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Self-regulatory efficacy and long-term physical activity engagement: Examining mediators from a randomized trial

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ABSTRACT

Objective: The purpose of this study was to examine self-regulatory efficacy (SRE) as an explanatory mediator of high-intensity interval training (HIIT) versus moderate-intensity continuous training (MICT) interventions in relation to physical activity levels over 6- and 12-months after condition assignment.
Methods: Two mediation models were run. The first model explored initial change in the first 6 months by examining 6-month SRE as a mediator of the relations between the independent variable (condition) and dependent variable (average of 3-month and 6-month physical activity). A second mediation model explored sustained change in the second 6 months by examining 12-month SRE as a mediator of the relations between the independent variable (condition) and dependent variable (average of 9-month and 12-month physical activity). Hayes' PROCESS macro was used to estimate the indirect effect. Adults ($n = 99$) who were overweight and low-active (mean age = 50.9 years, 69.7% female) were randomized to HIIT or MICT, with participants in both conditions receiving the same brief behavioural counselling.
Results: SRE at 12-months post-program was found to mediate the intervention effects (total indirect effect: 8.26 [1.41–17.91]) while SRE at 6-months post program was not found to mediate the intervention effects (total indirect effect: 5.05 [-1.12 – 13.98]). SRE was found to be an explanatory mechanism in predicting greater long-term physical activity engagement for those in MICT compared to HIIT.
Conclusions: These findings suggest that participants' perceived capabilities to self-manage their physical activity behaviour accounted for higher levels of maintained physical activity participation among participants in the MICT condition when compared to the HIIT condition one-year following participation in a diabetes prevention program.

Over 350 million adults worldwide are at risk for developing type 2 diabetes (T2D) and this number is expected to rise as the proportion of people with T2D is estimated to increase in most countries (International Diabetes Federation, 2017). Individuals can substantially reduce their risk of T2D *independent* of diet and weight loss through regular physical activity (Laaksonen et al., 2005; Lindström et al., 2003; Snitker et al., 2003). Unfortunately, adherence to regular physical activity is poor in those at risk for T2D (Knowler et al., 2002; Lindahl et al., 2009). Long-term adherence to a complex behaviour such as physical activity is challenging, and arguably requires greater capacity to effectively engage in self-regulation than does physical competency to perform a given physical activity on a one-off or occasional basis.

Targeting key self-regulatory mechanisms of behaviour change increases the potential for long-term adherence. Theories can guide which key psychological mechanisms of change are necessary to target and then behaviour change techniques (BCTs) can be implemented to change those targeted constructs (Carey et al., 2018; Connell et al., 2018). Interventions that incorporate theory and evidence-based behaviour change techniques have been found to be effective at modifying physical activity behaviour (Dishman & Buckworth, 1996; Michie & Johnston, 2012). As such, there is a consistent call for physical activity interventions to use evidenced-based, behaviour change theories that work by targeting modifiable social cognitions (Campbell et al., 2000; Goodwin et al., 2008; Green, 2001).

In recent years, HIIT has gained interest as a time-efficient, effective, and enjoyable exercise option. Compared to MICT, which consists of

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exercising at a constant intensity (e.g., lightly jogging at the same pace), HIIT is characterized by multiple brief bouts of higher intensity exercise followed by a brief period at a lower intensity (e.g., "1-min on, 1-min off").The *Small Steps for Big Changes* study was designed to examine the efficacy of high-intensity interval training (HIIT) versus moderate-intensity continuous training (MICT) for adults with low baseline levels of activity who were overweight. Participants in both conditions were provided with (brief) behaviour change counselling during 7 sessions over 2-weeks to help them develop the self-regulatory skills (e.g., self-monitoring, planning, behavioural practice) needed to sustain long-term physical activity behaviour. Additional information on the intervention can be found in the methods section and/or published protocol, main results, and theoretical underpinning papers (Bourne, Ivanova, et al., 2019; Bourne, Little, et al., 2020; Jung et al., 2020). The primary outcome for the trial corresponded to physical activity, which was assessed at baseline, 3-, 6-, 9-, and 12-months following the initial 2-week intervention and is reported elsewhere (Bourne, Little, et al., 2020). Although participants in both conditions significantly increased their moderate-to-vigorous physical activity (MVPA) behaviour throughout the 12 months post-intervention (average of the 3, 6, 9, and 12-month assessments) when compared to baseline, improvements were significantly greater in the MICT condition (+69 min) than the HIIT condition (+36 min) (Jung et al., 2020). Previous pilot data demonstrated that despite prescribing a greater total volume, participants in HIIT engaged in more MVPA at 6-months compared to the MICT group (Locke et al., 2018). Therefore, the greater MVPA increases favoring MICT (relative to HIIT) was unexpected and contrary to our a priori hypothesis (see [Bourne, Little, et al., 2020]). The differential MVPA improvements across the 12-months post-intervention reported in the published primary outcome paper appear to be driven by changes within the first 6-months. Different patterns of physical activity behaviour seem to appear for the first and the last 6-months of follow-up. With this in mind, the overall purpose of this study was to understand what mechanisms (as an exploratory analysis [Appelbaum et al., 2018]) might account for the differential MVPA changes across the 6- and 12-months post-intervention.

Development of the Small Steps for Big Changes intervention was guided in part by social cognitive theory (SCT) (Bandura, 1986, 1997), a commonly used theoretical framework for increasing physical activity behaviour (Ashford et al., 2010; Weinberg & Gould, 2010; Williams & French, 2011) and within diabetes prevention programs in particular (Cradock et al., 2017). The utility of SCT is credited to its central construct, self-efficacy. Self-efficacy is defined as individuals' confidence in their abilities to execute a specific course of action, and is believed to be one of the most consistent and strongest predictors of future physical activity behaviour in individuals living with T2D (Dutton et al., 2009; Plotnikoff et al., 2011). SCT provides a blueprint for effectively designing interventions by specifying the means by which to bolster self-efficacy to increase engagement in physical activity. SCT also specifies the social cognitive domains of self-efficacy posited to be important in relation to both the adoption and maintenance of behaviour change. Specifically, confidence in one's capabilities to successfully engage in a specified task (task self-efficacy) is projected to be critical during the adoption phase of engaging in a new behaviour, whereas one's confidence to self-manage and overcome barriers to continually enact a behaviour (self-regulatory efficacy [SRE]) is thought to be the crucial social cognition necessary for behavioural maintenance (Bandura, 2004). To understand the observed differential MVPA changes across the 6- and 12-months post-intervention, SRE's role in the maintenance of physical activity presents an important mechanism to explore in the maintenance of physical activity.

Behaviour change techniques (BCTs) are the active intervention components that target the theoretical mechanisms of change (i.e., self-regulatory efficacy) (Michie & Johnston, 2012). Elucidating the mechanisms of change through which BCTs impact a targeted behaviour is needed to advance behaviour change science and design more effective interventions. Regular engagement in health behaviours, like exercise, is complex and requires self-regulation (e.g., self-monitoring, scheduling, goal setting; Carver & Scheier, 2011). The Small Steps for Big Changes intervention purposefully delivered BCTs (e.g.,1.2 problem solving, 1.1 goal setting [behaviour], 1.3 goal setting [outcome]) to specifically bolster participants' self-regulatory skills and the self-efficacy to enact those skills (Michie et al., 2013). While the intervention delivery was the same for both groups, it is possible that the enactment of these skills differs when self-regulating HIIT compared to MICT. The motivation to perform the two exercises might differ, the two exercise modalities may require different problems to be solved, or one modality might be easier to schedule than the other. As such, SRE may mediate the behaviours differently. The present exploratory analysis, in line with SCT and the intervention design, sought to explore whether SRE mediated the intervention effects on MVPA 12 months following the initial 2-week training plus counselling component between the HIIT and MICT conditions. Two separate mediation analyses were run. The first mediation model explored initial change in the first 6 months by examining 6-month SRE as a mediator of the relations between condition and average of 3-month and 6-month physical activity. A second mediation model explored sustained change in the last 6 months by examining 12-month SRE as a mediator of the relations between the condition and average of 9-month and 12-month physical activity. We expected SRE to mediate average physical activity engagement for MICT at 6- and 12-months post-intervention.

2. Methods

2.1. Design

The protocol of this registered trial (ClinicalTrials.gov # NCT02164474) is published elsewhere (Bourne, Little, et al., 2020). As such, an overview of the methods as relevant to the current investigation, is presented here.

2.2. Study design

In this two-arm parallel group randomized trial, participants (who were overweight or obese and not meeting physical activity guidelines) were randomized to one of two physical activity conditions, HIIT or MICT, plus brief behavioural counselling. Cardiorespiratory fitness and minutes spent in free-living MVPA were compared 12-months following a brief, two-week physical activity intervention complemented by counselling framed by social cognitive theory. For a detailed breakdown of the theoretical underpinnings and specific behavioural change techniques of the intervention, please see Bourne, Ivanova, et al. (2019).

2.3. Procedure

The intervention consisted of two phases: (a) a two-week physical activity training and counselling phase, and (b) a 12-month follow-up phase. Within the first phase, all participants engaged in 10 physical activity sessions over the two-week training period. Seven of the sessions were supervised in the laboratory, and three sessions were conducted independently at home by participants to foster independence. Each supervised physical activity session consisted of either HIIT or MICT and 10 min of one-on-one counselling. Those in MICT progressed from ~20 min to ~50 min of moderate-intensity physical activity. Those in HIIT progressed from 4 to 10 x 1-min high-intensity intervals. Behavioural counselling content was identical in each condition and had two primary objectives. The first objective was to help individuals initiate exercise by enhancing their confidence to perform physical activity (task self-efficacy) by providing opportunities to practice engaging in physical activity, ask questions specific to form and intensity, and experiencing physiological sensations associated with the prescribed physical activity. The second (and major) objective was to help individuals self-

manage physical activity in the long term by enhancing their confidence to self-manage physical activity (SRE) by providing opportunities to practice self-monitoring behaviour, plan physical activity behaviour, work through physical activity barriers, and practice independent physical activity.

2.4. Assessments

Baseline assessment occurred prior to the intervention. Following the completion of the 2-week intensive phase of the intervention, participants were instructed to engage in physical activity of the assigned modality (i.e., HIIT or MICT) three times per week for 12-months. Follow-up assessment time points occurred at post-, 3-, 6-, 9-, and 12-months. Self-regulatory efficacy was measured via questionnaire at baseline, post-intervention, and at 6- and 12-months follow-up. At the end of each follow-up appointment, participants were given an accelerometer to wear for the seven days following the appointment to assess physical activity. In this way, SRE was measured prior to physical activity to satisfy temporal conditions for mediation (Weinstein, 2007). For this paper, only measures pertinent to the current analyses are included. For a full overview of all measures, please see Bourne, Little, et al. (2020).

2.5. Participants

Eligible participants were between the ages of 30 and 65, were not meeting physical activity guidelines (i.e., engaged in 2 or less bouts of moderate and/or vigorous aerobic physical activity per week in the previous 6-months), had a body mass index (BMI) between 24 and 40 kg/m^2, and were cleared to engage in vigorous physical activity using the Physical Activity Readiness Questionnaire-Plus (PAR-Q+) (Warburton et al., 2011). Participants were recruited through paper (e.g., posters in community centers, coffee shops) and online (e.g., social media) advertisements in the local community. Exclusion criteria included any contraindication to exercise, prior history of cardio- or cerebrovascular disease or myocardial infarction, diagnosed with type 2 diabetes, currently taking glucose-lowering medications, uncontrolled hypertension (systolic blood pressure >160 mmHg and/or diastolic blood pressure >99 mmHg) or a change in cardiovascular medication in the previous 6-months.

2.6. Measures

2.6.1. Self-regulatory efficacy

Participants' confidence in their abilities to self-manage physical activity behaviour (e.g., schedule, plan, set goals) was assessed using a 14-item measure adapted from Shields and Brawley (2006). An exemplar item is "How confident are you that you can develop solutions to cope with time management challenges with respect to your exercise schedule (over the next four weeks)?" Participants were asked to rate their confidence as a percentage ranging from 0% (not at all) to 100% (extremely confident). The overall scale means were used in the analyses and demonstrated strong internal consistency (α's $\geq$ 0.90). SRE was measures at baseline, post-intervention, 6, and 12 months.

2.6.2. Physical activity

Objectively measured purposeful moderate-to-vigorous physical activity (i.e., bouts of MVPA for $\geq$10 min; MVPA10+) was assessed by triaxial accelerometry (Actigraph GT3X-BT). Participants were instructed to wear an accelerometer on their right hip for seven consecutive days. Freedson cut points (Freedson et al., 1998) were used to identify time spent in MVPA during wear time on valid days (i.e., days with 10+ hours of wear time). Time spent in moderate and vigorous physical activity intensities were averaged across valid wear days and multiplied by seven to provide a weekly estimate of physical activity at each measurement time point. Purposeful physical activity was operationalized as minutes spent in MVPA in bouts of at least 10 min while allowing for drops in accelerometer counts for up to 1 min (MVPA10+) (Freedson et al., 1998), in line with physical activity guidelines at the time of study implementation that specified that bouts of physical activity should be accumulated in bouts of 10 min or more (Canadian Society for Exercise Physiology, 2018). Differential improvements in average MVPA10+ were witnessed in the primary outcomes paper (Jung et al., 2020), therefore this study chose to examine the mechanisms behind the differential average MVPA10+ improvements. The 6-month average MVPA was calculated by averaging the 3- and 6-month assessments and the 12-month average MVPA was calculated by averaging the 9-, and 12-month assessments.

2.7. Data analyses

Data were analyzed in SPSS (version 24) using an intention-to-treat analysis. Multiple imputation is a recommended analytic procedure for managing missing data from randomized trials (see review on missing data by Graham (2009)). Five imputed datasets with 10 iterations were computed. Results from the five imputations were pooled. Auxiliary variables (e.g., baseline values, demographic factors) were used in the imputation model to aid missing value estimation.

This study examined the effects of SRE measured at 6- and 12-months post-intervention in mediating the relationship between intervention condition and 6- and 12-month average MVPA by performing two independent mediation analyses and controlling for baseline MVPA (Hayes, 2018). Prior to the mediation we examined multicollinearity between variables through bivariate (Pearson) correlations between the study variables (see Table 3). The path coefficients are presented in unstandardized form, allowing for more substantive interpretation (i.e., changes in minutes of physical activity) (Hayes, 2018). When interpreting coefficients in the results section, a positive coefficient for the direct effect between condition and 6- or 12-month average MVPA suggests that the intervention effect favours the MICT condition. The PROCESS macro version 3.3 was used to estimate the hypothesized mediating effects of both indirect and direct effects based on 5000 bootstrapping samples at 95% biased-corrected confidence intervals (Hayes, 2018). Confidence intervals are derived by a bootstrap sampling distribution that represent the computed indirect effect from all samples and ranking the indirect effects obtained from low to high. Confidence intervals that do not cross zero (either all positive or negative) suggest that the true effect is not zero and that the null hypothesis can be rejected.

3. Results

Participants had an average age of 50.9 years (SD = 9.40), were predominantly female (28.2% male), and 88.9% self-identified as Caucasian. There were no significant baseline imbalances between groups (Jung et al., 2020). For a full overview of study attrition details, please see (Bourne, Little, et al., 2020). Demographic information is presented in Table 1.

3.1. Self-regulatory efficacy and physical activity

Table 2 presents the physical activity and SRE means and standard deviations for the sample and intervention condition. Table 3 presents the correlations between the main study variables (SRE and physical activity).

3.2. Mediation model: predicting MVPA across the first six months

Fig. 1 depicts 6-month SRE as a mediator of the relations between the IV (condition) and DV ($6M_{avg}$ physical activity). Overall, the mediation containing 6-month SRE decreased the magnitude of the effect between condition and 6-month average physical activity (c = 40.99 [16.94,

Table 1
Descriptive Statistics of Participants.

	All (N = 99)	HIIT (n = 47)	MICT (n = 52)
Age (years)	50.9 (9.40)	51.8 (8.80)	50.0 (9.90)
Sex *n* (%)			
Male	28 (28.20)	13 (27.70)	15 (28.90)
Female	69 (69.70)	33 (70.20)	36 (69.20)
Did not answer	2 (2.10)	1 (2.10)	1 (1.90)
Body Mass (kg)	89.3 (20.36)	89.4 (21.70)	89.3 (19.30)
Ethnic Origin, *n* (%)			
Caucasian	88 (88.9)	41 (87.2)	47 (90.4)
Latin American	2 (2.02)	1 (2.1)	1 (1.9)
Asian	3 (3.03)	2 (4.3)	1 (1.9)
Native/Aboriginal	2 (2.02)	1 (2.1)	1 (1.9)
Other	2 (2.02)	1 (2.1)	1 (1.9)
Missing	2 (2.02)	1 (2.1)	1 (1.9)
Annual Household Income, *n* (%)			
$0 – $24,999	4 (4.04)	1 (2.1)	3 (5.8)
$25,000 - $49,999	11 (11.1)	4 (8.5)	7 (13.5)
$50,000 - $74,999	18 (18.2)	11 (23.4)	7 (13.5)
$75,000 - $ 99,999	20 (20.2)	11 (23.4)	9 (17.3)
$100,000 +	44 (44.4)	19 (40.4)	25 (48.1)
Missing	2 (2.02)	1 (2.1)	1 (1.9)
Education, *n* (%)			
High school	13 (13.1)	8 (17.02)	5 (9.6)
College Diploma	32 (32.3)	17 (36.2)	15 (28.8)
Bachelor's Degree	35 (35.4)	14 (29.8)	21 (40.4)
Post-Graduate Degree	16 (16.2)	6 (12.8)	10 (19.2)
Missing	3 (3.03)	2 (4.3)	1 (1.9)

Note: All values are mean (SD) unless indicated as *n* (%). n = 2 missing values.

Table 2
Means and Standard Deviations for the Sample and Intervention Conditions for pre, 6-month average MVPA, 12-month average MVPA, and SRE.

	All (N = 99)	HIIT (n = 47)	MICT (n = 52)
Pre MVPA	36.33 (49.00)	31.85 (42.93)	40.39 (53.66)
$6M_{avg}$ MVPA	103.64 (67.51)	79.95 (52.54)	125.06 (72.31)
$12M_{avg}$ MVPA	87.87 (59.83)	75.99 (44.00)	98.60 (69.53)
Pre SRE	76.60 (14.61)	75.64 (13.93)	77.47 (15.17)
6M SRE	79.13 (15.59)	76.46 (16.11)	81.54 (14.72)
12M SRE	79.12 (16.15)	74.20 (18.77)	83.57 (11.73)

Note. All values are mean (SD), SRE = self-regulatory efficacy; MVPA = moderate to vigorous physical activity. $6M_{avg}$ = average of 3- and 6-month time-points, $12M_{avg}$ = average of 9-, and 12-month time-points.
*p < 0.05.
**p < 0.01.

Table 3
Correlations for the Sample and Intervention Conditions for pre, 6-month average MVPA, 12-month average MVPA, and SRE.

	Pre SRE	6M SRE	12M SRE	Pre MVPA	$6M_{avg}$ MVPA	12 M_{avg} MVPA
Pre SRE						
6M SRE	.206**					
12M SRE	.132**	.533**				
Pre MVPA	.191**	0.049	0.086			
$6M_{avg}$ MVPA	.101*	.294**	.370**	.377**		
$12M_{avg}$ MVPA	.212**	.183**	.299**	.389**	.601**	

Note. All values are mean (SD), SRE = self-regulatory efficacy; MVPA = moderate to vigorous physical activity. $6M_{avg}$ = average of 3- and 6-month time-points, $12M_{avg}$ = average of 9-, and 12-month time-points.
*p < 0.05.
**p < 0.01.

65.04], and c' = 35.94 [12.32, 59.57]). A confidence interval for the total indirect effect based on 5000 bootstrap samples crossed zero (5.05 [-1.12, 13.98]), as did the effect for the pathway between condition and 6-month SRE (see Fig. 1). The pathway between 6-month SRE and 6-month average physical activity did not cross zero (see Fig. 1), indicating that 6M SRE predicted $6M_{avg}$ physical activity. In summary, 6-month SRE was not a mediator of the relationship between condition and 6-month average physical activity.

3.3. Mediation model: predicting MVPA across the 12-month follow-up

Fig. 2 depicts 12-month SRE as a mediator of the relations between the IV (condition) and DV ($12M_{avg}$ physical activity). Overall, 12-month SRE decreased the magnitude of the effect between condition and 12-month average physical activity (c = 18.69 [-3.41, 40.79], and c' = 10.43 [-11.98, 32.84]). Condition indirectly influenced average physical activity over 12-months post-program through 12-month SRE (R^2 = 22.9%). The confidence interval for the total indirect effect (8.26 [1.41–17.91]) based on 5000 bootstrap samples did not cross zero including the individual mediation pathways between condition and 12-month SRE and between 12-month SRE and 12-month average physical activity (see Fig. 2). Although the confidence intervals for the direct effect (c') and total effect (c) between condition and 12-month average physical activity both crossed zero after accounting for the mediator, recent mediation analysis experts emphasize that to determine mediation one must examine the estimate of the indirect effect and its significance and whether there was a decrease from the total effect (c) to the direct effect (c') (Hayes, 2018). Since the direct effect was a positive coefficient this indicates the intervention effect favours the MICT condition. Therefore, in line with Hayes (2018), 12-month SRE was a mediator of 12-month average physical activity for the MICT condition.

3.4. Additional analyses

To account for the limitation of averaging two MVPA measures and the impact of averaging on temporal order, an additional analysis was conducted using only the 6-month/12-month MVPA measure as a mediator between condition and 6-month/12-month physical activity. As SRE was collected 1-week prior to MVPA data collection, the mediation model preserves temporal order. Comparable results are seen for the early and late phase (see supplementary file A). In addition, the outcome measurement (MVPA10+) has been designed and used for measuring continuous activity and may be less sensitive to measuring interval activity. Additional analyses were conducted to investigate using total MVPA minutes rather than MVPA10+ and yielded similar results with the same substantive interpretation (see supplementary file B). Thus, in this study it appears that HIIT bouts could be detected using MVPA10+ as the recovery periods were high enough to be counted as MVPA.

4. Discussion

The Small Steps for Big Changes randomized trial, grounded in SCT and designed to examine the efficacy of HIIT versus MICT, has been shown to be effective in increasing free-living purposeful MVPA (Jung et al., 2020). The present study represented an exploratory analysis of the mechanisms leading to the differential improvements in MVPA between HIIT and MICT over the first 6-months and over the last 6-months post-intervention (with larger increases in MVPA among those in the MICT condition). Consistent with SCT and the intervention's design, this study investigated whether SRE mediated the intervention effects for MVPA between HIIT and MICT groups. Contrary to our hypothesis, SRE at 6-months was not found to mediate the intervention effects on 6-month average physical activity. In line with our second hypothesis, SRE at 12-months was found to mediate the MICT effects on average physical activity levels over the last 6-months. While the mediation effects were small, the presence of a mediating effect may reflect the differences in how the two exercise modalities are self-regulated as the behavioural counselling intervention was the same for both groups. The

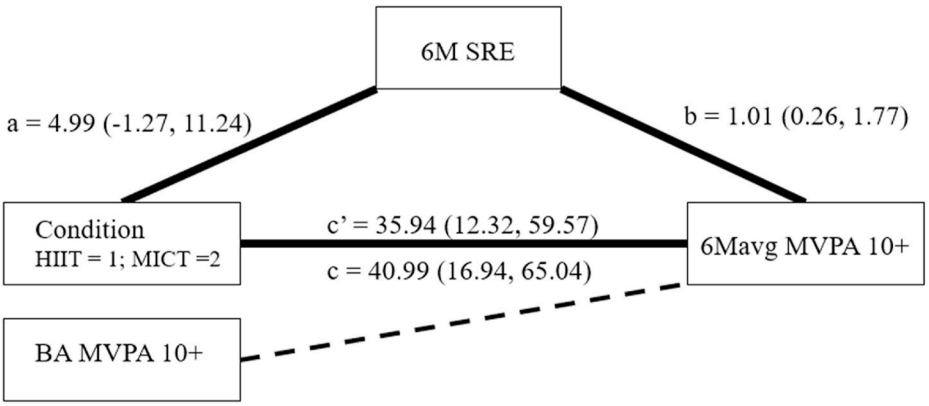


Fig. 1. Main effects and confidence intervals of the direct and total mediation effects for 6-month SRE on 6-month average MVPA 10+ with baseline MVPA 10+ as a covariate.

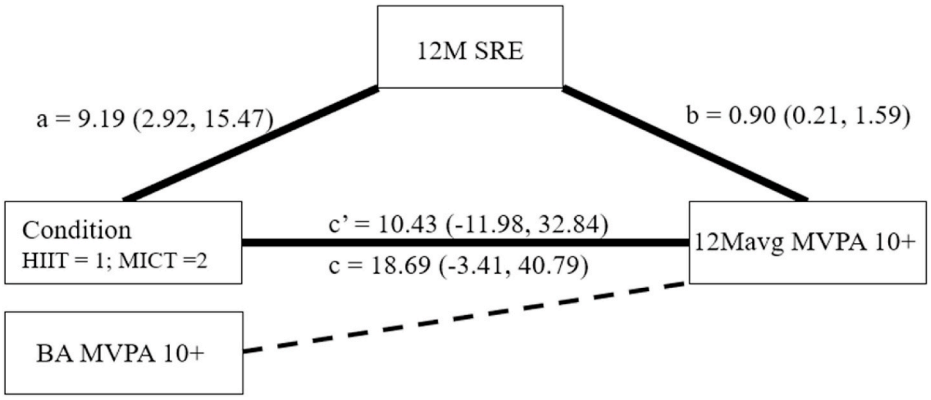


Fig. 2. Main effects and confidence intervals of the direct and total mediation effects for 12-month SRE on 12-month average MVPA 10+ with baseline MVPA 10+ as a covariate.
Note. SRE = self-regulatory efficacy; MVPA 10+ = bouts of moderate to vigorous physical activity for ≥10 min; BA = baseline; $12M_{avg}$ = average of 9-, and 12-month time-points; c = the total effect of condition on 12Mavg MVPA 10+; c' = the direct effect of condition on 12Mavg MVPA 10+ after controlling for the 12M SRE. The dashed line represents the covariate that was included in the model but was not a main path of interest. Condition was coded as follows: HIIT = 1 and MICT = 2. A positive coefficient for the direct effect between condition and 12M MVPA 10+ suggests that the intervention effect favors MICT – that those in MICT were more physical active than those in HIIT.

findings are discussed relative to practical and theoretical implications.

SRE is a psychological resource that is necessary for the ongoing self-management of long-term physical activity (Bandura, 2004). Behaviour change techniques were systematically employed to enhance SRE beliefs about physical activity and physical activity self-management within the HIIT and MICT conditions (e.g., planning, self-monitoring; see (Bourne, Ivanova, et al., 2019) for a complete list of BCTs utilized in the trial). Findings align with the results from a review and meta-analysis of interventions delivering BCTs to increase self-efficacy and physical activity in individuals with obesity (Olander et al., 2013). In Olander and colleagues' review, action planning, self-monitoring, self-management, and social support were the BCTs most strongly associated with increases in self-efficacy. Teaching the use of cues/prompts, prompting practice, and prompting rewards were associated with the largest changes in physical activity. While the design of the current study does not allow us to tease apart the impact of individual BCTs on SRE or behaviour, our findings add to the review by Olander and colleagues (Olander et al., 2013) by suggesting that the package of behaviour change techniques delivered to the HIIT and MICT conditions were effective at promoting changes in physical activity, albeit greater increases for MICT.

In contrast to Rhodes and Pfaeffli (2010), who found limited evidence for the mediating effects of self-efficacy in physical activity interventions, our findings suggest that SRE mediated MICT intervention effects on average physical activity 12-months post-intervention. While Rhodes and Pfaeffli (2010) suggest that additional mediation evidence is needed to fully support self-efficacy as a mediator, one possible reason for the difference in findings could be due to the present study examining the self-regulatory domain of self-efficacy. One's SRE is thought to be the social cognition necessary for maintenance of a behaviour (Bandura, 2004). In line with theory that suggests engaging in repeat behaviours requires SRE (Bandura, 1997), our results indicate that SRE mediated physical activity across the last half of the follow-up (i.e., months 6–12). In other words, what distinguished those who were active and those who were less active was their confidence to self-regulate (e.g. schedule and plan) physical activity repeatedly in their day-to-day lives. Despite previous research investigating SRE as a mechanism in maintenance of physical activity (e.g. Dutton et al., 2009; Olson & McAuley, 2015; Parschau et al., 2013), limited research has examined mediating effects of an intervention on longer-term behaviour (as assessed 12 months or more after an intervention).

Interestingly, individuals in the MICT condition had higher SRE (than those in the HIIT condition) with SRE thereafter contributing to more minutes of MVPA. Within social cognitive theory, Bandura suggested that there is a dynamic relationship between social cognitions (e.g., SRE) and physical activity, whereby past physical activity is a source of information which can bolster SRE, which then leads to greater future physical activity. Individuals may have more experience engaging in MICT across their lifetime compared to HIIT. It could be that participants were able to draw on these past experiences to bolster their SRE while performing MICT during the study, compared to those performing HIIT. A second possible explanation for this could be that individuals perceive, whether correctly or not, that there are fewer difficulties planning and scheduling a MICT session compared to a HIIT session. Over time participants may have become more confident in their capability to self-regulate a consistent MICT session (e.g., 1-h walk anywhere, without requiring a change of clothing). In contrast, HIIT may require consistent cognitive effort for participants to become

confident in their capability to self-regulate a HIIT session as there is, whether correctly perceived or not, additional planning required (e.g. specific equipment or terrain [hill], change of clothes, post-workout shower, set intensity-level and interval parameters). Finally, HIIT is performed at a higher intensity and we speculate that it may require a different set of self-regulatory skills that focus more on emotion and motivation regulation (Gross, 2013). There have been recent debates (Williams & Rhodes, 2016) and preliminary experimental research (Williams et al., 2020) suggesting that the measurement of self-efficacy may inadvertently tap into motivation rather than perceived capability. Future research should aim to disentangle these two constructs with new quantitative measurement tools or the use of qualitative methodologies to understand the decisional processes between being capable to engage in physical activity bouts and the motivation to engage in a physical activity bout (Beauchamp, 2016). More research is needed on long-term HIIT engagement and specifically the role of SRE, emotional, and motivational determinants to the maintenance of HIIT.

4.1. Strengths

This study had a number of strengths. First, missing data was imputed, resulting in the preservation of sample size and statistical power. Second, the design and analyses allowed for SRE to be examined to predict long-term physical activity behaviour. This study used a theory-based intervention testing the mediating effects of a key theoretical construct, SRE, in the long-term engagement of physical activity for two different exercise conditions. Interventions that have systematically applied theory are likely to be successful compared to ones "loosely informed" by theory (Michie & Prestwich, 2010; Painter et al., 2008). The experimental design and use of theory allowed for a strong causal test of theory for which correlational studies could not do. Mediation is necessary for theory testing to expand the generalizability to different health contexts (Rothman, 2004). Third, the intervention systematically employed BCTs to target the sources of SRE, providing further substantiation to the rationale for examining it as a mechanism of change. Lastly, behaviour outcomes were measured rather than intentions, which has been a limitation of past theory testing research (Weinstein, 2007). The use of accelerometer data to measure physical activity helped us avoid inherent biases in self-reported physical activity.

4.2. Limitations

The current study presented an exploratory analysis of potential intervention mechanisms and was underpowered. The observed effects between exercise modalities should be viewed as hypothesis-generating for future research. The current intervention controlled for baseline physical activity to account for part of the dynamic relationship between physical activity and SRE. However, we did not assess the reciprocal relationship, whether physical activity mediated increases in SRE. Future theory-based research should examine whether increases in SRE are mediated by increases in physical activity. The measures used for SRE (assessed at 6- and 12-months post-intervention) used a broader range of time (asking "confidence over the next 4 weeks") compared to the physical activity measures which spanned the one week following SRE measurement. The lack of correspondence might have attenuated the relationship between SRE and physical activity. However, measuring SRE beliefs during a one-week time period may have been too short a timeframe to adequately capture the challenge and self-regulatory capability required to manage ongoing physical activity behaviour. Future tests of theory could consider an assessment of physical activity in line with the SRE measure (i.e. assess SRE 4 weeks prior to MVPA) and should include an SRE measurement at each follow-up time-point for a more complete longitudinal analysis. In the current analysis, SRE was assessed at the 6- and 12-month follow-up time-points, whereas physical activity was additionally captured at 3- and 9-months. To account for this limitation, while using the current experimental data as best as possible to explore results from the main outcomes paper, we conducted two separate mediation assessments to account for early (3-, and 6-months MVPA) and late phase (9-, 12-months MVPA) across the follow-up period. Future studies with adequate power should consider cross-lag panel mediation modelling to better ascertain intervention effects in relation to the trial's putative psychological mediators and criterion outcomes, when assessed on multiple occasions, over time. In addition, the outcome measurement (MVPA10+) has been designed and used for measuring continuous activity and may be less sensitive to measuring interval activity. There is no agreed-upon method to extract high-intensity interval bouts within typical accelerometry-assessed indicators of MVPA. Counting sheer minutes based on Freedson cut-points of MVPA might not be sensitive enough to detect interval training behaviour. Therefore, this method may underestimate the amount and frequency of HIIT in which participants engaged (Freedson et al., 1998). Finally, simple summation and comparison of combined moderate- and vigorous-minutes discounts the value of vigorous as compared to moderate activity, thus providing a very conservative approach towards HIIT.

5. Conclusions

Predicting physical activity one year following a health behaviour change intervention is complex and SRE may be an important mediator of sustained physical activity engagement. Present findings suggest that 12-months following a diabetes prevention program, participants in the MICT condition had higher perceived capability to self-manage their physical activity behaviour, accounting for higher levels of maintained physical activity engagement compared to the HIIT condition. Future research should continue to examine SRE as a mediator in maintenance of long-term physical activity, as well as other targeted social cognitions. Given the potential difference in self-regulatory skills required to manage HIIT and MICT, future research should consider using or developing SRE measures that include other self-regulatory skills, like emotion regulation.

Author statement

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Trial registration

ClinicalTrials.gov # NCT02164474. Registered on June 12, 2014.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.

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Note. SRE = self-regulatory efficacy; MVPA 10+ = bouts of moderate to vigorous physical activity for ≥10 min; BA = baseline; $6M_{avg}$ = average of 3- and 6-month time-points; c = the total effect of condition on 6Mavg MVPA 10+; c' = the direct effect of condition on 6Mavg MVPA 10+ after controlling for the 6M SRE. The dashed line represents the covariate that was included in the model but was not a main path of interest. Condition was coded as follows: HIIT = 1 and MICT = 2. A positive coefficient for the direct effect between condition and 6M MVPA 10+ suggests that the intervention effect favors MICT – that those in MICT was more physical active than those in HIIT.

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