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Mediating Effects of the 'eCoFit' Physical Activity Intervention for Adults at Risk of, or Diagnosed with, Type 2 Diabetes

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Abstract

Background The study aim was to examine the mechanisms of physical activity behaviour change in the multi-component *eCoFit* randomised controlled trial (RCT) among adults diagnosed with, or at risk of, T2D.

Method The RCT included two phases: phase 1 (weeks 1–10) integrated group sessions (outdoor physical activity and cognitive mentoring) and the use of the eCoFit smartphone application (app), and phase 2 (weeks 11–20), which included the use of the eCoFit smartphone application only. Participants ($n = 84$) were assessed at baseline and 10 and 20 weeks from baseline. Physical activity was assessed using pedometers, and the following mediators were tested: action self-efficacy, barrier self-efficacy, recovery self-efficacy, implementation intentions, intention to have regular physical activity, outcome expectations, risk perception and implicit associations related to physical activity. The PROCESS INDIRECT Macro was used to perform mediation analyses.

Results Significant mediation pathways were found for implementation intention measured at 10 weeks, AB (95% CI = 486.04 [128.19, 1073.42]). No significant pathways were found for the other social–cognitive and implicit attitudinal mediators.

Conclusion Increased daily steps among the intervention participants were explained by increased implementation intentions. The eCoFit study successfully operationalised implementation intentions in the smartphone app designed to promote outdoor physical activity.

Trial Registration The trial was approved by a University Human Research Committee and is registered with the Australian New Zealand Clinical Trial Registry (ACTRN12615000990527).

Keywords Physical activity · Implicit attitudes · Implementation intentions · Self-efficacy · Type 2 diabetes

Introduction

The risk and prevalence of type 2 diabetes (T2D) has dramatically increased over the past decade. Current estimates report that this chronic disease is expected to rise to 592 million USD globally (10.1%) by 2035 [1]. Regular physical activity is essential for the prevention and treatment of T2D and also helps to support good mental health [2, 3]. However, physical activity levels among this population are insufficient; for example, in the USA, only 39% of adults with diabetes are physically active vs. 58% of adults without this disease [4]. People with T2D report numerous behavioural and cognitive barriers to physical activity that are specific to this chronic condition. These include feelings of tiredness, emotional distress associated with diabetes self-management, burden and uncertainty over the diagnosis and progression of T2D and problems with adherence to self-care management. Thus, there is a strong rationale for designing innovative interventions that target physical activity behaviour change in adults at risk of or diagnosed with T2D.

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It is well-established that theoretically designed interventions can increase physical activity among adults with T2D [5–8]. However, there is somewhat limited understanding regarding the mechanisms responsible for physical activity behaviour change among this population because few studies have conducted mediation analyses. Mediation analysis can facilitate a better understanding of the underlying processes of behaviour change in an intervention by helping to determine if changes in the outcomes are due to intervention components or other extraneous factors.

Research which focused on the mediating effects of physical activity for adults at risk of, or diagnosed with, T2D has been mainly guided by the social cognitive theory (SCT) [9], theory of planned behaviour [10–12] and the transtheoretical model [5, 13]. In a study conducted by Plotnikoff and colleagues [14], perceived behavioural control, barrier self-efficacy and intentions mediated the effect of the physical activity intervention among women with T2D. Changes in social–ecological and neighbourhood resources, as well as support from family and friends, were also found to mediate the intervention effects on physical activity among this population group [15, 16]. In another study guided by SCT, Lubans and colleagues [16] found that participants' use of resistance training planning strategies (i.e. strategies to overcome barriers and formulate plans) mediated the effect of the home-based exercise resistance training program on T2D participants' behaviour.

The health action process approach model (HAPA) has also been investigated to test its applicability to physical activity behaviour change in adults with T2D [17, 18]. The HAPA is a stage-based model that acknowledges the importance of different constructs as individuals move through the phases of behaviour change. The key constructs of the first phase include action self-efficacy, outcome expectancies and risk perception. After a person forms the intention, the HAPA model assumes that the person is moving towards the volitional phase where different factors play an important role in barrier self-efficacy, recovery self-efficacy, action planning and coping planning. In the volitional phase, action planning and coping planning emerge as important constructs. The HAPA model was found to be well-placed to predict physical activity across a large cohort of individuals with T2D [18]. However, limited investigation of this model has been conducted for physical activity interventions among T2D populations [19].

Making concrete plans and identifying strategies to overcome barriers to participation can help support behaviour change. Implementation intentions are self-regulatory strategies that support goal achievement by specifying when, where and how the behaviour is going to be performed (i.e. the action plan) and by associating situational contexts (i.e. the 'if' component) with the corresponding adequate goal-directed response (i.e. the 'then' component) [20, 21]. A meta-analytic review conducted by Bélanger-Gravel et al. [20] confirmed that implementation intention is a successful strategy in physical activity behaviour change and also has been pointed to as a particularly effective strategy when it is combined with barrier management [20].

It is increasingly recognised that complex health behaviours such as physical activity are explained not only by explicit motivational processes (e.g. intention) but also by implicit attitudes or processes [22, 23]. The dual models suggest that cognition and behaviour are the outcome of two broad systems of information processing the reflective system and impulsive system where implicit, non-conscious processes play a significant role [24, 25]. The impulsive–reflective model is one of the dual models which explains the role of explicit and implicit factors that influence individual's cognition and behaviour [25]. Implicit processes can be described as cognitive, affective and motivational processes that may influence behaviour without (and/or with limited control of) a person's awareness [23]. In the domain of physical activity, implicit attitudes have received the most attention and can be described as automatic affective reactions towards the object (e.g. physical activity behaviour) resulting from the particular positive or negative associations that are activated automatically when one encounters a relevant stimulus (e.g. gym, outdoor park) [23, 26]. A recent systematic review of the effects of non-conscious regulatory processes revealed that physical activity behaviour is partially regulated by implicit associations, priming effects and habits [27–29]. Despite these promising cross-sectional findings, there is limited evidence from experimental studies in testing these non-conscious processes [23, 30, 31]. Thus, it is not known if implicit attitudes can be changed for physical activity and if changes can lead to increases in physical activity.

Although many behaviour change theories have been used to guide the development of physical activity interventions, no particular theory has more utility than others for changing behaviour. As such, it has been suggested that integrating theories may increase the effectiveness of physical activity interventions [32–34]. The *eCoFit* physical activity intervention was designed for adults diagnosed with, or at risk of, T2D using Bandura's SCT [35], cognitive–behavioural therapy strategies adapted for physical activity, [36] and the HAPA model [37, 38]. The multi-component intervention included the use of smartphone technology, social support and the outdoor physical environment. The program was designed to improve aerobic and muscular fitness by using the outdoor environment as a cost-free gym alternative [39]. The aim of the current paper was to examine the mechanisms of physical activity behaviour change (i.e. action self-efficacy, barrier self-efficacy, recovery self-efficacy, implementation intentions, intention for regular physical activity, outcome expectations, risk perception and implicit attitudes) in the eCoFit intervention.

Methods

Participants

Eighty-four eligible inactive adults (18–80 years; mean age 45 years; body mass index (BMI) 25–40 kg/m^2) were recruited from Newcastle, New South Wales, Australia. Eligible participants were then sent an information statement detailing the study requirements and a consent form. All participants were required to provide written informed consent prior to being enrolled into the trial. Participants were stratified for T2D group (at risk of T2D, diagnosed with T2D) and sex and individually randomised to either the 20-week eCoFit intervention group or wait-list control group (intervention condition = 42, control condition = 42). The trial was approved by a University Human Research Committee and is registered with the Australian New Zealand Clinical Trial Registry (ACTRN12615000990527). The design, conduct and reporting adhere to the CONSORT guidelines.

Design and Intervention

The eCoFit intervention was evaluated using a two-arm RCT design. Study assessments were conducted at baseline and 10 and 20 weeks. A detailed description of the study methods [40] and results [39] can be found elsewhere. In short, participants randomised to the theory-based intervention group received a 20-week eCoFit program which was delivered in two phases. In phase 1 (initiation; 1–10 weeks), participants received 5 integrated, group, face-to-face sessions, which consisted of cognitive mentoring sessions with a psychologist (30 min), followed by outdoor physical activity sessions with an exercise physiologist (60 min). The aim of the cognitive mentoring sessions was to educate on strategies to overcome barriers related to physical activity, whereas the outdoor physical activity sessions focused on providing necessary knowledge and skills in using the outdoor physical environment (e.g. parks, benches) to increase muscular strength and aerobic fitness. Participants were also provided with the eCoFit smartphone app. The eCoFit app was designed to support physical activity participation through the use of the outdoor environment. The app included workout circuits tailored to the location, goals and progress-tracking options (implementation intentions) and cognitive–behaviour strategies to reduce physical activity barriers. In phase 2 of the study (maintenance; 11–20 weeks), participants used the smartphone app only. The eCoFit intervention was developed in reference to SCT [41] and the HAPA model [37] and included cognitive–behavioural therapy strategies adapted for physical activity [36]. The key constructs of SCT (i.e. self-efficacy, goal-setting outcome expectations and social support) and HAPA (i.e. self-efficacy, action and coping planning) were operationalised in the face-to-face component of the study. A description of the intervention strategies used in increasing physical activity is provided in Table 1.

Measures

Measures were obtained at baseline and 10 and 20 weeks. No incentives were provided to attend follow-up assessments. Measures were taken by trained research assistants who adhered to standardised procedures.

Physical Activity

The study outcome was physical activity measured objectively by using pedometers (Yamax, model: Digi-Walker Electronic Pedometer). Pedometers were worn by participants for seven consecutive days, except while swimming or bathing, or if there was a potential for damage to the device (e.g. contact sports). Participants were instructed to keep their normal routines during the 7-day period. Trained research assistants provided participants with physical activity log sheets and asked them to record the number of steps accumulated at the end of each day and to then rest the device. Participants were asked to record any additional activity (e.g. cycling, contact sports and swimming) on the log sheet, as well as the duration of each activity. Participants were also requested to record any non-wearing time on the physical activity log sheet of activities.

All hypothesised mediators, including the intention for regular physical activity, implementation intentions, action self-efficacy, barrier self-efficacy, recovery self-efficacy, outcome expectations and risk perception, were assessed at baseline and 10-week follow-up. The social–cognitive measures were framed within a 10-week time reference.

Intention to Be Physically Active

To assess participants' intention, a 3-item scale was used which was scored on a 4-point Likert-type scale [14] (e.g. 'I intend to get regular physical activity on a regular basis', 'I intend to be physically active regularly for a minimum of 30 minutes at least five times a week', 'I intend to get regular physical activity as part of my leisure-time'). The responses range from 1 (totally disagree) to 4 (totally agree). Cronbach's alphas for the study's social–cognitive measures are presented in Table 2.

Implementation Intentions

The 7-item scale was scored on a 5-point Likert-type scale, with responses ranging from 1 (not at all) to 5 (completely) [21, 42]. Implementation intentions for physical activity were

Table 1 Description of intervention components and targeted mediators in the *eCoFit* intervention

Intervention component	Description	Mediator tested
Cognitive mentoring sessions	The sessions were delivered by a clinical psychologist. Training on strategies to overcome barriers and increase their motivation was provided to the participants to increase the physical activity adherence.	Outcome expectations Barrier self-efficacy Action self-efficacy Recovery self-efficacy Risk perception
Outdoor physical activity sessions	Sessions were delivered by a personal trainer. Outdoor physical activity and practical education on how to use the outdoor physical environment (e.g. parks, benches) to increase muscular strength and aerobic fitness were provided to the participants.	Outcome expectations Barrier self-efficacy Action self-efficacy Recovery self-efficacy
eCoFit smartphone app	The app included the description of '*eCoFit* challenges' in 11 different park locations, the option to complete aerobic and resistance training sessions indoors or at home, goal-setting and self-monitoring options, the inclusion of the short cognitive–behavioural tasks to increase motivation, overcome barriers, and develop positive physical activity behaviours, and links to social media.	Implementation intention Implicit associations*

* Mediation analysis for implicit associations was conducted for the physical activity maintenance (10-20 weeks)

assessed by adapting Gollwitzer's principle of implementation intentions (e.g. 'when', 'where', 'how', 'with whom', 'what to do if') for physical activity behaviour (e.g. 'To what extent do you have concrete plans for when you will do regular physical activity?', 'To what extent do you have concrete plans for what to do if you miss a physical activity session?').

Action/Task Self-Efficacy

Action self-efficacy was measured using a 4-item scale adapted for physical activity [37, 43]. Results were scored on a 4-point Likert-type scale, with responses ranging from 1 (not at all) to 4 (exactly true) (e.g. 'How sure are you that you can begin exercising regularly? I am sure that I can change to a physically active life style/I am sure I can be physically active once a week').

Barrier Self-Efficacy

Barrier self-efficacy was assessed using 10 items (from a 13-item scale) [9]. Results were scored on a 5-point Likert-type scale, with responses ranging from 1 (not at all confident) to 5 (extremely confident) (e.g. 'I am confident that I can participate in regular physical activity when I am a little tired').

Recovery Self-Efficacy (Adapted for Physical Activity)

Recovery self-efficacy was assessed using a 3-item measure [38]. Results were scored on a 4-point Likert-type scale, with responses ranging from 1 (not at all true) to 4 (exactly true) (e.g. 'Imagine you stopped exercising for some time. How confident are you about restarting exercises? I am sure I can be physically active again regularly, even if I postpone my plans several times').

Outcome Expectancies

To assess outcome expectancies, a 12-item scale was employed [9, 44], and results were scored on a 5-point Likert-type scale, with responses ranging from 1 (strongly disagree) to 5 (strongly agree) (e.g. 'Regular physical activity will help me feel less tired').

Risk Perception

General health risk and general health severity were measured using 6-item scales [45] scored with 7-point Likert-type scales ranging from 1 (very unlikely) to 7 (very likely) (e.g. 'How likely is it you will have, at some time in your future, a stroke?'). Perceived threat (severity, vulnerability and fear) related to T2D was assessed with a 3-item scale [46] scored on a 5-point Likert-type scale, with responses ranging from 1 (definitely not) to 5 (definitely yes) (e.g. 'Getting further diabetes complications would be a very bad thing to happen to me').

Implicit attitudes were assessed at 10- and 20-week follow-up (not at baseline). Mediation analysis for implicit associations was conducted for the physical activity maintenance phase (10–20 weeks) on the hypothesised implicit mediators.

Implicit Attitudes Towards Physical Activity and Sedentary Behaviour

Implicit attitudes towards physical activity were measured using an adapted version of the implicit association test (IAT) [47, 48]. A modified version of the IAT for physical activity was developed and used in the eCoFit study to ascertain the valence (positive 'good' or negative 'bad') of participants' implicit attitudes. Participants completed a speed-sorting task to assess the strength of positive/good (vs. negative) implicit

Table 2 Baseline characteristics of *eCoFit* outcome values and mediators for physical activity

Model variable (Cronbach's alpha)	Control ($n = 42$)		Intervention ($n = 42$)	
	Mean (SD)		Mean (SD)	
	Baseline	20 weeks	Baseline	20 weeks
Physical activity (steps)	6117 (3203)	6628 (3168)	6799 (3730)	8650 (3612)
	Baseline	10 weeks	Baseline	10 weeks
Barrier self-efficacy ($\alpha = 0.89$)	3.10 (1.0)	2.84 (0.7)	3.26 (0.6)	3.29 (0.8)
Action self-efficacy ($\alpha = 0.88$)	3.29 (0.7)	3.24 (0.6)	3.44 (0.5)	3.37 (0.4)
Recovery self-efficacy ($\alpha = 0.84$)	2.91 (0.9)	2.93 (0.8)	3.08 (0.6)	3.01 (0.7)
Outcome expectations ($\alpha = 0.85$)	4.33 (0.6)	4.38 (0.5)	4.38 (0.4)	4.51 (0.4)
Intention to physical activity ($\alpha = 0.83$)	3.49 (0.6)	3.38 (0.5)	3.59 (0.4)	3.49 (0.5)
Implementation intention ($\alpha = 0.86$)	2.77 (1.0)	2.95 (0.9)	3.12 (0.8)	3.52 (0.6)
Risk perception ($\alpha = 0.89$)	4.93 (1.1)	4.90 (0.9)	5.20 (1.3)	5.08 (1.0)
	10 weeks	20 weeks	10 weeks	20 weeks
Implicit associations*	0.66 (0.48)	0.53 (0.35)	0.61 (0.37)	0.60 (0.39)
	Baseline	–	Baseline	–

*Tests–retest reliability ICC = 0.42, $p = 0.007$; ICC estimates and their 95% confidence intervals were calculated using SPSS statistical package version 24 based on the mean rating, consistency and two-way mixed-effects model

associations towards physical activity and of negative/bad (vs. positive) implicit associations towards sedentary behaviour. Reaction times in milliseconds were recorded to sort word pairs which were either conceptually compatible (good/physical activity, bad/sedentary behaviour) or conceptually incompatible (bad/physical activity, good/sedentary behaviour). Targeted stimuli for four categories included the following words: *good category*—outstanding, smart, honest, love and excellent; *bad category*—terrible, awful, repulsive, evil and horrible; *physical activity category*—rowing, running, exercising, sprinting and football; *sedentary behaviour category*—watching TV, sitting, computer use and video games. The stimuli were selected through the pilot questionnaires where participants ($n = 20$) were asked to rate on a scale from 1 (very weak) to 11 (very strong) the extent to which each word evoked a strong or weak association with one of the four categories. Words which were rated the highest and which matched the word lengths of the opposite category were selected for the final IAT stimuli. The test included a random-counter-balancing version for compatible pairs vs. incompatible pairs and random changes in the orientation of the categories displayed on the screen (left, right) between different IAT tests. This test included seven blocks with different numbers of trials (block 1–20 trials, block 2–20 trials, block 3–20 trials, block 4–40 trials, block 5–30 trials, block 6–20 trials, block 7–40 trials) suggested by the authors [48]. The IAT score (*D*-index) is based on the amount of time it takes a person, on average, to sort the words in the two critical blocks of the IAT [48]. The difference in reaction time in critical blocks results in a measure (*D*-index) of the associations between concepts (physical activity vs. sedentary behaviour) and positive or negative valence ('good', 'bad' respectively). Results were calculated following Greenwald and colleagues' [48] recommendations.

Statistical Analyses

To test study objectives, analyses were conducted in IBM SPSS Statistics for Mac, Version 24.0 using the PROCESS INDIRECT Macro (model 4) [49] to (i) calculate the regression coefficients for the effect of the intervention on the hypothesised mediators (pathway A); (ii) examine the associations between the mediator variables at 10 weeks and physical activity (steps) at 20 weeks, independent of group assignment (pathway B); and (iii) estimate the total (pathway C), direct (pathway C′) and indirect (pathway AB) intervention effects. All analyses were adjusted for baseline values for the mediators and outcomes (mean differences). The macro also generated bias-corrected bootstrapped 95% asymmetrical confidence intervals around the indirect effect. When confidence intervals did not include zero, significant mediation was established. As recommended in the literature [50], temporal sequencing was employed to strengthen the evidence for mediation in the current analyses (i.e. regression models were designed to determine if physical activity at the 20-week follow-up was mediated by underlying mechanisms assessed at the 10-week assessment). Missing data for all mediators were imputed using the expectation maximisation procedure in SPSS. This was deemed appropriate as Little's test did not reject the assumption that the data were missing completely at random ($\chi^2 = 1123.5$, $df = 1228$, $p = 0.984$). The amount of complete data for each time point was 100, 79 and 72% at baseline and 10 and 20 weeks, respectively. Finally, simple mediation models (model 4) were conducted for each mediator [49]. The mediation analysis for the implicit attitude was conducted only for phase 2 of the intervention (maintenance phase; 10–20 weeks). Therefore, the examination of the associations was conducted between the mediator IAT variables at

20 weeks and physical activity (steps) at 20 weeks. The analysis was adjusted for the physical activity baseline values and for the IAT 10-week values.

The eCoFit study was adequately powered to detect changes in the two primary outcomes (i.e. aerobic fitness and lower body muscular fitness). The study was sufficiently powered to detect medium-to-large mediation effects using the distribution of the bias-corrected bootstrap procedure, which is one of the most powerful mediation tests available [51].

Results

The baseline characteristics of the sample and sample size calculation are detailed elsewhere [39]. In total, 84 participants completed baseline assessments. Participant retention rate was 79% at 10 weeks (mid-program) and 71% at 20 weeks. The majority (70%) of the participants were born in Australia, and the mean age was 44.7 (14.0) years. Baseline values for the mediators and moderators of physical activity can be seen in Table 2. At baseline, mean (SD) physical activity level (steps) for the control condition was 6117 (± 3203) steps/day, and for the intervention group 6799 (± 3730) steps/day.

Effect of the Intervention on the Potential Mediators (Pathway A)

Values reported in the table and in the text are unstandardised regression coefficients, adjusted for baseline values. A significant intervention effect was observed for barrier self-efficacy (A [SE] = 0.292 (0.121), $p < 0.05$) and implementation intentions (A [SE] = 0.367 (0.141), $p < 0.05$). There were no statistically significant pathways examining the effect of the intervention physical activity maintenance phase (10–20 weeks) on the hypothesised mediator-implicit attitudes (see Table 3).

Associations Between Change in Mediators and Change in Physical Activity (Pathway B)

Action self-efficacy (B [SE] = 1800.7 (683.9), $p < 0.05$), intention to physical activity (B [SE] = 1568.9 (712.55), $p < 0.05$) and implementation intentions (B [SE] = 1321.2 (457.0), $p < 0.01$) were associated with physical activity at 20 weeks (after adjustment for baseline measures). There were no statistically significant associations between physical activity and the following mediators: barrier self-efficacy, recovery self-efficacy, outcome expectations, risk perception and implicit attitudes.

Significance of the Mediation Effect (Pathway AB)

Based on the results of the product-of-coefficients test, there was a statistically significant mediation effect for implementation intentions only (AB (95% CI = 486.04 [128.19, 1073.42])) (see Table 3). Increases in implementation intentions at 10 weeks, due to the intervention, explained significant increases in the number of daily steps of 486. All other mediated effects, including implicit attitudes, were non-significant (see Table 3).

Discussion

The primary objective of the study was to examine the mechanisms of physical activity behaviour change in the eCoFit intervention for adults with, or at risk of, T2D. The eCoFit intervention significantly increased implementation intentions and showed slight increase of barrier self-efficacy for the intervention condition. However, results of the mediation analysis showed that only implementation intentions (i.e. 'if–then' plans) mediated the intervention effect on participants' steps at the 20-week follow-up. At 10 weeks, participants reported significant increases in concrete plans regarding when, where, how, how often and with whom they were going to perform their physical activity. Additionally, most of the participants specified what they planned to do if something stopped them from being regularly active and what they would do if they missed a physical activity session.

Implementation intentions were operationalised in the eCoFit intervention through the 'Goals' option in eCoFit smartphone app [39, 40]. This feature allowed participants to set the day, time and place, and also specify with whom the workout circuit would be completed and what the person would do to stick to the initial physical activity goal ('What I will do to make it happen'). The integration of the implementation intentions app feature was incorporated to set the specific plans (when, where, how, with whom) and create an opportunity for performing physical activity on a regular basis. Mental representation of the repeated successful situations such as a completed workout becomes highly activated and easily accessible for the individuals in the future [21]. This increased mental accessibility should make it easier for individuals to implement the intended plan of regular exercise during the consecutive attempts. It was assumed that the eCoFit app will help in the mental representation of the outdoor physical activity that will lead eventually (over time) to greater automatisation of the physical activity behaviour. To date, research shows support for the use of implementation intentions in the physical activity domain [20]. A meta-analysis conducted by Bélanger-Gravel et al. [20] included 26 independent studies, and the overall effect size of implementation intentions on physical activity was 0.31, 95% CI

Table 3 Results of the mediation model examining effect of the intervention (baseline to 20 weeks) on the hypothesised mediators at 10 weeks

OMediators	C′ (SE)[a]	A (SE)[b]	B (SE)[c]	C (SE)[d]	AB (SE)[e] [95% CI]
Barrier/coping self-efficacy	1797.7 (767.7)*	0.292 (0.121)*	586.72 (531.92)	2021.5 (741.4)**	171.65 (167.55) [− 63.01, 629.28]
Action/task self-efficacy	1906.43 (717.29)**	− 0.051 (0.076)	1800.71 (683.90)*	2021.45 (741.41)**	− 92.05 (159.60) [− 563.69, 112.77]
Recovery self-efficacy	1901.28 (742.47)*	0.085 (0.142)	707.15 (512.23)	2021.45 (741.41)**	60.33 (119.27) [− 95.55, 405.97]
Outcome expectations	1929.72 (743.31)*	0.079 (0.090)	875.83 (843.59)	2021.45 (741.41)**	69.75 (102.50) [− 70.52, 376.21]
Intention to physical activity	1842.44 (729.15)*	0.059 (0.102)	1568.93 (712.55)*	2021.45 (741.41)**	93.86 (157.81) [− 158.78, 508.37]
Implementation intentions	1342.76 (748.02)	0.367 (0.141)*	1321.24 (457.00)**	2021.45 (741.41)**	486.04 (220.05) [128.19, 1073.42]
Risk perception	2012.96 (747.98)**	− 0.070 (0.130)	58.65 (388.65)	2021.45 (741.41)**	− 4.11 (55.99) [− 165.18, 78.26]
Implicit attitudes[f]	1155.45 (678.92)	0.090 (0.075)	− 210.46 (904.07)	1141.39 (672.31)	− 19.07 (112.54) [− 424.90, 121.67]

Note: Significant effect: *$p < 0.05$; **$p < 0.01$

SE, standard error; *CI*, confidence interval

[a] C′ = direct effect of the intervention on steps

[b] A = intervention effect on mediators

[c] B = association between mediators and steps

[d] C = total effect model

[e] AB = indirect or 'mediated' effect (product-of-coefficients estimate)

[f] Results of the mediation model examining effect of the intervention physical activity maintenance phase

[0.11, 0.51]. The findings from our study provide further evidence in support of promoting and using implementation intentions in pre-clinical populations.

The intervention effect on barrier self-efficacy was statistically significant, but changes were not associated with changes in behaviour. None of the other psychosocial mediators changed as a result of the intervention. The eCoFit face-to-face sessions implemented at the beginning of the program successfully addressed the most common barriers related to physical activity, and therefore, higher levels of barrier self-efficacy were present among the intervention group in comparison with the control condition. The CBT strategies were used to help in overcoming negative, sabotaging thoughts related to the initiation of outdoor physical activity.

Other mediators, including action self-efficacy, recovery self-efficacy, intention, outcome expectations and risk perception, did not mediate the relationship between treatment and physical activity at follow-up. The lack of significance for intention may be caused by processes, such as intention activation and intention elaboration, stated in the literature [21, 42]. In brief, intention activation is a process by which a person can change the direction of the intention towards a more enjoyable short-term reward. In physical activity, this process is relevant, as physical activity requires the investment of time and effort to observe long-term effects. Therefore, people may change the intention towards instant gratification, such as watching a good movie, over going for a walk. The second process mentioned above, intention elaboration, relates to the extent to which people fail to develop a detailed action plan for complex behaviours after forming an intention. For complex behaviours such as physical activity, this is a crucial step, as these behaviours require a sequence of actions (e.g. choosing an enjoyable activity, acquiring appropriate clothes, fitting exercise in a daily schedule), which people often do not take into consideration after intention formation; this intention–behaviour gap can be reduced by implementation intentions [21].

Baseline and 10-week assessments showed that participants had relatively high values for self-efficacy (action, barrier, recovery), and null findings may be due to a 'ceiling effect'. It is also possible that high appraisals of self-efficacy actually represented participants' motivation, meaning participants' overestimated their self-efficacy levels due to their high motivation to be physically active [52]. Therefore, participants who reported greater intention for physical activity (who are more motivated to engage in exercise) may be more likely to report that they 'can engage in physical activity' in the face of potential barriers. This high motivation to change sedentary lifestyles may enhance the estimation of one's belief regarding physical activity self-efficacy. Risk perception and outcome expectancy in the current study also failed to mediate the intervention's effect on daily steps. Concerns regarding limited evidence for outcome expectations as a mediator of physical activity have been addressed in the literature [53, 54].

The current study included additional mediation analyses for the implicit attitudes related to physical activity during the maintenance phase of the physical activity trial. To our knowledge, this appears to be the first RCT to test the effects of implicit attitudes on physical activity in adults with or at risk of T2D. Implicit attitudes measured at 10 weeks did not mediate the effects of the intervention on daily steps assessed at 20 weeks. The lack of significant mediation may be explained by the fact that the eCoFit intervention recruited inactive

adults who may likely have been exposed to many years of negative experiences related to physical activity. A longer period of intervention exposure and/or participating in the recommended behaviour may be needed to observe change from negative to positive implicit attitudes for this population group. An alternative explanation may stem from a recent systematic review which explored the hypothesis that sedentary behaviours (behaviours minimising energetic cost) are rewarding and, therefore, are associated with a positive affective valence [55]. This draws from the evolutionary perspective that behaviours which minimise energetic cost are likely to be rewarding. Further, the automatic processes can be problematic when they come into conflict with the controlled processes. Specifically, inactive individuals may fail to exercise regularly, despite conscious intentions to be active, due to competing automatic processes [55]. This conflict was recently highlighted by the affective–reflective theory of physical activity which posits that inactive individuals can fail to implement their intention to become more active because of a restraining action impulse resulting from the pleasurable affect associated with being at rest [24]. The hypothesis that minimising energetic cost is rewarding needs to be further tested, as current studies omit the role of sedentary behaviour and its neuropsychological and neurophysiological pathways. More research using RCTs is needed to better understand this potential mechanism of controlled and automatic processes in physical activity behaviour change.

The practical implication of testing social–cognitive components is that people at risk of or diagnosed with T2D benefited from implementation intentions by creating specific plans on how to execute their intentions, and this strategy led to increased numbers of steps assessed at follow-up. The operationalisation of implementation intentions in the eCoFit smartphone app was found to be successful in translating intention (to be more physically active) into a detailed plan and into actual behaviour. The development of implementation intentions increased self-efficacy, helped in overcoming barriers and daily obstacles in physical activity and led to increased daily physical activity. More research is needed with this population group to better understand the use of smartphone technology to deliver theory-driven strategies which focus on planning and overcoming the most common barriers related to physical activity change and maintenance.

The study has several limitations that warrant mention. A relatively small community sample was used, with the wide age range and with the majority (70%) being women. We acknowledge our relatively small sample size that prevented us from detecting small mediation effects and testing multiple mediator models. Our results should be taken with caution considering the lack of correction for multiple testing. However, these exploratory analyses within the strong study design provide meaningful direction for future studies of this kind. Implicit attitudes in the current paper were only included in phase 2 of the intervention (physical activity maintenance) due to the delay in developing and piloting IAT. Hence, future designs should include baseline measures in the analysis to better understand the underlying mechanisms of implicit associations and to demonstrate how and if fluctuation occurs throughout both the initiation and maintenance phases of the physical activity intervention. Further testing in this area should consider test words more closely related with physical activity behaviour (when testing affective attitudes) to enhance the validity of the IAT. Future research should also focus on the longer-term impact of these mediating and moderating processes in the initiation and maintenance of physical activity.

In summary, the eCoFit intervention, which integrated cognitive–behavioural strategies, social support, the outdoor physical environment and a smartphone app, demonstrated promising results for increasing objectively measured physical activity. This relationship was mediated by changes in implementation intentions, which was operationalised in the eCoFit smartphone app. Our findings highlight the importance of developing 'if–then' plans, which may help guide future physical activity interventions for adults with, or at risk of, T2D.

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Compliance with Ethical Standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Conflict of Interest The authors declare that they have no conflict of interest.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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