-component workplace physical activity intervention which offered financial incentives, with other evidence-based behavior change techniques, to employees working in office-based occupations (Marteau, Ashcroft, & Oliver, 2009). Its primary aim was to increase physical activity behavior during working hours. Interest has grown in the potential of workplace interventions to promote physical activity as adults spend more than 50% of their workday waking hours there (Conn, Hafdahl, Cooper, Brown, & Lusk, 2009). People who work in predominantly office-based occupations tend to spend a large part of their day inactive, and public organizations have been shown to have higher sickness absenteeism rates than private sector organizations (Black, Frost, & Frost, 2011; Hamilton, Hamilton, & Zderic, 2007). For example, whilst our objective measure of physical activity behavior (pedometer steps/day) indicated that participants assigned to both the intervention and control groups had a fairly high level of baseline physical activity, over 50% of participants were categorized as having 'low' physical activity levels according to self-reported General Physical Activity Questionnaire (GPAQ) (Hunter et al., 2019, 2018). However, evidence regarding the effectiveness of workplace physical activity interventions is mixed especially for long-term behavior change (Hutchinson & Wilson, 2012; Malik, Blake, & Suggs, 2014).

UK government recommendations suggest that using financial incentives may be effective to promote health behavior change (e.g. increased physical activity) (Department of Health, 2010) and there is some evidence that people can be incentivized, financially or non-financially, to increase their physical activity levels at least in the short-term (Magnus, Robert, & Eva, 2010; Mitchell et al., 2013). However, it has been noted that aside from monetary value, other factors relating to the provision of rewards (e.g. frequency, immediacy) may have the potential to impact on their effectiveness for achieving behavior change (Adams, Giles, McColl, & Sniehotta, 2014). Previous research has generally produced little indication for long-term effectiveness of financial incentives for achieving behavior change (Barte & Wendel-Vos, 2017; Cahill, Perera, Kate, & Rafael, 2011; Finkelstein et al., 2016; Giles, Robalino, McColl, Sniehotta, & Adams, 2014; Mantzari et al., 2015; Marteau et al., 2009; Molema et al., 2016). There is also limited evidence of the effect of varying incentive levels over time. According to self-determination theory, one potential barrier to achieving long-term behavior change is that financial incentives may undermine intrinsic motivation (Deci, Koestner, & Ryan, 1999;

Promberger & Marteau, 2013), but there is little evidence regarding the impact on intrinsic motivation of offering financial incentives in combination with other behavior change techniques. In contrast to previous research, the results of a recently published Cochrane review suggest that financial incentives may actually be effective for achieving long-term smoking cessation, even after incentives are withdrawn (Notley et al., 2019). Therefore, in the current study financial incentives were embedded in a complex intervention, as recommended (Marteau et al., 2009) to establish their utility in conjunction with other evidence-based behavior change techniques.

Paradoxically, for participants in the PAL scheme, there was a small but significant decline in pedometer (Yamax Digiwalker CW-701) steps/day for the intervention group compared to controls at six months relative to baseline, and no significant difference at 12 months. Specifically, analysis of covariance showed there was a significant decrease in mean steps/day for the intervention group compared to the control group (adjusted *b*=-336, 95% CI: -612 to -60, p=0.02) at six months when adjusting for randomization stratum, season and baseline pedometer steps/day. Mean steps/day decreased from baseline by 947 steps (SD 2702; Median 718) in the intervention group, and by 398 steps (SD 2471; Median 561) in the control group (Hunter et al., 2018). Several authors have claimed that investigation of causal mechanisms is more valuable when interventions have negative findings as information about which components (if any) were successful, and which were not, can inform the design of future studies (Cheong, Mackinnon, & Khoo, 2003; Whittle, Mansell, Jellema, & van der Windt, 2017). The present study purposefully embedded mediation analyses from the outset (Hunter et al., 2016). All analyses, including the logic model (figure 1) describing how the intervention was hypothesized to change physical activity behavior were previously published in the study protocol (Hunter et al., 2016). For example, hypothesized short-term mediators included constructs such as financial (i.e. extrinsic) motivation, physical activity self-efficacy, intentions and outcome expectations. Hypothesized long-term mediators included constructs such as habit, intrinsic motivation and planning. The selection of behavior change techniques and subsequent mapping onto hypothesized mediating constructs are discussed more fully below. The present paper aimed to investigate these pre-specified pathways, which were grounded in learning theory (Johnston, 2016; Marteau et al., 2009) and social cognitive theory (Bandura, 1997), with insights from self-determination theory (Deci et al., 1999) as described below. Our objectives included: (1) to investigate whether changes in the proposed constructs could explain the intervention's

overall negative effect on physical activity behavior; and (2) to determine which intervention components, if any, may have been beneficial and which may have been detrimental for changing physical activity behavior.

Methods

Trial procedures (including study design, participant recruitment, randomization, intervention and control conditions) have been previously reported and an overview is provided in additional file 1 (Hunter et al., 2016, 2018). The study employed a cluster randomized controlled trial design. Participants were healthy adults working in office-based occupations in public sector organizations in Lisburn and Belfast city centres (NI) and were randomly allocated by cluster (i.e. smallest workplace unit for each organization) to the intervention group or to a waiting-list control group. This trial was registered with Current Controlled Trials, number ISRCTN17975376. Ethical approval for this study was received from the Office of Research Ethics Committees Northern Ireland (ORECNI) on 21st May 2014 (REC ref: 14/NI/0090). All participants provided written informed consent.

Overview of Intervention and Waiting-List Control Group

The PAL scheme was a six-month intervention which incorporated use of a novel physical activity tracking system, with sensors placed in specified outdoor locations within 2 km of the workplace, in combination with web-based self-monitoring of physical activity behavior (relevant behavior change techniques include self-monitoring, prompts/cues, habit formation, adding objects to the environment). The main intervention component was the provision of financial incentives (Hunter et al., 2016). The number of 'points' accumulated in the intervention depended on participants' minutes of physical activity, i.e. one 'point' for one minute of physical activity with a monetary value of approximately £0.03 (or US $0.04) for a maximum of 30 minutes/day, informed by contingent valuation experiment (Tang, Hutchinson, Longo, Hunter, & Kee, 2017), and could be redeemed for rewards at local businesses (e.g. coffee shop vouchers, restaurant vouchers, cinema tickets; extrinsic motivation). Participants were encouraged to partake in 150 minutes/week of physical activity (Department of Health, 2011) and provision of 'points' and rewards were contingent on meeting these goals (goal setting). Rewards were phased (i.e. offered less frequently in the last three months of the intervention) to reduce the emphasis on extrinsic motivation since learning theory states that sudden withdrawal of rewards can cause the newly initiated behavior to be extinguished (Johnston, 2016; Marteau et al., 2009). Subsequently, it was expected that internalization of the behavior would be achieved by realigning the scheme's focus from financial incentives towards its other components. For example, there is evidence in

the literature that goal-setting (Wilson & Brookfield, 2009) and social support (Deci & Ryan, 1987; Moreno-Murcia, Belando, Huéscar, & Torres, 2017) are associated with higher levels of intrinsic motivation, and our study's process analysis showed an association between use of the scheme's monitoring and feedback components and higher levels of identified regulation and integrated regulation (Murray et al., 2019). Maps of possible walking/jogging routes, and examples of physical activity opportunities tailored to each workplace were available on the study website (providing information on where/when to perform physical activity). Other behavior change techniques included regular tailored motivational emails (prompts/cues), tailored feedback and links to other resources (e.g. physical activity and healthy eating advice) (Marteau et al., 2009). Discussion forums on the website provided a platform for participants to contact researchers and other participants (social support). The target behavior was workplace physical activity. The most common form of physical activity undertaken by participants was walking. However, other physical activities such as jogging, active travel to/from work, and gym-based activities were also incentivised through the location of the sensors. The intervention also provided rewards, and encouraged participants to set goals, in terms of minutes of physical activity.

Participants randomly assigned to the control group received no intervention during the six-month intervention period but were placed on a waiting-list to participate in the scheme at the end of the study period (i.e. after 12-month outcomes were completed). It was agreed with the funders to end follow-up at 12 months, rather than 18 months as originally intended, due to delays in initial recruitment and negative findings for the primary outcome at the six-month follow-up.

Intervention Development and Proposed Theoretical Mechanisms

The logic model describing the processes by which the PAL scheme was hypothesized to change physical activity behavior has previously been published (Hunter et al., 2016) and an adapted version is shown in figure 1 (reflecting the shorter follow-up than originally intended). The approach to intervention development that was used in the PAL study fits within the "Theory and evidence based" category of a recently published intervention development taxonomy (O'Cathain et al., 2019), and is similar to the methods described in the Medical Research Council Framework (Craig et al., 2008).

Firstly, behavior change techniques were selected based on evidence for their effectiveness for increasing physical activity behavior. The main intervention component was the offering of financial incentives, which was selected based on government recommendations (Department of Health, 2010) and evidence of

189 effectiveness for promoting short-term behavior change (Magnus et al., 2010; Mitchell et al., 2013). Financial
190 incentives were also combined with other evidence-based behavior change techniques as recommended in
191 this literature (Marteau et al., 2009). For example, self-regulation techniques (e.g. self-monitoring and
192 feedback, goal setting, and prompts to behavior) for which there is clear evidence of effectiveness were
193 included (Dombrowski et al., 2012; Michie, Abraham, Whittington, McAteer, & Gupta, 2009; Williams &
194 French, 2011).

195 Secondly, we determined which behavior change theories could explain how the intervention should
196 lead to increased physical activity behavior in the short- and long-term, identified which mediators we needed
197 to measure to investigate these hypothesized pathways of change, and constructed our logic model. The
198 financial incentive component of the intervention was based on principles of learning theory (Miller & Dollard,
199 1941) by providing an immediate financial reward (i.e. extrinsic/financial motivation) for behaviors that offer
200 future health gains. Learning theory proposes that behavioral repetition, newly brought about, should lead to
201 the forming of habits (Johnston, 2016; Lally & Gardner, 2013; Miller & Dollard, 1941). Therefore, we
202 hypothesized that long-term physical activity behavioral maintenance would be achieved via increased habit
203 formation by the time rewards were withdrawn (Baugh, 1994). Habit formation also fit within a self-regulation
204 control theory framework (Carver & Scheier, 1981) and we measured several other mediators with relevance
205 for self-regulation (e.g. self-efficacy, planning, habit). According to social cognitive theory (Bandura, 1997), we
206 also hypothesized that the use of motivational messages (persuasion) and social support (vicarious experience)
207 would increase self-efficacy, and that satisfaction with the consequences of behavior change would act as a
208 reinforcing mechanism for behavior change in addition to the reinforcement of the financial incentives. Thus,
209 we also measured social norms, workplace norms, and outcome satisfaction as putative mediating constructs.

210 As the logic model indicates, the intervention offers multiple components that could trigger several
211 different mechanisms, potentially from other behavior change theories. Mediators of short-term behavior
212 change were hypothesized to be distinct from mediators leading to long-term behavior change (Kassavou,
213 Turner, Hamborg, & French, 2014; Rothman, Baldwin, Hertel, & Fuglestad, 2011; Schwarzer et al., 2007).
214 Changes in mediators of short-term behavior change were expected to occur at four-six weeks, whilst changes
215 in mediators of long-term behavior change were hypothesized to occur at six months (Schwarzer et al., 2007).
216 It has been proposed that long-term maintenance is achieved when participants are satisfied with the
217 outcomes of behavior (e.g. feel fitter) and wish to sustain the benefit, in line with Rothman's theory of

behavioral maintenance (Rothman, 2000). Furthermore, the Health Action Process Approach (HAPA) model proposes that two validated forms of phase-specific self-efficacy (i.e. maintenance and recovery self-efficacy) are important for achieving maintenance (Schwarzer, 1992, 2008). Some constructs were hypothesized to be important short-term and long-term mediators (i.e. planning, social norms, identified regulation, integrated regulation, intrinsic motivation). At baseline, it was assumed that there would be no active workplace social norm to impact on behavior. However, there may have been a 'social norm' for physical activity from a non-workplace environment. Therefore, we included a general social norm measure as a hypothesized short-term mediator. Given that the primary targeted behavior was workplace physical activity, it was hypothesized that as the intervention progressed, participants would have increased perceptions that partaking in physical activity was the workplace 'norm' (by seeing other work colleagues, who were also participating in the PAL scheme, increasing their workplace physical activity) and would be encouraged to maintain their physical activity long-term.

Self-determination theory proposes that the provision of financial rewards may undermine or 'crowd out' intrinsic motivation (Promberger & Marteau, 2013), or hinder the process of internalization (Deci, Koestner, & Ryan, 2001). These processes are hypothesised to be detrimental for achieving long-term behavior change (Deci & Ryan, 1985; Michie, West, Campbell, Brown, & Gainforth, 2014). Therefore, relevant constructs from this theory (i.e. identified regulation, integrated regulation, intrinsic motivation) were measured to consider potential negative effects of the intervention.

A detailed mapping of behavior change techniques and theories onto hypothesized mediators is available in additional file 1 (table 1.1).

Outcome Measures

Outcome data were collected at baseline (demographics, physical activity and mediators), four weeks (short-term mediators), six months (physical activity and long-term mediators) and 12 months (physical activity). A summary of measurement instruments are reported in additional file 1 (table 1.2).

Physical activity behavior

The primary outcome was steps/day objectively measured over seven consecutive days using sealed pedometers (Yamax Digiwalker CW-701, Japan) (Bassett et al., 1996; Bravata et al., 2007; Schneider, Crouter, Lukajic, & Bassett, 2003), considered valid if the participant provided ≥250 steps/day for three or more days (Tudor-Locke et al., 2005). These cut-points are in line with those used in the study's main outcomes analyses

(Hunter et al., 2019, 2018). This outcome was collected at baseline, six and 12 months. As we hypothesised that participants would be motivated to undertake physical activity outside the workplace setting, we chose a method of measurement that captured total physical activity behaviour.

Mediator measurements

Short-term mediators of physical activity behavior

Constructs which we hypothesized to be important short-term mediators of physical activity behavior change were measured at baseline and four weeks and included *outcome expectations* (Finch et al., 2005), physical activity *self-efficacy* (Marcus, Rossi, Selby, Niaura, & Abrams, 1992), *intention* (Fishbein & Ajzen, 1977), *planning* (Sniehotta, Schwarzer, Scholz, & Schüz, 2005), *financial motivation for physical activity* (Moller & McFadden, 2012; Ryan, Frederick, Lepes, Rubio, & Sheldon, 1997), *self-determined motivation for physical activity* (i.e. *identified regulation, integrated regulation, intrinsic motivation*) (Markland & Tobin, 2004; Wilson, Rodgers, Loitz, & Scime, 2007) and *social norms* (Ball, Jeffery, Abbott, McNaughton, & Crawford, 2010).

Long-term mediators of physical activity behavior

Constructs which we hypothesized to be important long-term mediators of physical activity behavior change were measured at baseline and six months and included *planning* (Sniehotta et al., 2005), *self-determined motivation for physical activity* (i.e. *identified regulation, integrated regulation, intrinsic motivation*) (Markland & Tobin, 2004; Wilson et al., 2007), *habit* (Verplanken & Orbell, 2003), *recovery* and *maintenance self-efficacy* (Scholz, Sniehotta, & Schwarzer, 2005), *outcome satisfaction* (Finch et al., 2005; Rothman, Sheeran, & Wood, 2009), *social norms* and *workplace norms* (Ball et al., 2010).

Statistical Analysis

All questionnaire items were scaled so that lower values indicated lower levels of the mediator/outcome. The following analyses should be interpreted with caution due to issues with multiple testing and power. The level of significance was $p<0.05$. We did not make adjustments for multiple testing as the practice is widely contested and debated in the medical research literature (Feise, 2002; Perneger, 1998; Rothman, 1990). Throughout our results we have highlighted those results which would have been non-significant had we used a more stringent significance criterion ($p<0.01$). Missing data was handled using listwise deletion, similar to the approach adopted in the study's main paper which found no difference to the primary outcome when imputing missing data using multiple imputation by chained equations (MICE) (Hunter et al., 2018). Furthermore, since the ultimate goal of the current manuscript was to examine the efficacy of the

PAL intervention to change physical activity behavior via increases in the hypothesized mediating constructs, it was deemed more appropriate to base the analyses on "completers" in the interest of testing intervention dose. Analyses were carried out using Stata 13 (StataCorp, 2013).

Between-group differences in six-month physical activity were reported by comparing six-month pedometer steps/day between intervention and control groups using an analysis of covariance (ANCOVA) adjusting for randomization stratum (Large >50, Medium 20-50, Small <20 or Schools/Colleges), season (December 2015-April 2016, July-August 2016) and baseline pedometer steps/day with standard errors (SEs) and p-values corrected for clustering (three clusters based on size and one cluster for educational establishments). This was repeated for 12-month pedometer steps/day. We tested whether missing pedometer data at six and 12 months varied between groups, in terms of socio-demographic variables collected at baseline (additional file 1, table 1.3) or in terms of baseline mediator measurements (table 1), using cluster-adjusted independent samples t-tests for continuous variables and cluster-adjusted chi-square tests for categorical variables. Correlation matrices of (1) baseline mediators and pedometer steps/day; (2) four-week mediators, and; (3) six-month mediators and pedometer steps/day; are shown in additional file 2.

Single mediator models

Previous systematic reviews have utilized a 'relatively lenient' definition of physical activity behavior change maintenance as occurring at least six months post-baseline (Murray et al., 2017, 2018). Furthermore, a recently published mediation analysis examining physical activity among cancer survivors defines their adoption phase as occurring up to six months and their maintenance phase as occurring between six and 12 months (Kindred, Pinto, & Dunsiger, 2019). Therefore, it is conceivable that both our hypothesized short-term and long-term mediators could be important for behavior change at six months post-baseline. All of our measured short-term and long-term mediators were examined in mediator models that included six-month pedometer steps/day as the dependent variable. Single mediator models were run using the structural equation modelling based product-of-coefficients approach (Preacher & Hayes, 2008). In each model, the independent variable was group assignment, the mediating variable was the follow-up (i.e. four-week or six-month) mediator score, and the dependent variable was six-month pedometer steps/day. Analyses were adjusted for randomization stratum, season, baseline values of the mediator and baseline pedometer steps/day, with SEs and p-values corrected for clustering. In line with the study's main outcome analysis (Hunter et al., 2018), we adopted the approach of adjusting absolute values of the mediators and outcomes

for baseline values. A sample Stata program for this analysis is available in additional file 2 (study data is available upon request from the authors). We also conducted the analysis using residualized change scores, with no major differences to the results (data not presented).

Results are reported for tests of intervention effects on hypothesized mediators, tests of the association of hypothesized mediators with physical activity, indirect effects (i.e. the significance of mediated effects) and direct effects (i.e. intervention effects on physical activity controlling for hypothesized mediators) (figure 2) (Mackinnon, 2008). The significance of indirect effects was determined by 95% confidence intervals (CIs) estimated using the bias-corrected bootstrap (with 10,000 iterations) procedure (Mackinnon, 2008; MacKinnon, Lockwood, & Williams, 2004). The maximum-likelihood (ML) method of estimation was used. Model fit was assessed using the coefficient of determination (CD), a measure of the proportion of variance that is explained by the model (Nagelkerke, 1991), and standardized root mean square residual (SRMR) (<0.08 was considered a good fit) (Hooper, Coughlan, & Mullen, 2008) which are reported with Structural Equation Models adjusting SEs and p-values for clustering in Stata.

Mediators of 12-month pedometer steps/day were examined with single mediator models for all long-term mediators (i.e. mediators measured at six months) individually using the same procedure. Since none of our hypothesized short-term mediators (i.e. mediators measured at four weeks) showed an association with six-month pedometer steps/day, they were not subjected to further testing. The established criteria for mediation are: (1) significant intervention effect on mediator; (2) significant association of mediator with physical activity; (3) significant indirect effect of intervention on physical activity through mediator.

Post-hoc power analyses and sensitivity analyses

Whilst the study was specifically powered to detect between-group differences in primary outcome (i.e. pedometer steps/day) (Hunter et al., 2019, 2018), post-hoc power calculations have been conducted to determine power levels for all mediator analyses using the app developed by Schoemann and colleagues specifically for mediation analyses (Schoemann, Boulton, & Short, 2017). Results are reported in tables 2 and 3.

It has been suggested that Bayesian methods can potentially increase power in mediation analyses, particularly for small sample sizes (Yuan & MacKinnon, 2009). Since power was low for some of our models, we conducted sensitivity analyses employing a Bayesian approach to analysing mediating effects using the 'brms'

package in R with 10,000 iterations (Bürkner, 2017). For each model, estimated values are the mean of the posterior distribution with 95% High Density Intervals (HDI).

Results

Baseline Characteristics, Descriptive Statistics and Physical Activity Outcomes

A total of 853 participants from 37 workplace clusters were recruited and randomized into two groups (n=457 intervention, n=396 control). Baseline characteristics are presented in additional file 1, table 1.3. Means and SDs for pedometer steps/day and mediator scores are presented in table 1. There was a significant decrease for interventions versus controls in pedometer steps/day at six months (adjusted mean difference: *b*=-336, SE=141, p=0.02; n=456). At 12 months, there was no between-group difference in pedometer steps/day (*b*=-570, SE=356, p=0.11; n=368). The CONSORT flow diagram for this study has been previously published (Hunter et al., 2018) and is available to view in additional file 1, figure 1.1. The dropout rate was 26.4% (225 participants) at six months with a further 10.8% (92 participants) lost to follow-up by 12-month data collection. Missing data did not vary between groups for the main outcome (i.e. pedometer steps/day) at six or 12 months. There was some indication that missing pedometer data at six and 12 months varied according to baseline levels of recovery self-efficacy ($p \leq 0.007$) and maintenance self-efficacy ($p \leq 0.02$).

Mediator Outcomes: Single Mediator Models

Hypothesized short-term mediators

For single mediator models including mediators measured at four weeks and pedometer steps/day measured at six months, none of the measured mediators met all of the established criteria for mediation. Models including *intentions*, *social norms*, *identified regulation*, *integrated regulation* and *intrinsic motivation* showed that there were significant, positive intervention effects on the mediator ($p \leq 0.03$). Using a more stringent significance criterion ($p<0.01$), results for models including *intentions* and *identified regulation* would have been non-significant. None of the models showed a significant association of the mediator with physical activity or significant indirect effects (table 2, additional file 2). SRMR values were close to zero for all models, and CD values ranged from 0.56-0.76.

Hypothesized long-term mediators

For single mediator models including mediators measured at six months and pedometer steps/day measured at six months, the model including *habit* as a mediator met all of the established criteria for mediation. There were significant, positive indirect effects in single mediator models that included *integrated*

regulation (mean between-group difference in pedometer steps/day attributable to mediator, adjusted for baseline levels: *ab*=94.7, 95% CI: 18.7, 204.4), *intrinsic motivation* (*ab*=59.0, 95% CI: 3.09, 154.5) and *habit* (*ab*=198.7, 95% CI: 84.3, 369.9). Using a more stringent significance criterion (p<0.01), only the indirect effect in the model including *habit* retained significance. The model including *habit* showed that there was a significant, positive intervention effect on the mediator (p<0.01). Models including *planning*, *social norms*, *identified regulation*, *integrated regulation*, *intrinsic motivation* and *habit* showed significant, positive associations of the mediator with physical activity (p≤0.01). The model including *workplace norms* showed a significant, negative association of the mediator with physical activity (p=0.02). Using a more stringent significance criterion (p<0.01), the result for the model including *workplace norms* would have been non-significant (table 2, additional file 2). SRMR values were close to zero for all models, and CD values ranged from 0.62-0.76. Thus, whilst the total intervention effect on pedometer steps/day at six months was negative, this was partially mitigated by increases in *integrated regulation, intrinsic motivation* and *habit* (baseline-six months), implying that participants experienced less of a decline in physical activity when they increased their levels of these constructs.

For single mediator models including mediators measured at six months and pedometer steps/day measured at 12 months, the models including *integrated regulation* and *habit* as a mediator met all of the established criteria for mediation. There were significant, positive indirect effects in single mediator models including *planning* (*ab*=115.0, 95% CI: 3.71, 285.5), *integrated regulation* (*ab*=128.0, 95% CI: 27.3, 313.2) and *habit* (*ab*=153.3, 95% CI: 39.3, 333.1). Using a more stringent significance criterion (p<0.01), only the indirect effects in the models including *habit* and *integrated regulation* retained significance. Models including *integrated regulation*, *intrinsic motivation* and *habit* showed that there were significant, positive intervention effects on the mediator (p≤0.03). Using a more stringent significance criterion (p<0.01), the result for the model including *integrated regulation* would have been non-significant. Models including *planning*, *identified regulation*, *integrated regulation*, *habit* and *recovery self-efficacy* showed significant, positive associations of the mediator with physical activity (p<0.01) (table 3, additional file 2). SRMR values were close to zero for all models, and CD values ranged from 0.38-0.67.

Results of the Bayesian mediation models are presented in additional file 3. Two indirect effects were non-significant according to their 95% HDIs, namely: (1) the model including six-month intrinsic motivation as the mediator and six-month pedometer steps/day as the outcome; and (2) the model including six-month

planning as the mediator and 12-month pedometer steps/day as the outcome. However, since these effects were already borderline significant according to the respective 95% CIs estimated in the main analyses, we can conclude that our results remain largely unchanged.

Discussion

This study investigated intervention mechanisms of the financial-incentive based PAL Scheme intervention using mediation analyses. We investigated various potential mechanisms, derived from several leading theories, including the constructs of physical activity *self-efficacy*, more internal forms of motivation (i.e. *identified regulation, integrated regulation, intrinsic motivation*), self-regulation (i.e. *planning*), *habit formation* and *outcome satisfaction*. Formal mediation tests show that habit formation, internal forms of motivation and self-regulation may be important long-term mediators for physical activity behavior change. There was no evidence that physical activity behavior change was achieved through increased *outcome satisfaction* or *self-efficacy* and none of our measured short-term mediators, including financial (extrinsic) motivation, showed evidence of mediating physical activity behavior change. Overall, nine out of 29 (31%) tests of intervention effects on mediators and six out of 29 (21%) formal tests of the indirect effect were significant. Our findings suggest that whilst the intervention was effective in changing some targeted mediating constructs, these changes were generally not translated to changes in physical activity behavior. For significant mediators, indirect effects were in the opposite direction to the overall negative intervention effect on physical activity. Therefore, decreases in physical activity at six months may have been mitigated by modest physical activity increases through increases in some mediators. Without these effects, the observed decreases in the intervention group would have been greater.

What This Study Adds

Short-term mediators of physical activity behavior change

Whilst assignment to the intervention group led to increases in some putative short-term mediators, these increases were not related to physical activity behavior change at six months. Three potential reasons are: (1) Changes in short-term mediators do not induce change in physical activity behavior; (2) Changes in short-term mediators are not carried through to physical activity behavior change at six months (i.e. perhaps physical activity behavior change caused by changes in short-term mediators occurs at an earlier time-point). This may support the idea that participants were in the behavioral maintenance stage at six months, in line with the definition of behavior change maintenance adopted in previous systematic reviews (Murray et al.,

2017, 2018); (3) The measured short-term mediators were potentially less relevant for our sample, which had high daily step counts at baseline indicating that they may not have been 'initiating' physical activity behavior. Notably, whilst constructs such as physical activity self-efficacy have frequently been shown to be important mediators or predictors of physical activity behavior in previous studies (Burke, Beilin, Cutt, Mansour, & Mori, 2008; Darker, French, Eves, & Sniehotta, 2010; Dutton et al., 2009; Rovniak, Anderson, Winett, & Stephens, 2002; Sharma, Sargent, & Stacy, 2005), physical activity self-efficacy was not shown to be a significant mediator in the present analysis. Emerging literature disputes the causal role of self-efficacy in behavior change (French, 2013) and several systematic reviews show that the supporting evidence is far from compelling (Murray et al., 2018; Rhodes & Pfaeffli, 2010; Teixeira et al., 2015).

Long-term mediators of physical activity behavior change

Contrary to hypotheses proposed by self-determination theory (Deci et al., 1999), which have been supported by the results of previous laboratory-based studies (Promberger & Marteau, 2013), the present findings show that intrinsic motivation has not been adversely impacted by the provision of financial incentives (i.e. extrinsic rewards) in line with the study's process analysis (Murray et al., 2019). Correlation matrices shown in additional file 2 confirm that there was no significant relationship between financial motivation and identified regulation, integrated regulation or intrinsic motivation. This supports the results of the study's process analysis which found no relationship between the rate with which participants redeemed their earned points for financial incentives and levels of identified regulation, integrated regulation or intrinsic motivation (Murray et al., 2019). In fact, assignment to the financial-incentive based intervention group resulted in increases in *intrinsic motivation* compared to the control group at six months. By contrast, our results do show that increases in more internal forms of motivation (i.e. integrated regulation, intrinsic motivation) were associated with increased physical activity at six and 12 months, which supports the idea proposed by self-determination theory that higher levels of intrinsic motivation are beneficial for long-term behavior change (Deci & Ryan, 1985; Michie et al., 2014). The finding of significant indirect effects (i.e. the product of coefficients representing: (1) the relationship between intervention assignment and the mediator; and (2) the relationship between the mediator and physical activity) through *integrated regulation* and *intrinsic motivation* (i.e. the most internalized forms of regulation and motivation) is consistent with the findings of previous systematic reviews, which find evidence for a positive relation between more autonomous forms of motivation and physical activity (Teixeira, Carraça, Markland, Silva, & Ryan, 2012; Teixeira et al., 2015).

Focus groups (reported elsewhere) revealed that participants generally appreciated the scheme's self-regulation aspects (e.g. self-monitoring, target setting, planning, making a commitment, accountability) and felt a sense of accomplishment when they met goals or saw improvements (Gough, Prior, Kee, & Hunter, 2018). Therefore, it appears that the PAL scheme supported the self-determination theory psychological need for 'competence' (Deci & Ryan, 1985). The relevance of self-regulation techniques and self-monitoring for physical activity behavior has also previously been evidenced (Bird et al., 2013; Bravata et al., 2007; Michie et al., 2009; Williams & French, 2011). For example, Harkin and colleagues found monitoring goal progress can help promote behavior change (Harkin et al., 2016) in line with a control theory framework (Carver & Scheier, 1982).

Mediation analyses indicated that the strongest indirect effects of group assignment on six-month physical activity occurred through habit formation and this finding has support in the theoretical and empirical literature (Gardner, de Bruijn, & Lally, 2011; Kassavou et al., 2014; Kaushal & Rhodes, 2015; Lally & Gardner, 2013; Verplanken & Orbell, 2003; Wood & Rünger, 2016). The emphasis placed on the scheme's self-regulation techniques supports the observation that people develop habits after a period of successful self-regulation, which may have been brought about by the use of plans (Kwasnicka, Dombrowski, White, & Sniehotta, 2016). Habits are formed when the behavior becomes regular, automatic and ingrained in the self-concept (Kassavou et al., 2014; Verplanken & Orbell, 2003). Prompts in the social (e.g. email reminders sent by the study team and having work colleagues participating in the scheme) and physical (e.g. seeing sensors surrounding the workplace) environments could have aided habit formation. This is also in line with several habit theories which hypothesize that environmental cues associated with prior and new behaviors determine whether the new behavior is maintained (Hofmann, Friese, & Wiers, 2008; Hunt & Martin, 1988; Verplanken & Aarts, 1999). When participants utilized the scheme's self-regulatory, social and environmental aspects to increase their physical activity habits, this mitigated the overall negative impact on physical activity.

Surprisingly, *outcome satisfaction, recovery* and *maintenance self-efficacy*, which literature suggests are particularly important in the long-term were not shown to be important mediators in the present analysis (Luszczynska & Schwarzer, 2003; Ochsner, Scholz, & Hornung, 2013; Rothman, 2000; Schwarzer, 1992, 2008). Three potential explanations include: (1) These constructs have not been impacted by the intervention; (2) Measures are not effectively capturing the construct; (3) These constructs are not important for physical activity interventions in the workplace (i.e. in the present context). It has been noted that these constructs

have been tested in relatively few physical activity studies (Arbour-Nicitopoulos, Duncan, Remington, Cairney, & Faulkner, 2014; Barg et al., 2012; Caudroit, Stephan, & Le Scanff, 2011; Kassavou et al., 2014; Perrier, Sweet, Strachan, & Latimer-Cheung, 2012; Schwarzer et al., 2007). It is therefore plausible that we do not know enough about how to appropriately measure these constructs with respect to physical activity behavior. Recently published guidance on development of complex interventions highlights the importance of considering how interventions are related to the context in which they operate and how this can contribute towards explaining whether they work (Craig et al., 2018). For example, it is conceivable that our particular study context altered participants' perceptions that they could maintain their workplace physical activity (e.g. if they were suddenly faced with a tight deadline at work).

Explaining the Intervention's Overall Negative Impact on Behavior

Whilst changes in four-week mediators were not translated to changes in physical activity behavior, there were positive indirect effects through some six-month mediators which were in the opposite direction to the intervention's overall negative effect on physical activity behavior. Thus, our results contribute further evidence supporting the results of a recent systematic review, which found that in studies examining mediators of behavior change maintenance in physical activity interventions for healthy adults, only 34% of 413 tests of intervention effects on mediators were significant (Murray et al., 2018). This suggests that the selected behavior change techniques may not have been effective for changing the targeted mediators. Other constructs need to be measured and tested as mediators of intervention effect. For example, we examined the constructs of identified regulation, integrated regulation and intrinsic motivation, i.e. more autonomous forms of motivation (Deci & Ryan, 1985), to test the self-determination theory hypothesis that financial incentives undermine more internal forms of motivation. We also measured extrinsic (financial) motivation to examine the hypothesis that financial incentives would trigger short-term behavior change and found a null effect. A more comprehensive assessment of motivation may also have included the more controlled forms of motivation such as introjected regulation and external regulation (Deci & Ryan, 1985), and would have allowed us to assess whether financial incentives led to decreased physical activity through these constructs. Although the majority of our measured mediators were socio-cognitive variables, recent research highlights that socio-cognitive theories can only partially account for physical activity behavior because they focus on 'explicit' processes and do not reflect the 'implicit' processes that determine behavior (Chevance, Bernard, Chamberland, & Rebar, 2019). Future studies should attempt to capture these processes by measuring implicit

attitudes to physical activity, for example. Another criticism of socio-cognitive theories is that they do not appropriately account for temporal considerations (Scholz, 2019). It is possible that our classical intervention study design, measuring outcomes at six-month intervals, may have missed some important effects occurring at a more micro temporal timescale (e.g. our short-term mediators may have shown a stronger association with shorter-term behavior).

As previously noted, an intervention's success depends on considering the social and political context in which it operates. For PAL scheme participants, several potential explanations for the observed negative effect on physical activity behavior include: (1) A novelty or "observation" effect may have affected the control group more than the intervention group given that the intervention group were more continuously aware of their physical activity whilst the control group were only aware of having their physical activity monitored when they wore pedometers at six and 12 months during data collection (Rodrigues, O'Brien, French, Glidewell, & Sniehotta, 2015; Spence, Burgess, Rodgers, & Murray, 2009); (2) The impact of the political context (e.g. throughout the trial, there was austerity related re-structuring of the local authorities and within the civil service which resulted in upheaval or uncertainty about job location and security for some participants in the intervention and control groups); (3) The impact of perceived implementation limitations (e.g. instances when sensors incorrectly recorded physical activity; vouchers which were lacking in variety, with inconvenient expiration dates) highlighted by participants during focus groups may have led to some participants becoming frustrated (Gough et al., 2018; Murray et al., 2019).

Theoretical Implications

The results of the present study have important implications for some commonly employed behavior change theories. Specifically, our findings suggest that the tested behavior change models, drawn from multiple commonly used behavior change theories, were not sufficient to explain the overall decrease in objectively-assessed physical activity behavior for intervention participants versus controls (Scott, Eves, French, & Hoppé, 2007). Notably, the negative effect of an intervention including financial incentives on behavior was not explained by intrinsic motivation, as predicted. These theories should be developed and expanded for testing in future intervention studies. For example, theories should be developed that fully account for the 'explicit' and 'implicit' processes of behavior change, give consideration to the nuanced temporal structure of the behavior change process, incorporate a broader range of contextual influences (such as those listed in the previous section: potential novelty effects, the political context, perceived

implementation limitations) and provide testable mechanisms for interventionists to investigate. Recent attention to the role of 'dual process' theories (Chevance et al., 2019), calls for stronger theorizing on temporal considerations in health psychology (Scholz, 2019), and for greater focus on context when developing interventions (Craig et al., 2018) are steps in the right direction.

Our findings have important implications for some of the main contentious issues surrounding use of financial incentives for behavior change. Firstly, extrinsic (e.g. financial) rewards are not thought to produce long-term behavioral changes since withdrawal of the reward causes the behavior to be extinguished according to learning theory (Johnston & Sniehotta, 2010). Secondly, self-determination theory proposes that the use of financial incentives has a 'crowding out' effect on intrinsic motivation for behaviors which are already internalized (Promberger & Marteau, 2013), or that they may hinder the process of internalization (Deci et al., 2001). By contrast, our results suggest that the use of financial incentives in a behavior change intervention can actually lead to increased intrinsic motivation if rewards are delivered as part of a complex behavior change intervention with multiple components (Marteau et al., 2009). Furthermore, our results show that more internal forms of motivation increased whilst physical activity decreased. The provision of financial rewards does not appear to have impacted physical activity behavior since financial motivation was not related to pedometer steps/day. Previous studies have found that the monetary value and type (e.g. individual versus group-based) of the reward can impact its effectiveness for behavior change (Finkelstein, Linnan, Tate, & Birken, 2007; Kullgren et al., 2013). Possibly the incentive was not attractive enough to entice those participants who were initially inactive to start (and by repetition, to 'learn') physical activity behavior in the first place. This is notwithstanding the fact that the incentive element was informed by the results of a Contingent Valuation experiment conducted at baseline with all participants, and further refined through focus group discussions with a representative sample of office-based public sector employees in NI (Tang et al., 2017).

Strengths and Limitations

The main study outcome was an objective measure of pedometer steps/day with proven reliability and validity (Bassett et al., 1996; Bravata et al., 2007; Schneider et al., 2003). We examined different constructs as short- and long-term mediators of physical activity behavior change. Formal mediation analyses were pre-specified in our study protocol (Hunter et al., 2016), included mediators measured prior to physical activity outcomes and controlled for baseline values. Thus, this study exemplifies most of the elements of good

565 practice, improving upon previous studies which rarely conduct formal mediation tests (n=12/39), have not
566 pre-specified mediation analyses in published study protocols (n=0/12) and usually do not measure
567 hypothesized mediators prior to physical activity outcomes (n=3/12) (Murray et al., 2018). Bias-corrected
568 bootstrap CIs were used in assessing the significance of indirect effects and are also recommended
569 (Mackinnon, 2008; MacKinnon et al., 2004). To improve the research area, there is a need for more physical
570 activity intervention studies to publish well-conducted mediation analyses with consideration of these
571 strengths (i.e. objective physical activity measures, theory derived mediator measures, long-term follow-up,
572 formal methods of mediation analysis). Whilst a strength of the PAL study was the integration and testing of
573 multiple behavior change theories, the need to minimize participant burden meant that we could not measure
574 and test all of the constructs relevant to any individual theory.

575 This study was not specifically powered to detect changes in mediating variables and post-hoc power
576 analyses indicated that power for some analyses was low. However, we conducted a sensitivity analysis using a
577 Bayesian approach, which resulted in no major differences. Mediators were derived as the average of self-
578 report questionnaire items, which were based on previously used validated measurement instruments. The
579 internal consistency of some mediators was low (additional file 1, table 1.2). The dropout rate was high at six
580 and 12 months, and participants in both the intervention and control group showed high physical activity
581 levels at baseline which declined at the six-month follow-up, potentially indicating a measurement reactivity
582 effect (French & Sutton, 2010, 2011). We used a 'completers only' analysis approach in the interest of testing
583 intervention dose on the hypothesized mediating variables. Since missing data did not vary between groups or
584 in terms of baseline characteristics (with the exception of recovery and maintenance self-efficacy scores which
585 were not shown to be significant mediators), we are confident that this approach did not bias our results.
586 Whilst other potential pathways may exist, we were unable to test these since we only measured the
587 hypothesized mediating variables outlined in our pre-specified logic model. Some of our models included
588 mediators that were measured at the same time-point as the outcome variable. However, since behavioral
589 'maintenance' may occur at six months we deemed it important to examine potential mediating effects of our
590 long-term mediators on six-month physical activity behavior. Our study design, measuring outcomes at six-
591 month intervals, may have missed some important effects. Arguably, our primary outcome (i.e. steps/day) did
592 not capture all possible forms of physical activity, such as cycling or swimming, which is a common limitation
593 of wearable devices. However, walking was the most common form of physical activity undertaken by

594 participants, and participants were encouraged to wear pedometers for all activities during data collection
595 (apart from water-based activities, contact sports and sleep) which would have captured spill-over effects
596 beyond workplace physical activity. Finally, these analyses should be interpreted with caution due to multiple
597 testing.

598 **Implications for Future Research**

599 The examined constructs drawn from multiple behavior change theories were not sufficient for
600 explaining the PAL scheme's overall negative effect on physical activity behavior. Theories should be further
601 developed which accurately capture the process of physical activity behavior change for specific types of
602 individuals and which include a broader range of potential influences on behavior (e.g. individual-level 'explicit'
603 and 'implicit' processes with attention given to temporal considerations, influences in the social and physical
604 environment, the political context and factors related to the research process itself such as novelty effects or
605 issues related to intervention fidelity). Further research is needed to increase understanding of the
606 psychological processes underlying measurement reactivity effects (French & Sutton, 2011). Future research
607 should further explore the utility of integrating various theoretical approaches to behavior change (e.g.
608 psychological, social, environmental and behavioral economic theories) in complex interventions with various
609 interacting, evidence-based behavior change techniques, and in specific contexts. Inclusion of self-regulation
610 techniques (e.g. self-monitoring, goal-setting) with social and environmental prompts should aid physical
611 activity habit formation and allow for the internalization of the behavior, making it more sustainable long-
612 term. Our results suggest that financial incentives do not *necessarily* reduce intrinsic motivation when
613 delivered as part of a multi-component evidence-based programme. Future research should examine the
614 impact on intrinsic motivation when financial incentives are offered on their own, and consider the role of
615 more external forms of motivation (e.g. introjected regulation, external regulation).

616 **Conclusion**

617 Mediation analyses did not contribute towards explaining the overall decreases in physical activity
618 behavior observed for intervention group participants versus controls in the PAL study. For example, changes
619 in the hypothesized short-term mediators, including financial (extrinsic) motivation, were not translated to
620 changes in physical activity behavior. However, changes in some long-term mediators were related to changes
621 in physical activity behavior at six and 12 months. Specifically, there were positive indirect effects of *integrated*
622 *regulation, intrinsic motivation* and *habit* on six-month physical activity and positive indirect effects of

integrated regulation, *planning* and *habit* on 12-month physical activity. Participants who increased their levels of these constructs (e.g. by focusing on the scheme's self-regulation, social or environmental aspects rather than financial incentives) experienced less of a decline in physical activity. Contrary to the hypothesis of self-determination theory, the present findings suggest that levels of intrinsic motivation are not necessarily negatively impacted by providing financial incentives, if they are embedded in a complex multi-component behavior change programme. This was demonstrated by the observed increases in *more internal forms of motivation* for physical activity at four weeks and six months for interventions compared to controls with no significant intervention effect for *financial (i.e. extrinsic) motivation* for physical activity at four weeks. Furthermore, levels of *financial motivation* were not associated with *internal motivation*. Thus, our findings oppose one of the main criticisms on the use of financial incentives for health behavior change often cited in the literature. Therefore, future physical activity intervention studies should give greater attention to how financial incentives can encourage short- and long-term behavior change. By contrast, our results do show that increases in more internal forms of motivation (i.e. integrated regulation, intrinsic motivation) were associated with increased physical activity behavior at six and 12 months, which supports the self-determination theory proposal that higher levels of intrinsic motivation are beneficial for long-term behavior change. *Self-regulation*, with social and environmental prompts, has been shown to be effective for habit formation. Behavior change theory should be expanded to account for all of the individual-level 'explicit' and 'implicit' process that explain behavior, with consideration given to the temporal nature of these processes, and the broader social and political environmental context within which they occur. Future studies should be designed to investigate these mechanisms.

Acknowledgements

This study has been funded via the National Institute for Health Research Public Health Research Programme; Award no: 12/211/82. The funding body had no role in the design of the study or collection, analysis, and interpretation of data or in writing the manuscript. The study team would also like to acknowledge funding from the Public Health Agency and South Eastern Health and Social Care Trust. JMM is supported by a PhD studentship funded by the Department for the Economy, Northern Ireland (DfE). RFH is supported by a Career Development Fellowship from the National Institute of Health Research (NIHR) and acknowledges funding support from the HSC Research and Development Division. DPF is supported by the NIHR Manchester Biomedical Research Centre (IS-BRC-1215-550 20007). The authors would like to

acknowledge the work of the wider PAL study team in leading the study, delivering the intervention and collecting the data with thanks to Professor Chris Patterson for providing on-going advice on conducting and interpreting statistical analyses, and to Dr. Jen Badham for cleaning the data. The views and opinions expressed therein are those of the authors and do not necessarily reflect those of the PHR programme, NIHR, NHS or the Department of Health.

Disclosure of potential conflicts of interest

Professor Frank Kee and Professor David French are members of the NIHR PHR Research Funding Board. Professor Frank Kee is also a member of NIHR PHR Prioritisation Group. All other authors declare they have no competing interests.

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Table 1

Baseline, four-week and six-month scores on mediator variables and physical activity

	Baseline				Four weeks				Six months			
	Intervention		Control		Intervention		Control		Intervention		Control	
VARIABLES	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Physical activity self-efficacy (1-5)	439	2.91 (0.97)	376	2.92 (0.94)	344	2.83 (0.89)	319	2.80 (0.92)				
Intentions (1-7)	435	5.38 (1.68)	375	5.37 (1.75)	343	5.42 (1.58)	321	5.09 (1.77)				
Outcome expectations (1-5)	418	3.37 (0.62)	354	3.36 (0.64)	318	3.25 (0.67)	292	3.27 (0.60)				
Financial motivation (1-7)	439	1.71 (1.16)	376	1.79 (1.28)	345	2.12 (1.36)	320	2.06 (1.42)				
Planning (1-4)	414	2.37 (0.69)	363	2.45 (0.69)	344	2.29 (0.70)	319	2.32 (0.75)	255	2.35 (0.74)	235	2.32 (0.71)
Social norms (1-7)	414	3.87 (1.20)	357	4.04 (1.14)	346	3.93 (1.16)	317	3.78 (1.29)	253	3.90 (1.13)	235	3.90 (1.12)
Identified regulation (1-5)	438	3.81 (0.87)	375	3.92 (0.83)	346	3.99 (0.78)	319	3.89 (0.83)	262	3.93 (0.82)	239	3.91 (0.87)
Integrated regulation (1-5)	439	3.12 (1.13)	373	3.27 (1.11)	344	3.37 (1.08)	319	3.24 (1.10)	258	3.41 (1.10)	238	3.31 (1.12)
Intrinsic motivation (1-5)	438	3.52 (0.99)	376	3.63 (0.97)	346	3.70 (0.88)	320	3.58 (0.94)	259	3.70 (0.91)	239	3.63 (0.97)
Habit (1-5)	437	2.89 (1.32)	375	3.08 (1.24)					256	3.18 (1.40)	235	2.87 (1.45)
Workplace norms (1-5)	439	3.20 (0.82)	377	3.20 (0.85)					260	3.19 (0.76)	237	3.14 (0.83)
Recovery self-efficacy (1-4)	438	2.36 (0.82)	375	2.34 (0.79)					261	2.41 (0.73)	238	2.41 (0.70)
Maintenance self-efficacy (1-4)	438	2.79 (0.86)	376	2.77 (0.89)					262	2.69 (0.83)	237	2.69 (0.75)
Outcome satisfaction (1-5)	404	3.85 (0.68)	352	3.87 (0.65)					257	3.87 (0.62)	233	3.80 (0.69)
Pedometer steps/day	414	7,977 (3,602)	359	7,651 (3,204)	210[†]	7,790 (3,462)	180[†]	8,203 (3,401)	249	6,990 (3,078)	236	7,576 (3,345)

[†]12-month outcome measures.

Table 2

Results of single mediator models with six-month pedometer steps/day as the dependent variable

Hypothesized mediators	n	Intervention effect on mediator		Association of mediator with physical activity		Direct effect		Indirect effect		Proportion (%)	Power[3]	CD[4]	SRMR[5]
		a (SE)	P-value	*b* (SE)	P-value	*c'* (SE)	P-value	*ab* (SE)	95% CI	*ab/(c'+ab)*	*1-β*		
Short-term mediators[1]													
Physical activity self-efficacy	417	0.11 (0.08)	0.15	293 (161)	0.07	-373 (156)	**0.02**	32.7 (28.2)	-2.87, 116.0	-10%	0.09	0.65	<0.001
Intentions	415	0.39 (0.18)	**0.03**	-29 (58)	0.62	-309 (167)	0.06	-11.2 (30.2)	-89.9, 38.5	3%	0.81	0.56	<0.001
Outcome expectations	363	-0.04 (0.05)	0.38	-44 (143)	0.76	-404 (182)	**0.03**	1.84 (14.4)	-16.6, 49.7	-0.5%	0.03	0.66	<0.001
Financial motivation	420	0.20 (0.15)	0.19	13 (75)	0.87	-338 (156)	**0.03**	2.55 (17.9)	-27.6, 51.8	-1%	0.01	0.59	<0.001
Planning	403	0.06 (0.06)	0.34	-51 (287)	0.86	-288 (170)	0.09	-3.06 (17.5)	-60.4, 19.9	1%	0.07	0.60	<0.001
Social norms	405	0.24 (0.09)	**<0.01**	-137 (87)	0.12	-298 (158)	0.06	-33.3 (32.7)	-131.2, 8.09	10%	0.06	0.56	<0.001
Identified regulation	417	0.14 (0.06)	**0.03**	94 (282)	0.74	-339 (177)	0.06	13.1 (35.5)	-50.5, 98.1	-4%	0.45	0.68	<0.001
Integrated regulation	416	0.22 (0.07)	**<0.01**	106 (231)	0.65	-347 (175)	**0.05**	22.9 (38.4)	-46.9, 111.4	-7%	0.44	0.76	<0.001
Intrinsic motivation	418	0.16 (0.06)	**<0.01**	37 (252)	0.88	-341 (173)	**0.05**	5.99 (34.8)	-62.4, 81.5	-2%	0.46	0.72	<0.001
Long-term mediators[2]													
Planning	382	0.09 (0.06)	0.15	547 (180)	**<0.01**	-221 (176)	0.21	50.6 (42.3)	-17.3, 153.3	-30%	0.08	0.63	<0.001
Social norms	382	0.08 (0.09)	0.37	262 (94)	**<0.01**	-299 (174)	0.09	22.0 (32.7)	-23.4, 115.8	-8%	0.05	0.62	<0.001
Identified regulation	403	0.06 (0.06)	0.30	550 (211)	**<0.01**	-299 (181)	0.10	35.1 (36.9)	-32.4, 116.9	-13%	0.06	0.71	<0.001
Integrated regulation	399	0.17 (0.09)	0.07	571 (188)	**<0.01**	-362 (181)	**0.05**	94.7 (46.3)	**18.7, 204.4**	-35%	0.24	0.76	<0.001
Intrinsic motivation	400	0.13 (0.07)	0.06	456 (176)	**0.01**	-321 (181)	0.08	59.0 (36.8)	**3.09, 154.5**	-23%	0.19	0.71	<0.001
Habit	394	0.41 (0.14)	**<0.01**	482 (105)	**<0.01**	-429 (188)	**0.02**	198.7 (70.7)	**84.3, 369.9**	-86%	0.89	0.66	<0.001
Workplace norms	400	0.10 (0.06)	0.11	-362 (158)	**0.02**	-233 (187)	0.21	-36.1 (32.6)	-129.6, 5.61	13%	0.09	0.68	<0.001
Recovery self-efficacy	402	-0.02 (0.07)	0.83	163 (150)	0.28	-277 (177)	0.12	-2.47 (17.1)	-55.6, 21.0	1%	0.01	0.54	<0.001
Maintenance self-efficacy	403	-0.02 (0.08)	0.84	208 (134)	0.12	-267 (185)	0.15	-3.41 (19.6)	-57.1, 29.0	1%	0.05	0.57	<0.001
Outcome satisfaction	376	0.07 (0.05)	0.21	407 (250)	0.10	-347 (192)	0.07	28.0 (29.8)	-11.6, 112.7	-9%	0.34	0.63	<0.001

[1]Short-term mediators measured baseline and four weeks; [2]Long-term mediators measured baseline and six months; [3]Power calculated using the Schoemann, Boulton and Short (2017) app for mediation analyses; [4]CD: coefficient of determination; [5]SRMR: standardized root mean square residual (<0.08 indicates good fit).

NB: results are coefficients and cluster-adjusted standard errors and p-values from single mediator models. Bias-corrected bootstrap confidence intervals for the indirect effect are reported (10,000 reps). Independent variable=Group assignment, Mediating variable=follow-up scores of mediators, Dependent variable=follow-up scores of outcome (six-month pedometer steps/day). All paths are adjusted for strata, season, baseline values of the mediator and baseline pedometer steps/day. Unstandardized coefficients are extracted.

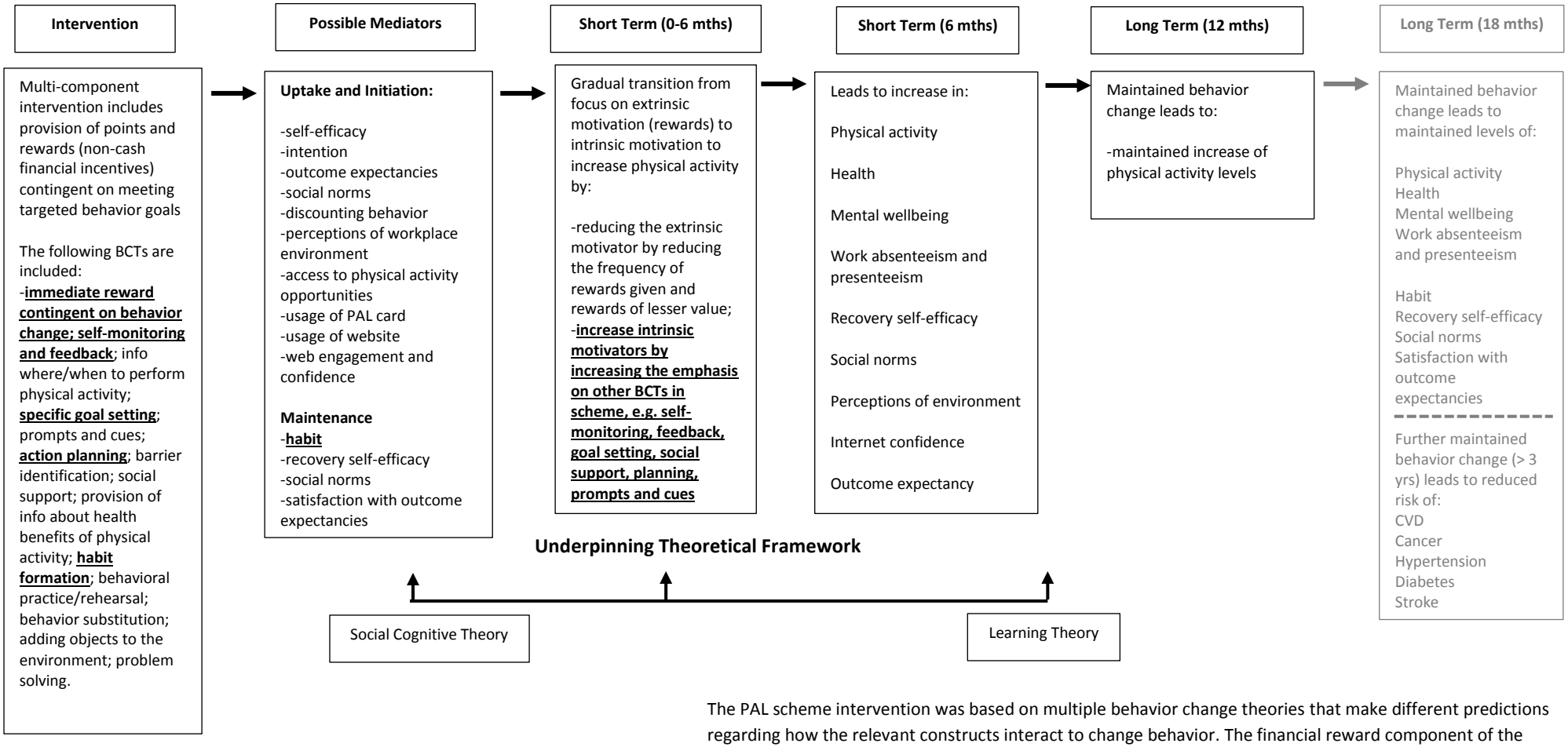
Table 3

Results of single mediator models with 12-month pedometer steps/day as the dependent variable

Hypothesized mediators	n	Intervention effect on mediator		Association of mediator with physical activity		Direct effect		Indirect effect		Proportion (%)	Power[2]	CD[3]	SRMR[4]
		a (SE)	P-value	*b* (SE)	P-value	*c'* (SE)	P-value	*ab* (SE)	95% CI	*ab/(c'+ab)*	*1-β*		
Long-term mediators[1]													
Planning	314	0.14 (0.07)	0.06	832 (280)	**<0.01**	-932 (238)	**<0.01**	115.0 (70.2)	**3.71, 285.5**	-14%	0.09	0.52	<0.001
Social norms	313	0.10 (0.12)	0.42	-13 (156)	0.93	-726 (274)	**<0.01**	-1.25 (22.9)	-64.9, 37.0	0.2%	0.04	0.50	<0.001
Identified regulation	326	0.10 (0.07)	0.17	559 (198)	**<0.01**	-632 (277)	**0.02**	56.9 (48.5)	-13.9, 181.3	-10%	0.06	0.60	<0.001
Integrated regulation	323	0.21 (0.10)	**0.03**	617 (235)	**<0.01**	-747 (268)	**<0.01**	128.0 (68.8)	**27.3, 313.2**	-21%	0.24	0.67	<0.001
Intrinsic motivation	323	0.19 (0.08)	**0.01**	336 (204)	0.10	-634 (266)	**0.02**	65.1 (49.9)	-1.37, 204.5	-11%	0.19	0.60	<0.001
Habit	318	0.45 (0.17)	**<0.01**	340 (121)	**<0.01**	-659 (287)	**0.02**	153.3 (73.7)	**39.3, 333.1**	-30%	0.89	0.55	<0.001
Workplace norms	323	0.13 (0.09)	0.16	-314 (184)	0.09	-668 (288)	**0.02**	-40.1 (38.7)	-157.9, 5.28	6%	0.06	0.57	<0.001
Recovery self-efficacy	323	-0.02 (0.09)	0.83	476 (170)	**<0.01**	-648 (278)	**0.02**	-9.40 (43.1)	-111.1, 70.1	1%	0.04	0.38	<0.001
Maintenance self-efficacy	325	-0.05 (0.11)	0.66	186 (198)	0.35	-628 (267)	**0.02**	-8.74 (24.2)	-93.2, 18.1	1%	0.05	0.43	<0.001
Outcome satisfaction	305	0.01 (0.07)	0.88	379 (258)	0.14	-811 (258)	**<0.01**	3.66 (31.1)	-46.3, 89.9	-0.5%	0.33	0.48	<0.001

[1]Long-term mediators measured baseline and six months; [2]Power calculated using the Schoemann, Boulton and Short (2017) app for mediation analyses; [3]CD: coefficient of determination; [4]SRMR: standardized root mean square residual (<0.08 indicates good fit).

NB: results are coefficients and cluster-adjusted standard errors and p-values from single mediator models. Bias-corrected bootstrap confidence intervals for the indirect effect are reported (10,000 reps). Independent variable=Group assignment, Mediating variable=follow-up scores of mediators, Dependent variable=follow-up scores of outcome (12-month pedometer steps/day). All paths are adjusted for strata, season, baseline values of the mediator and baseline pedometer steps/day. Unstandardized coefficients are extracted.

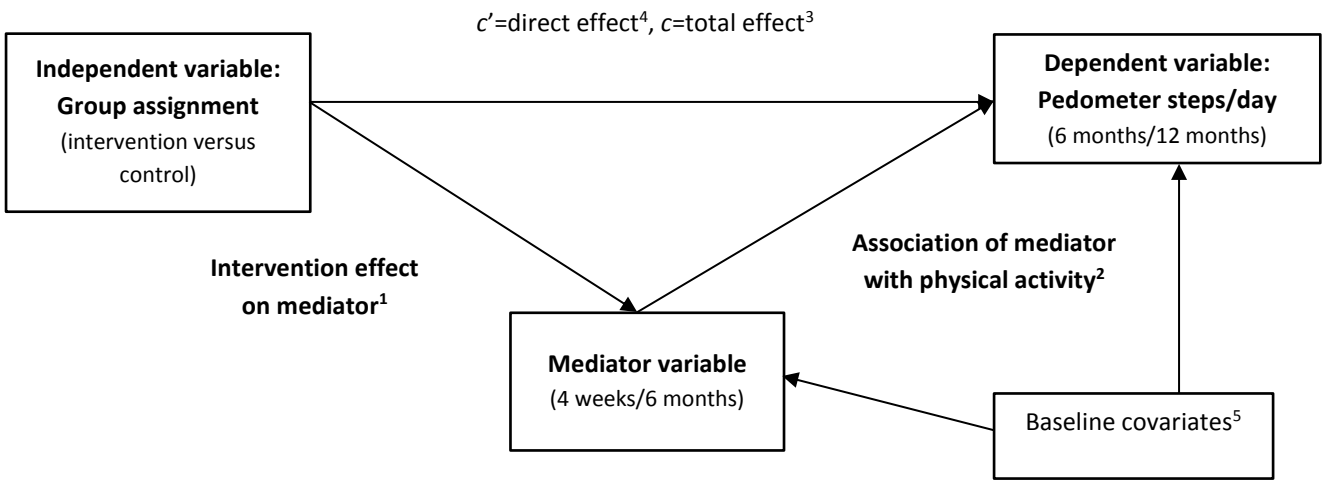


*This figure is adapted from the trial protocol paper. In this version, behavior change techniques, mediators and outcomes, which were subsequently shown to have significant effects, are highlighted in bold and underlined. The hypothesized 18-month outcomes have been greyed as 18-month follow-up was not completed following the null intervention effects observed at earlier follow-ups.
Source: Hunter RF, Brennan SF, Tang J, et al. Effectiveness and cost-effectiveness of a physical activity loyalty scheme for behavior change maintenance: a cluster randomised controlled trial. BMC Public Health 2016;16:618.

Figure 1. Logic model of the Physical Activity Loyalty scheme*

The PAL scheme intervention was based on multiple behavior change theories that make different predictions regarding how the relevant constructs interact to change behavior. The financial reward component of the intervention was based on learning theory by providing an immediate reward (extrinsic motivation) for behaviours that offer future health gains. It also contained elements of other approaches, such as goal setting, prompts, self-monitoring, and habit formation which fit within a self-regulation control theory framework, motivational messages (persuasion), and social support (vicarious experience) which should increase self-efficacy according to social cognitive theory. Social cognitive theory also holds that satisfaction with the consequences of behaviour change can act as a reinforcing mechanism, in addition to the reinforcement of financial rewards. The rationale for the phasing of rewards in the latter half of the intervention was to reduce the emphasis on extrinsic motivation and increase the emphasis on intrinsic factors. A central premise of self-determination theory is that the provision of financial rewards may 'crowd out' intrinsic motivation, or hinder the process of internalization, which is detrimental for achieving behavior change maintenance. Behavioral repetition was expected to lead to the forming of habits, and behavioral maintenance, by the time rewards were withdrawn.

NB. BCT=behavior change technique.



[1]*a*=path coefficient representing magnitude of effect of group assignment on mediator variable.
[2]*b*=path coefficient representing magnitude of effect of mediator variable on pedometer steps/day.
[3]*c*=path coefficient representing magnitude of effect of group assignment on pedometer steps/day unadjusted for mediator.
[4]*c'*=path coefficient representing magnitude of effect of group assignment on pedometer steps/day adjusted for mediator.
[5]pedometer steps/day, mediator, strata, season.

Figure 2. Overview of single mediator models