Examining mediators of intervention efficacy in a randomised controlled m-health trial to improve physical activity and sleep health in adults.

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Abstract

Objectives: Examining mediators of intervention efficacy in an m-health intervention targeting physical activity and sleep in 160 Australian adults.

Design: Nationwide randomised controlled trial.

Main outcome measures: Moderate- and vigorous-intensity physical activity (MVPA), assessed using the Active Australia Questionnaire; sleep quality (Pittsburgh Sleep Quality Index); and sleep hygiene practices (Sleep Hygiene Index). Hypothesised psychosocial (e.g., self-efficacy) and behavioural (i.e., MVPA, sleep quality, sleep hygiene) mediators were tested on primary endpoint data (i.e., 3 months) using bias-corrected bootstrapping (PROCESS 2 for SPSS). All outcomes and mediators were assessed using self-report.

Results: At three months, the intervention had significantly improved sleep quality (d=0.48, 95% CI: -2.26, -0.33, p=0.009) and sleep hygiene (d=0.40, 95% CI: -3.10, -0.19, p=0.027). Differences in MVPA were not significant (d=0.24, 95% CI: -35.53, 254.67, p=0.139). Changes in MVPA were mediated by self-efficacy, perceived capability, environment, social support, intentions and planning, some of which showed inconsistent mediation (suppression). None of the hypothesised psychosocial factors mediated sleep outcomes. Changes in sleep hygiene mediated changes in sleep quality.

Conclusions: Several psychosocial factors mediated changes in physical activity but not in sleep outcomes. Mediation effects of sleep hygiene on sleep quality highlight the importance of providing evidence-based strategies to improve sleep quality.

Keywords: Physical activity, sleep quality, sleep hygiene, psychosocial determinants, mediation analysis

Introduction

Reductions in the global incidence of non-communicable diseases (e.g., heart disease, type-2-diabetes, obesity) will rely on substantial improvements in multiple health behaviours (Institute of Medicine (US) Committee on Health and Behavior, 2001), including physical activity and sleep, in combination with supportive social, built, and policy environments. However, relative to single-behaviour approaches, fewer interventions have targeted multiple behaviours (Nigg & Long, 2012). The evidence shows there is potential for greater health improvements, if multiple behaviours are targeted together (James et al., 2016) and there are studies suggesting results may be more favourable if behaviours that share a synergistic relationship are combined in a single intervention (Buman et al., 2014; Lippke, Nigg, & Maddock, 2012).

Insufficient physical activity and poor sleep health are both highly prevalent in the adult population (Murawski et al., 2018). It appears they also share a reciprocal relationship (Kline, 2014; Rayward et al., 2018), whereby changes in one behaviour produce changes in the other and vice versa. Many interventions seek to foster behaviour change by enhancing processes of self-regulation. Both physical inactivity and poor sleep health can be improved, if evidence-based behaviour change techniques (BCT) are implemented to initiate or modify self-regulatory processes (Duff et al., 2017; Murawski, Wade, Plotnikoff, Lubans, & Duncan, 2018; Samdal, Eide, Barth, Williams, & Meland, 2017). Only very few studies have targeted physical inactivity and poor sleep health in combination, and none have used a delivery format with potential for wide reach (Murawski, Plotnikoff, et al., 2018). Consequently, there is relatively little knowledge of the factors that operate in an intervention combining these two behaviours. Testing mediators of intervention efficacy contributes essential knowledge on mechanisms of behaviour change and may help increase the effectiveness of behavioural interventions, that may then target factors that are known to drive changes in behaviour. This

knowledge is important, even in the absence of a statistically significant intervention effect (O'Rourke & MacKinnon, 2018), which as such may be explained by the examined mediating variables.

The evidence indicates that improvements in mediators specific to self-regulation (e.g., planning) are associated with larger increases in physical activity however, the evidence for other psychosocial mediators of physical activity (e.g., self-efficacy, outcome expectations) is mixed (R. E. Rhodes & Pfaeffli, 2010). In the context of sleep health, findings from studies that have examined psychosocial mediators of behaviour change are scarce, but studies have shown that improved sleep hygiene practices are linked to improved sleep quality (Buysse, 2014).

The Synergy Study employed a randomised waitlist-controlled design and targeted physical activity and sleep quality as co-primary outcomes in a three-month intervention using an m-health approach (Murawski, Plotnikoff, et al., 2018). The primary endpoint of the intervention was three months and the intervention consisted of a mobile app (Balanced) that promoted goal-setting, self-monitoring and utilization of feedback combined with educational resources, weekly summary reports and engagement prompts. Variables that are thought to change as a result of modified self-regulation were selected for examination in the current study, as the Synergy Study purposefully operationalised key constructs of the psychosocial theories (i.e., Social Cognitive Theory (Albert Bandura, 1998)) that guided the development of the intervention (Murawski, Plotnikoff, et al., 2018).

At three months, the intervention significantly improved sleep quality (d=0.48, 95% CI: -2.26, -0.33, p=0.009) and resulted in a higher proportion of participants reporting good quality sleep (OR=13.13, 95%CI=2.94, 58.64, p=0.001) (Murawski et al., 2019). Significant short-term improvements were also observed for sleep hygiene practices (d=0.40, 95% CI: -3.10, -0.19, p=0.027). There was no significant between-group difference for minutes of

77 moderate-and-vigorous intensity physical activity (MVPA; *d*=0.24, 95% CI: -35.53, 254.67,
78 *p*=0.139). The main study findings were published elsewhere (Murawski, Plotnikoff,
79 Rayward, et al., 2019). The primary aim of the current study was to examine potential
80 mediators of intervention effects in the Synergy Study on the outcomes of MVPA, sleep
81 quality and sleep hygiene.
82
83 **Materials and Methods**
84 ***Trial Registration, Ethics and Study Protocol***
85 The trial was prospectively registered with the Australia New Zealand Clinical Trials
86 Registry (ACTRN12617000376347) and the Human Research Ethics Committee of the
87 University of [removed for peer review] (H-2016-0181) granted ethical approval. The
88 methods, measures and operationalisation of intervention components are described in greater
89 detail in a protocol paper (Murawski, Plotnikoff, et al., 2018). Informed consent was obtained
90 from all individual participants included in the study.
91 ***Study Design***
92 The Synergy Study was a randomised waitlist-controlled trial with online assessments at
93 baseline, three months and six months. Participants were recruited nationwide through social
94 media (Facebook). Participant consent, eligibility screening, enrolment and baseline
95 assessments were completed between June and August 2017 via the online platform Qualtrics
96 (Provo, Utah). After completing baseline, participants were randomly allocated to either the
97 intervention or the waitlist group (n = 80 per group). Allowing for attrition of 25%, a sample
98 size of 160 was required to detect statistically significant group differences in the co-primary
99 outcomes (i.e., weekly minutes of MVPA and sleep quality) at the primary endpoint (three
100 months). This sample also provided adequate power (0.80) to detect small ($\beta = 0.14$)

mediation effects at the primary endpoint, using bias-corrected bootstrapped confidence intervals (Fritz & MacKinnon, 2007; Murawski, Plotnikoff, et al., 2018).

Participants

To take part in the study, participants had to live in Australia, be 18 to 55 years of age, and self-report insufficient physical activity (i.e., <90 min/week) and poor sleep quality (i.e., *fairly bad* or *very bad*). The flow of participants is illustrated in Figure 1 and lists reasons for exclusion. The study protocol provides additional details (Murawski, Plotnikoff, et al., 2018).

Intervention

The Synergy Study purposely targeted a range of psychosocial factors (e.g., self-efficacy, outcome expectations) that are known to explain behaviour (Stacey, James, Chapman, & Lubans, 2016) and operationalised those using evidence-based strategies, such as self-monitoring and action planning (see Table 1 for a detailed overview) (Michie, Abraham, Whittington, McAteer, & Gupta, 2009; Williams & French, 2011). The intervention was delivered through a mobile app (Balanced) featuring educational resources, personal goals, self-monitoring logs (manual data entry by the user) and feedback in relation to personal goals, all in relation to a range of physical activity and sleep health components (i.e., active minutes, step count, resistance training, sleep duration, sleep/wake timing, sleep quality, sleep hygiene); and the app was complemented by a 12-week support package including personalised weekly summary reports, tool sheets with useful instructions and prompts upon disengagement. All aspects of the intervention were delivered using the app, or via Email and text messages. Although the intervention highlighted the importance of personally meaningful and achievable goals, participants were encouraged to gradually work towards the amount of weekly physical activity recommended for adults (at least 150 minutes of moderate or 75 minutes of vigorous intensity physical activity, or an equivalent combination, and resistance training on 2 days/week) and seven to nine hours of sleep (Hirshkowitz et al.,

2015; The Department of Health, 2014). A comprehensive handbook with guidance on getting started, and a pedometer were sent to participants in the mail. All assessments were hosted via online survey on the Qualtrics platform (Provo, Utah).

Measures

Sociodemographic variables (e.g., age, gender, education, chronic disease status) were assessed at baseline as per protocol (Murawski, Plotnikoff, et al., 2018). Behavioural outcomes and hypothesised mediators were assessed at baseline, three and six months.

Although the active phase of the intervention (i.e., personalised support) ceased at three months, participants were able to continue to use the app beyond the 3-month time point. However, the current paper only examines potential mediation effects that occurred between baseline and the primary endpoint (3 months).

Behavioural outcomes. The Active Australia questionnaire (AAQ) was used to assess minutes of moderate-to-vigorous intensity physical activity (MVPA) (Australian Institute of Health and Welfare, 2003). This instrument measures the duration and frequency of walking, moderate and vigorous intensity physical activity. Weekly totals for minutes of MVPA were calculated according to standard scoring criteria (the sum of minutes of walking, moderate- and vigorous-intensity (weighted by two) physical activity) and was one of two co-primary outcomes in the Synergy Study. The AAQ has acceptable psychometric properties and can be used to assess behaviour change in interventions (Brown, Burton, Marshall, & Miller, 2008; Reeves, Marshall, Owen, Winkler, & Eakin, 2010).

Sleep quality was specified as the second co-primary outcome to examine intervention efficacy. Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI). The PSQI is a valid, reliable and commonly used self-report measure (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). It encompasses several indicators of sleep health (i.e., subjective

sleep quality, sleep onset latency, sleep duration, sleep efficiency, sleep disturbances, sleep medication use and daytime dysfunction) and also captures participants' perceptions of the restorative effects of sleep (Backhaus, Junghanns, Broocks, Riemann, & Hohagen, 2002; L. Q. Rogers et al., 2017). The seven component scores are summed to create a total score ranging from 0-21 with lower scores indicating better sleep quality.

Sleep quality is a multi-component concept (Buysse, 2014), inclusive of aspects that fluctuate daily and may not be under the direct control of the individual. However, a range of daytime (and bedtime) behaviours can be modified to promote good overall sleep quality. These behaviours are commonly referred to as sleep hygiene practices and encompass self-regulatory processes that can be consciously controlled by the individual (Irish, Kline, Gunn, Buysse, & Hall, 2015). Thirteen different practices that are thought to influence sleep quality (e.g., different bed- and wake-times, sleeping in an uncomfortable environment, consuming stimulating beverages close to bedtime) were assessed using the Sleep Hygiene Index, which is a valid and reliable measure that also positively correlates with the PSQI (Mastin, Bryson, & Corwyn, 2006). Higher total scores correspond to sleep hygiene practices that are less favourable for good sleep quality. Additionally, in line with the wording of items used to assess the psychosocial mediators of sleep (see Table 1), sleep hygiene was assessed as an additional behavioural variable in this study. It was treated as a secondary outcome variable for the testing of sleep-specific psychosocial factors and as a mediator variable in a model where sleep quality was the outcome.

Hypothesised mediators. Changes in psychosocial and behavioural factors were specified as potential mechanisms driving changes in the co-primary outcomes during the intervention. The eight psychosocial mediators assessed in the Synergy Study included self-efficacy, perceived behavioural capability, environment, social support, outcome expectations, outcome expectancies, intention and planning. Items to assess these constructs were based on

previously used items for physical activity and adapted for sleep. The development and psychometric qualities of the scales used to assess the psychosocial determinants of sleep hygiene are described elsewhere (Murawski, Plotnikoff, & Duncan, 2019; Murawski, Plotnikoff, et al., 2018).. Separate sum scores were calculated for each construct with higher scores indicating stronger dispositions toward the behaviour (e.g., stronger intentions). MVPA was a hypothesised mediator of change in sleep quality and vice versa to evaluate the bi-directionality of the relationship between these two behaviours (Kline, 2014); and sleep hygiene was a hypothesised mediator of sleep quality, because the evidence shows that sleep hygiene interventions effectively improve sleep health (Irish, et al., 2015).

Analyses

Analyses were conducted in SPSS 25 using PROCESS v2.16.3 following Preacher and Hayes' procedures for simple mediation using single mediator models (Hayes, 2013). Differences in sample characteristics (e.g., age, gender) and baseline values of the outcomes (e.g., physical activity, sleep quality) between completers and non-completers (lost to follow-up) were examined using t-tests for continuous data and chi-squared tests for categorical data.

Prior to testing for mediation, ANCOVAs were fitted to complete case data, with fixed effects for baseline-values of the outcome and group (intervention versus control), to test between-group differences (i.e., intervention effect) in physical activity and sleep quality. Alpha levels of 0.025 were set to test the intervention effect on both co-primary outcomes. A similar ANCOVA approach (e.g., adjusted for baseline values of the outcome) was used to assess changes in the secondary outcome of sleep hygiene using an alpha of 0.05.

The conceptual model to examine mediation is shown in Figure 2, corresponding to the PROCESS macro Model Four (Hayes, 2013). In each of the models, Path A coefficients (denoted by letter *a*) give a measure of the effect of the intervention on the hypothesised mediator variable, Path B coefficients (denoted by letter *b*) represent the association between

the mediator and outcome variables and Path C' coefficients (denoted by *c'*) are estimates of the direct effect of the intervention on the outcome variable, conditional on holding the mediator variable constant. Coefficients for the A*B Path (denoted by *a*b*) represent the indirect or mediated effect. Coefficients can be interpreted as change in the outcome variable (i.e., minutes of MVPA, sleep quality and sleep hygiene scores) for a one-unit increase in the mediating construct. Alpha levels were set to 0.05 for all tests of mediation.

Estimates were calculated using bias-corrected bootstrapping on 5,000 samples (95% CI), adjusted for baseline values of the outcome and mediator variables. Results are expressed as unstandardised, baseline-adjusted coefficients, and confidence intervals that do not include zero indicate statistically significant mediation (Preacher & Hayes, 2008). Missing values were imputed using expectation maximisation (EM) (Dempster, Laird, & Rubin, 1977). Little's test was used to confirm if the data were missing completely at random (MCAR) (Little, 1988). Consistent with intention-to-treat, and to maximise power, results of analyses using EM were favoured over using complete cases or baseline carried forward (results based on complete case data and baseline carried forward are supplied as supplemental material; Table S1).

Results

Participants (n = 160) were middle-aged (M 41.5, SD 9.93), predominantly female (80%), overweight or obese (68%), of Caucasian descent (91.3%) and married or in a relationship (58.1%). Large proportions of participants stated living in urban areas (70.0%) and worked primarily during daytime (83.1%). Two thirds (66.3%) had one or more diagnosed chronic diseases. The sample had average symptom severity scores, consistent with mild depression (M 11.9, SD 8.37), normal to mild anxiety (M 7.0, SD 6.38) and mild stress levels (M 15.3, SD 6.9). At baseline, 58.8% of participants were insufficiently physically active (<150

minutes MVPA/week, and 95.6% reported poor quality sleep (PSQI total score >5). Sample characteristics including baseline values of proposed mediators are presented in Table 2.

Data from 125 participants were available from online surveys at the three-month endpoint (Figure 1), with 22% of missing data requiring imputation for intention-to-treat analyses. Data were missing completely at random ($\chi 2 = 53.27$, DF = 43, $p = 0.136$). The difference in number of withdrawals per group was not statistically significant ($p = 0.181$), however those who did not provide follow-up data tended to be more severely depressed ($p = 0.035$) and reported lower mental health-related quality of life ($p = 0.012$). Mean values for mediators and outcomes, based on complete case data, baseline carried forward and expectation maximisation (intention-to-treat) are presented as supplemental material (Table S2).

Mediators of physical activity

Effect of the intervention on physical activity (C' Path)

An adjusted between-group difference of 109 minutes was found in favour of the intervention group, but this difference was not statistically significant (Cohen's $d = 0.24$, 95% CI: -35.53, 254.67, $p = 0.139$). Analyses of direct effects of the intervention on physical activity adjusted for mediators (C' path) were also non-significant for all models, except for the model including self-efficacy as the mediator (Table 3), where, conditional on holding self-efficacy constant, the C' path coefficient showed a statistically significant effect (c = 103.24, $p = 0.019$).

Effect of the intervention on hypothesised mediators of physical activity (A Path)

Coefficients for direct baseline-adjusted effects of the intervention on hypothesised mediators (A Path) are reported in Table 3. Statistically significant inverse effects were observed for self-efficacy ($a = -3.04$, $p = 0.010$), outcome expectancies ($a = -0.60$, $p = 0.034$),

environment (a = -1.25, $p < 0.001$) and social support (a = -1.04, p = 0.033), all of which showed weakening psychosocial dispositions toward physical activity.

Effect of the hypothesised mediators on physical activity (B Path)

B path coefficients represent associations between changes in mediators and changes in the behavioural outcome (i.e., MVPA). The mediators for which there were statistically significant positive associations with physical activity included self-efficacy (b = 14.55; $p < 0.001$), perceived capability to be physically active (b = 39.57, $p < 0.001$), environment (b = 22.91, p = 0.049) and social support (b = 23.75, p = 0.002). A one-unit increase in intention was associated with an additional 64.67 minutes of MVPA per week ($p < 0.001$), and a one-unit increase in scores for plans to be physically active was associated with an additional 9.44 minutes per week (p = 0.008).

*Significance of the mediated effect on physical activity (A*B Path)*

The mediated effect is the product of coefficients from the A and B paths. Coefficients are shown in Table 3. Statistically significant effects were observed for self-efficacy, which accounted for 22% of the effect of the intervention on changes in weekly minutes of MVPA ($a*b$ [95% CI] -44.23 [-94.21 to -13.37]) and for perceived capability ($a*b$ [95% CI] -27.47 [-73.88 to -2.43]), environment ($a*b$ [95% CI] -28.57 [-69.42 to -5.84]), social support ($a*b$ [95% CI] -24.66 [-71.98 to -2.51]), intention ($a*b$ [95% CI] 25.38 [1.83 to 63.92]) and planning ($a*b$ [95% CI] 18.80 [2.14 to 54.07]), which explained between 11 and 19% of the variance explained by the mediators. Opposite signs for C' and A*B path coefficients indicate inconsistent mediation,(Tzelgov & Henik, 1991) which occurred for all MVPA-specific psychosocial factors, except for intention and planning, where greater intention and planning as a result of the intervention resulted in more physical activity.

Mediators of sleep quality

Effect of the intervention on sleep quality (C' Path)

There was a statistically significant effect on sleep quality, with greater improvements in sleep quality reported in the intervention group, relative to waitlist-controls (d = 0.48, 95% CI: -2.26, -0.33, p = 0.009).

Effect of the intervention on hypothesised mediators of sleep quality (A Path)

None of the hypothesised psychosocial mediators changed significantly as a result of the intervention (all $p > 0.05$). Statistically significant effects were found for sleep hygiene scores (a = -2.26, p = 0.002), indicating that the intervention improved sleep hygiene practices (higher scores indicate poorer sleep hygiene practices).

Effect of the hypothesised mediators on sleep quality (B Path)

Changes in perceived capability were negatively associated with changes in PSQI scores, showing that for each one-unit increase in perceived capability, there was a 0.10-point decrement in PSQI scores (p = 0.030), indicating improved sleep quality. An increase in outcome expectations, however, was significantly associated with higher PSQI scores (0.06 points, p = 0.029), thus a reduction in sleep quality. Further, there was a significant positive relationship between sleep hygiene and sleep quality in the expected direction, such that better sleep hygiene scores were associated with better sleep quality, both indicated by lower scores (b = 0.11, p = 0.020).

*Significance of the mediated effect on sleep quality (A*B Path)*

All the boot-strapped confidence intervals for tests of the mediated effect (A*B paths) included zero, indicating none of the psychosocial mediators had a statistically significant effect. However, sleep hygiene mediated the effect of the intervention on sleep quality ($a*b$ [95% CI] -0.24 [-0.58 to -0.05]), with 37% of the changes in sleep quality explained by changes in sleep hygiene.

Mediators of sleep hygiene

Effect of the intervention on sleep hygiene (C' Path)

The intervention had a statistically significant effect on sleep hygiene in favour of the intervention group (d = 0.40, 95% CI: -3.10, -0.19, p = 0.027).

Effect of the intervention on hypothesised mediators of sleep hygiene (A Path)

There was no significant relationship between the intervention and any of the sleep-specific psychosocial mediators.

Effect of the hypothesised mediators on sleep hygiene (B Path)

There was a statistically significant inverse relationship between changes in participants' perceived capability to keep good sleep hygiene and changes in actual sleep hygiene practices, with stronger perceptions being associated with better sleep hygiene practices (b = -0.24, p = 0.003).

Significance of the mediated effect on sleep hygiene (A*B Path). None of the intervention effects on sleep hygiene were mediated by any of the hypothesised psychosocial factors.

Discussion

The Synergy Study aimed to simultaneously improve physical activity and sleep quality in a sample of Australian adults. The study demonstrated significant group differences for sleep quality and sleep hygiene practices after three months in favour of the intervention. There was a statistically non-significant, yet meaningful (Wen et al., 2011) between-group difference in physical activity at the primary endpoint, as both groups had almost doubled their weekly total of minutes of moderate-to-vigorous intensity physical activity (MVPA).

Despite the absence of significant between-group differences in MVPA at three months, significant mediation effects were observed for six of the nine hypothesised psychosocial mediators (i.e., self-efficacy, perceived capability, environment, social support, intention, and

planning). However, inconsistent mediation effects were observed for self-efficacy, behavioural capability, environment and social support. This is substantiated by the direct effect (*c'*) and the mediated effect (*a*b*) having significant associations, but in opposite directions (MacKinnon, Krull, & Lockwood, 2000). An inconsistent mediation effect, which is also referred to as a *suppression* effect occurs if a counter-intuitive change is observed for a given mediator variable (e.g., self-efficacy), where the initial study aim was to strengthen such factors through the strategies provided. Existing evidence shows that stronger dispositions (e.g., higher levels of self-efficacy) lead to better intervention outcomes (e.g., more physical activity) (MacKinnon, Fairchild, & Fritz, 2007). Contrary to this, in the current study, there was improvement in actual behaviour (i.e., physical activity) albeit a reduction or weakening in some of the psychosocial dispositions toward physical activity. This has been previously observed for several of the proposed mediators (e.g., self-efficacy, outcome expectations) (Haerens, Cerin, Deforche, Maes, & De Bourdeaudhuij, 2007; Haerens et al., 2008; Hallam & Petosa, 2004). To some extent, the observed suppression effects could have been due to different mechanisms operating together in a complex pattern, or other unmeasured factors having had a stronger impact on actual behaviour. A systematic review of behaviour change interventions that targeted self-efficacy showed that an increase in physical activity despite reductions in self-efficacy, is not uncommon (Olander et al., 2013). This can be explained by changes in the way participants self-evaluate themselves throughout the process of receiving an intervention, which is consistent with Response Shift Theory (Sprangers & Schwartz, 1999). For example, it is possible that participants felt highly confident about imminent behavioural changes at the study outset and had high expectations of the support offered. Following three months of continuous goal-setting, self-monitoring and goal review based on feedback, participants may have developed a much more realistic view of their expectations and personal barriers to behaviour change (i.e., being sufficiently

physically active on a regular basis) (Lewis, Marcus, Pate, & Dunn, 2002; Vallance, Courneya, Plotnikoff, & Mackey, 2008).

Mediation effects without suppression were found for participants' intentions and plans to be physically active, both of which were improved by the intervention and also explained a proportion of the effect the intervention had on changes in physical activity. This may indicate that that the intention-behaviour gap, which is commonly reported in the behaviour change literature may have been minimised by the use of planning strategies (Papies, 2017; Prestwich & Kellar, 2014). Moreover, it is possible that participants felt an increased sense of being held accountable for progress toward goals (partially through targeted strategies such as use of prompts), which may have encouraged them to develop and adhere to action-oriented plans that favour physical activity. These plans may have helped participants to overcome setbacks and impediments to achieve behavioural goals (A. Bandura, 2004; Papies, 2017). This finding suggests that, while it is important to offer participants strategies to enhance their personal capacities to be physically active, it is also important to target intentions and action planning strategies as these have been associated with significant behaviour change (Adriaanse, Vinkers, De Ridder, Hox, & De Wit, 2011; Papies, 2017).

The findings from this study showed significant improvements in sleep quality and sleep hygiene practices in favour of the intervention, indicated by significant group-differences at 3 months. Analyses revealed that sleep hygiene mediated changes in sleep quality. This is consistent with the evidence, as sleep hygiene interventions are known to improve sleep health [40]. However, there was no support for the hypothesis that psychosocial factors specific to sleep hygiene behaviours act as mechanisms (mediators) of behaviour change, neither for an outcome that is somewhat distal (sleep quality), nor one that is more proximal (sleep hygiene) to behavioural self-regulation. (Irish, et al., 2015). It is possible that, although the intervention significantly improved sleep hygiene practices by providing clear examples

of how to implement changes, the psychosocial scales did not capture changes in underlying factors that are thought to be related to changes in these practices, such as person's self-efficacy in keeping bed and wake times consistent. While the measures may need to be refined to better capture underlying constructs, several scales (e.g., social support, outcome expectations) had ceiling effects, limiting the ability to assess mediation.

Based on the behavioural mediation paths examined in this study, there was no evidence of a bi-directional relationship between MVPA and sleep quality. A plausible reason for this could be the composite nature of the PSQI score, which was used to assess changes in sleep quality and is made up of multiple indicators of sleep health (Buysse, et al., 1989). A study that investigated the bi-directional associations between physical activity and different indicators of sleep health found that the quality of sleep (but not the duration) had a bi-directional relationship with physical activity (Rayward, et al., 2018). There is additional evidence from a meta-analysis, which found that effects of physical activity on different indicators of sleep health vary depending on the component of sleep that is assessed, with only small effects shown for sleep duration, and large effects for sleep quality (Kredlow, Capozzoli, Hearon, Calkins, & Otto, 2015). Thus, the testing of physical activity as a mediator in the context of individual PSQI composites may have resulted in different findings, however this was beyond the scope of the current paper.

This study also sought to shed light on whether the way the hypothesised mechanisms of behaviour change operate is behaviour-specific. There was no evidence that the same mechanisms have significant mediation effects across different behavioural (PA, sleep) outcomes. The absence of mediation effects at the psychosocial level, however, was consistent for both sleep outcomes. Nonetheless, the findings from this study underpin the important role of intentions and action planning to change physical activity and conceptually

399 align with psychosocial determinants theories (Fishbein, 2008), which place intentions and
400 plans within closer proximity to behaviour (outcome), relative to factors such as self-efficacy.
401 ***Strengths and Limitations***
402 To the authors' knowledge, this was the first study to examine a comprehensive set of
403 psychosocial and behavioural mediators in an intervention that targeted physical activity and
404 sleep simultaneously. Furthermore, it appears no previous studies have aimed to evaluate
405 intervention efficacy in a sleep intervention conducted in a population group without
406 diagnosed sleep conditions. This is important given the high prevalence of subclinical sleep
407 problems in the general adult population (Adams et al., 2017). Few studies have examined
408 psychosocial mediators of behaviour change in multi-behaviour interventions and the results
409 of this study provide initial evidence for mediators of behaviour change in m-health
410 interventions. Future studies with larger sample sizes are needed to examine multiple
411 mediators to account for the complexity and interactive nature of behaviour change
412 mechanisms.
413 There also were some limitations to the current study. Although the scales used in this
414 study have acceptable psychometric qualities (Murawski, Plotnikoff, & Duncan, 2019), they
415 have never before been used in an intervention context. The sample size (n = 160) may have
416 limited the power to detect mediation effects of small magnitude (MacKinnon, et al., 2007).
417 In addition, the use of self-report measures to assess mediating variables as well as outcomes
418 may have introduced bias due to limited recall accuracy and social desirability. Moreover,
419 the lack of effects on the hypothesised mediators of sleep hygiene (A path) may indicate
420 these measures were insufficiently sensitive to change (see Table 3). It is important to note
421 that the hypothesised mediators and outcomes were examined at the same time point, which
422 is common in mediation analyses. To allow for temporal sequencing, post-test mediator
423 assessments should take place before the post-test outcome assessments. Potential effect

moderators such as anxiety, depression or stress may have had some impact on changes in behaviour, which the analyses in this study did not account for due to lack of power for moderated mediation. Although app usage was monitored continuously and prompted in regular intervals for each participant, the extent to which participants used intervention components other than the app (e.g., pedometer, handbook, tool sheets) was not measured and may have had an influence on the intensity of exposure to the various behaviour change techniques. This may have limited the magnitude of change in participants' psychosocial disposition. It is important for future studies to assess participants' exposure to any strategies that are hypothesised to bring about changes in the mediators of interest. Future research may also examine what magnitude of change of psychosocial determinants is required to bring about meaningful changes in behaviour and which strategies are most useful in achieving this (i.e., through moderated mediation).

Conclusions

Several psychosocial mediators were identified for the outcome of MVPA, but none for sleep quality or sleep hygiene. Changes in sleep hygiene however, mediated changes in sleep quality, which supports the need for concise instructions and guidance for participants to be able to implement recommended practices. Additional studies are needed to further develop the evidence base for mechanisms of behaviour change in multi-behaviour interventions using an m-health approach.

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Declaration of Interest Statement

The authors declare no conflicts of interest.

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671 **Tables**
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Table 1.
Overview of intervention strategies (BCT), intervention components, and scale properties.

SELF-EFFICACY

Intervention components		**BCT**
In-app logs	Allowed entries for active minutes, daily steps, resistance training sessions, sleep and wake times, a sleep quality rating, as well as a checklist of 10 sleep hygiene goals.	▪ Self-monitoring
In-app progress charts	Provided a history with daily, weekly, and 3-month progress in relation to goals per behaviour.	▪ Goal review ▪ Feedback on performance
In-app dashboard traffic light	Produced feedback relating to goals based on total active minutes and total sleep duration.	▪ Goal review ▪ Feedback on performance ▪ Praise/rewards
Weekly summary reports (Email)	Provided weekly totals and averages by behaviour and prompted goal review, if needed.	▪ Graded tasks ▪ Goal review ▪ Feedback on performance ▪ Praise/rewards ▪ Relapse prevention/coping
SMS Prompts	Encouraged participants to resume logging (if no data were logged on >4 days/week).	▪ Feedback on performance ▪ Relapse prevention/coping ▪ Barrier identification/ problem solving

Scale properties	**PA-related self-efficacy**	**Sleep-related self-efficacy**
Item total (source)	10 items (Plotnikoff, Lippke, Courneya, Birkett, & Sigal, 2008)	9 items (Schwarzer & Luszczynska, 2015)
Example item	'I am confident that I can participate in regular physical activity when I am a little tired.'	'I am confident that I can avoid alcohol right before bedtime.'
Response options	*Not at all confident* (0) to *extremely confident* (4)	*Not at all confident* (0) to *extremely confident* (4)
Total score range	0–40	0–40
Scale reliability	0.90	0.76

BEHAVIOURAL CAPABILITY

Intervention components		**BCT**
In-app resources	Included current national guidelines on how much physical activity/week and how much sleep/night adults need as well as brief content on the when, the where, who with, and how of being active and sleeping well (e.g., sleep hygiene practices).	▪ Information on where and when to be active/engage in sleep promoting behaviours ▪ Instructions on how to be active and engage in sleep promoting behaviours
Weekly fact SMS	Short weekly text messages with educational content related to activity and/or sleep, and health to reinforce the importance of both behaviours.	▪ Information on where and when to be active/engage in sleep promoting behaviours ▪ Instructions on how to be active and engage in sleep promoting behaviours

Tool sheets (Email)	Promoted goal-setting, action planning, and stress management strategies (delivered in weeks 3, 6, 9).	▪ Instructions on how to be active and engage in sleep promoting behaviours ▪ Goal-setting ▪ Action planning ▪ Stress management ▪ Time management ▪ Barrier identification

Scale properties	**PA-related behavioural capability**	**Sleep-related behavioural capability**
Item total (source)	3 items (L.Q. Rogers, Humphries, Davis, & Gutin, 1998)	9 items (Dewar, Lubans, Morgan, & Plotnikoff, 2013; Dewar, Lubans, Plotnikoff, & Morgan, 2012)
Example item	'I can run or jog for 10 minutes without stopping.'	'Whenever I have the opportunity to use technological devices right before bedtime or in bed, I know how to avoid or remove them.'
Response options	*Never* (0) to *always* (4)	*Never* (0) to *always* (4)
Total score range	0–40	0–40
Scale reliability	0.70	0.77

OUTCOME EXPECTATIONS

Intervention components		**BCT**
Tool sheets (Email)	On the goal-setting tool sheet, participants were asked to think about the reasons for wishing to improve their health behaviours and what they anticipate as personal benefits from improved levels of activity and sleep (examples were provided).	▪ Information about the behaviour in relation to health.
In-app resources	This section included information on how physical activity and sleep contribute to health and well-being.	▪ Information about the behaviour in relation to health.

Scale proporties	**PA-related outcome expectations**	**Sleep-related outcome expectations**
Item total (source)	5 items (Dewar, et al., 2013; Dewar, et al., 2012)	9 items (Plotnikoff, et al., 2008)
Example item	'Being physically active can reduce my risk for some illnesses and diseases (e.g., heart disease, diabetes, some cancers, etc.)'	'For me, keeping consistent sleep and wake times would help me sleep better.'
Response options	*Strongly disagree* (0) to *strongly agree* (6)	*Strongly disagree* (0) to *strongly agree* (6)
Total score range	0–30	0–54
Scale reliability	0.92	0.84

OUTCOME EXPECTANCIES

Intervention components		**BCT**
Tool sheets (Email)	On the goal-setting tool sheet, participants were asked to think about the reasons for wishing to improve their health behaviours and why this is important.	▪ Information about the behaviour in relation to health.
In-app resources	This section included information on why physical activity and sleep are important.	▪ Information about the behaviour in relation to health.

Scale properties	PA-related outcome expectancies	Sleep-related outcome expectancies
Item total (source)	5 items (Dewar, et al., 2013; Dewar, et al., 2012)	9 items (Dewar, et al., 2013; Dewar, et al., 2012)
Example item	'To you, how important is reducing your risk for illness and disease?'	'To you, how important is keeping sleep and wake times consistent to sleep well?'
Response options	*Not at all important* (0) to *extremely important* (3)	*Not at all important* (0) to *extremely important* (3)
Total score range	0–15	0–27
Scale reliability	0.79	0.82

SOCIAL SUPPORT

Intervention components		BCT
Tool sheets (Email)	Included short examples on how to identify and manage barriers to being active and getting good sleep and how to use one's social support in favour of activity and sleep.	▪ Barrier identification ▪ Problem solving
In-app resources	Encouraged participants to utilise their social support to be physically active (e.g., finding an exercise buddy).	▪ Plan social support

Scale properties	PA-related social support	Sleep-related social support
Item total (source)	2 items (Liebreich, Plotnikoff, Courneya, & Boule, 2009)	9 items (Kor & Mullan, 2011; Ryan E. Rhodes, Hunt Matheson, & Mark, 2010)
Example item	'People in my social network are likely to help me participate in regular physical activity.'	'Most people who are important to me would encourage me to (e.g., reduce my stress levels).'
Response options	*Strongly disagree* (0) to *strongly agree* (4)	*Strongly disagree* (0) to *strongly agree* (4)
Total score range	0–8	0–36
Scale reliability	0.89	0.86

ENVIRONMENT

Intervention components		
Tool sheets (Email)	Included short examples on how to identify and manage barriers to being active and getting good sleep, and how to use one's environment in favour of activity and sleep.	▪ Environmental restructuring ▪ Barrier identification ▪ Problem solving
In-app resources	Encouraged participants to modify their environment to promote good sleep (e.g., bedroom temperature).	▪ Environmental restructuring ▪ Use of prompts

Scale properties	PA-related environment	Sleep-related environment
Item total (source)	3 items (Alexander, Bergman, Hagströmer, & Sjöström, 2006)	4 items (Hale, Hill, & Burdette, 2010)
Example item	There are sidewalks on most of the streets in my local area.'	'My neighborhood is noisy'
Response options	*Strongly disagree* (0) to *strongly agree* (4)	*Strongly disagree* (0) to *strongly agree* (4)

Total score range	0–12	0–4
Scale reliability	0.56	0.82

INTENTIONS

Intervention components		**BCT**
In-app goal-setting	Participants were asked to personalise their goals, but work towards recommended minima of physical activity and sleep duration (150 MVPA/week; 7-9h sleep/night); goals were carried forward from previous days, unless adjusted.	▪ Goal-setting ▪ Goal review ▪ Graded tasks
In-app dashboard traffic light	Participants were encouraged to put equal effort into improving both PA and sleep (i.e., two amber lights were better than one green and one red light).	▪ Teach use of prompts ▪ Self-monitoring
Tool sheets (Email)	Participants received goal-setting strategies for guidance (per behaviour). Examples were provided.	▪ Goal-setting ▪ Goal review ▪ Prompt practice

Scale properties	**PA-related intentions**	**Sleep-related intentions**
Item total (source)	1 item (Dewar, et al., 2013; Dewar, et al., 2012)	9 items (Dewar, et al., 2013; Dewar, et al., 2012; Kor & Mullan, 2011)
Example item	'Do you intend to do regular physical activity over the next three months?'	'I intend to avoid using technological devices, especially right before bedtime or in bed.'
Response options	*No, not really* (0) to *strongly intend* (6)	*No, not really* (0) to *strongly intend* (6)
Total score range	0–6	0–59
Scale reliability	N/A	0.85

PLANNING

Intervention components		**BCT**
Tool sheets (Email)	Participants received action planning strategies for guidance (per behaviour). Examples were provided.	▪ Action planning ▪ Time management ▪ Barrier identification ▪ Problem solving

Scale properties	**PA-related planning**	**Sleep-related planning**
Item total (source)	4 items (Trinh, Plotnikoff, Rhodes, North, & Courneya, 2012)	9 items (Trinh, et al., 2012)
Example item	'I have made plans concerning how I am going to get to a place to engage in regular physical activity.'	'I have planned where, when and how to avoid caffeine.'
Response options	*No detailed plans* (0) to *detailed plans* (6)	*No detailed plans* (0) to *detailed plans* (6)
Total score range	0–24	0–54
Scale reliability	0.96	0.92

Note. The scales' internal consistency was assessed using Cronbach's alphas (Green, 2003). Values of 0.8 to 0.9 indicate good internal consistency and values greater than 0.9 are considered excellent (Cronbach, 1951).

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Table 2.
Baseline sociodemographic, health, behavioural and psychosocial characteristics

	Intervention (n = 80)	Waitlist (n = 80)
Age M (SD)	41.1 (9.84)	41.9 (10.07)
Gender n (%)		
Male	14 (17.50)	18 (22.50)
Female	66 (82.50)	62 (77.50)
Body Mass Index (kg/m^2) M (SD)	28.7 (4.64)	27.2 (4.01)
Chronic disease status n (%)		
None	26 (32.50)	28 (35.00)
One or more	54 (67.50)	52 (65.00)
Symptom severity		
Depression[a]	11.3 (7.87)	12.6 (8.84)
Anxiety[b]	6.9 (5.94)	7.1 (6.83)
Stress[c]	15.3 (6.02)	15.4 (7.46)
Physical activity M (SD)		
MVPA minutes/week	164.0 (165.45)	191.3 (244.12)
RT days/week	0.4 (0.92)	0.1 (0.52)
RT minutes/week	8.3 (23.64)	1.9 (7.81)
Sleep quality M (SD)[d]	9.2 (3.07)	9.2 (2.86)
Sleep hygiene[e] M (SD)	32.3 (6.72)	32.4 (6.63)
Psychosocial mediators PA M (SD)[f]		
Barrier self-efficacy	18.5 (7.42)	17.9 (7.36)
Behavioural capability	7.1 (2.66)	6.4 (2.78)
Outcome expectations	18.1 (3.67)	17.5 (4.74)
Outcome expectancies	13.0 (2.27)	13.2 (2.18)
Environment[g]	9.0 (2.58)	8.4 (2.49)
Social support	7.2 (4.03)	6.7 (3.50)
Intention	4.4 (1.60)	4.3 (1.36)
Planning	10.0 (7.79)	9.9 (7.42)
Psychosocial mediators Sleep M (SD)[f]		
Self-efficacy	25.0 (5.75)	23.8 (5.17)
Behavioural capability	26.4 (5.20)	24.9 (5.52)
Outcome expectations	39.9 (10.67)	42.1 (9.02)
Outcome expectancies	20.3 (5.08)	20.6 (4.89)
Environment	3.0 (0.73)	2.9 (0.72)
Social support	27.1 (5.78)	26.7 (6.67)
Intention	45.2 (8.34)	44.4 (7.65)
Planning	27.0 (16.07)	27.4 (16.06)

Note. [a] depression scores range from 0-9 (normal), 10-13 (mild), 14-20 (moderate), 21-27 (severe), 29+ (extremely severe); [b] anxiety scores range from 0-7 (normal), 8-9 (mild), 10-14 (moderate), 15-19 (severe), 20+ (extremely severe); [c] stress scores range from 0-14 (normal), 15-18 (mild), 19-25 (moderate), 26-33 (severe), 34+ (extremely severe); [d] scores range from 0-21 (scores >5 indicate poor quality sleep); [e] scores range from 13-65 (lower scores indicate better sleep hygiene); [f] higher scores indicate stronger psychosocial dispositions towards behaviour.

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Table 3.

Results from simple mediation testing psychosocial and behavioural mediators of changes in physical activity, sleep quality and sleep hygiene.

	A path (X on M)		**B path (M on Y)**		**C' path (X on Y[a])**		**A*B (Mediated effect)**		
	a (SE)	***p***	**b (SE)**	***p***	**c' (SE)**	***p***	**ab (SE)**	**95% CI**	**R^2**
DV = Physical activity									
Self-efficacy	-3.04 (1.16)	**0.010**	14.55 (2.95)	**<0.001**	103.24 (43.66)	**0.019**	-44.23 (20.28)	**-94.21 to -13.37**	0.22
Behavioural capability	-0.69 (0.36)	0.056	39.57 (9.81)	**<0.001**	77.77 (44.72)	0.084	-27.47 (17.24)	**-73.88 to -2.43**	0.19
Outcome expectations	-1.00 (0.58)	0.083	12.12 (6.39)	0.060	72.91 (46.39)	0.118	-12.17 (9.04)	-35.82 to 0.55	0.11
Outcome expectancies	-0.60 (0.28)	**0.034**	21.39 (13.06)	0.104	77.89 (46.57)	0.097	-12.87 (12.64)	-50.70 to 1.74	0.11
Environment	-1.25 (.32)	**<0.001**	22.91 (11.53)	**0.049**	92.22 (48.28)	0.058	-28.57 (15.46)	**-69.42 to -5.84**	0.11
Social support	-1.04 (0.48)	**0.033**	23.75 (7.46)	**0.002**	87.85 (45.71)	0.057	-24.66 (16.51)	**-71.98 to -2.51**	0.14
Intention	0.39 (0.20)	0.052	64.67 (17.70)	**<0.001**	34.40 (44.82)	0.444	25.38 (15.81)	**1.83 to 63.92**	0.17
Planning	1.99 (1.04)	0.056	9.44 (3.51)	**0.008**	43.70 (45.88)	0.342	18.80 (12.29)	**2.14 to 54.07**	0.13
Sleep quality	-1.35 (0.40)	**0.001**	-7.61 (9.17)	0.408	52.19 (47.91)	0.278	10.25 (13.26)	-12.89 to 40.83	0.09
DV = Sleep quality									
Self-efficacy	-0.48 (0.66)	0.472	-0.04 (0.05)	0.396	-1.25 (0.40)	**0.002**	0.02 (0.06)	-0.04 to 0.22	0.36
Behavioural capability	-0.71 (0.71)	0.322	-0.10 (0.04)	**0.030**	-1.26 (0.40)	**0.002**	0.07 (0.10)	-0.04 to 0.36	0.38
Outcome expectations	-1.24 (1.22)	0.313	0.06 (0.03)	**0.029**	-1.22 (0.40)	**0.003**	-0.07 (0.09)	-0.34 to 0.04	0.36
Outcome expectancies	-0.03 (0.61)	0.959	0.05 (0.05)	0.329	-1.30 (0.40)	**0.002**	0.00 (0.05)	-0.12 to 0.08	0.36
Environment	0.02 (0.07)	0.758	-0.23 (0.44)	0.607	-1.31 (0.41)	**0.002**	-0.01 (0.04)	-0.13 to 0.05	0.34
Social support	-0.79 (0.91)	0.386	0.05 (0.04)	0.138	-1.31 (0.40)	**0.001**	-0.04 (0.07)	-0.27 to 0.04	0.37
Intention	0.58 (1.27)	0.650	0.02 (0.03)	0.515	-1.32 (0.41)	**0.001**	0.01 (0.05)	-0.04 to 0.17	0.34

Planning	0.21 (1.97)	0.916	-0.01 (0.02)	0.524	-1.31 (0.40)	**0.001**	0.00 (0.05)	-0.14 to 0.07	0.35
Physical activity	62.44 (46.24)	0.179	-0.001 (0.001)	0.408	-1.31 (0.41)	**0.002**	-0.04 (0.06)	-0.23 to 0.04	0.35
Sleep hygiene	-2.26 (0.71)	**0.002**	0.11 (0.04)	**0.020**	-1.08 (0.41)	**0.009**	-0.24 (0.13)	**-0.58 to -0.05**	0.37
DV = Sleep hygiene									
Self-efficacy	-0.47 (0.66)	0.477	-0.14 (0.09)	0.104	-2.25 (0.71)	**0.002**	0.07 (0.14)	-0.10 to 0.55	0.42
Behavioural capability	-0.68 (0.71)	0.341	-0.24 (0.08)	**0.003**	-2.37 (0.70)	**0.001**	0.16 (0.19)	-0.13 to 0.66	0.44
Outcome expectations	-1.24 (1.23)	0.314	-0.03 (0.05)	0.517	-2.32 (0.72)	**0.002**	0.04 (0.10)	-0.06 to 0.39	0.41
Outcome expectancies	-0.04 (0.61)	0.951	-0.04 (0.09)	0.640	-2.30 (0.71)	**0.001**	0.00 (0.07)	-0.12 to 0.18	0.42
Environment	0.02 (0.07)	0.754	-0.85 (0.78)	0.276	-2.19 (0.71)	**0.003**	-0.02 (0.09)	-0.35 to 0.08	0.41
Social support	-0.79 (0.90)	0.385	-0.06 (0.06)	0.304	-2.27 (0.70)	**0.002**	0.05 (0.10)	-0.06 to 0.41	0.42
Intention	0.57 (1.27)	0.652	-0.02 (0.04)	0.651	-2.21 (0.71)	**0.002**	-0.01 (0.07)	-0.21 to 0.08	0.41
Planning	0.21 (1.97)	0.913	-0.02 (0.03)	0.471	-2.25 (0.71)	**0.002**	0.00 (0.08)	-0.21 to 0.13	0.41

Note. [a] the effect of the intervention on given outcome holding the mediator variable constant; X = Independent variable (Intervention); M = Mediator variable; Y = Dependent variable (Outcome); SE = Standard error; CI = Confidence interval; ($100*R^2$) = percent variance explained; numbers in bold font indicate a statistically significant effect.

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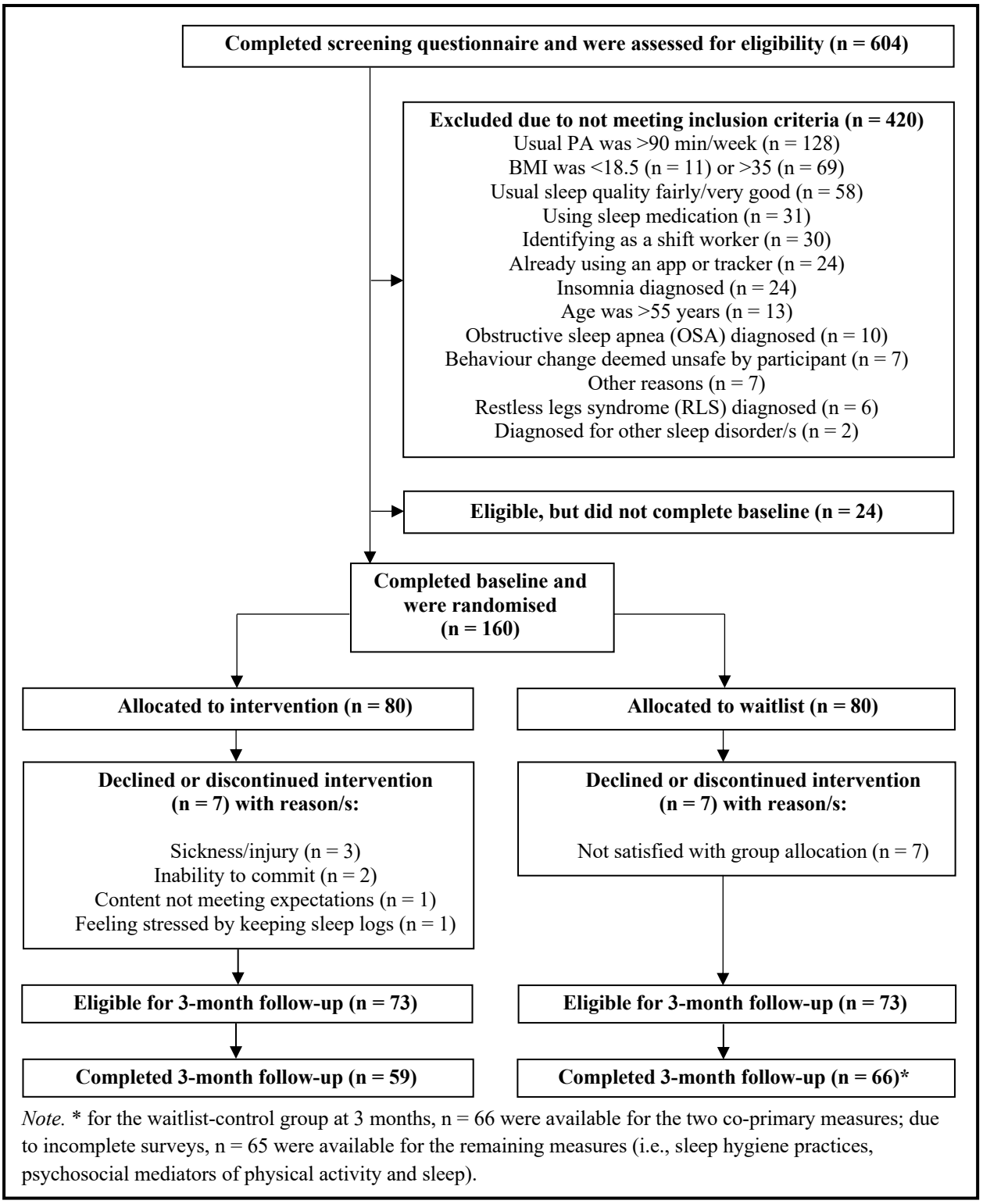
Figures



Note. * for the waitlist-control group at 3 months, n = 66 were available for the two co-primary measures; due to incomplete surveys, n = 65 were available for the remaining measures (i.e., sleep hygiene practices, psychosocial mediators of physical activity and sleep).

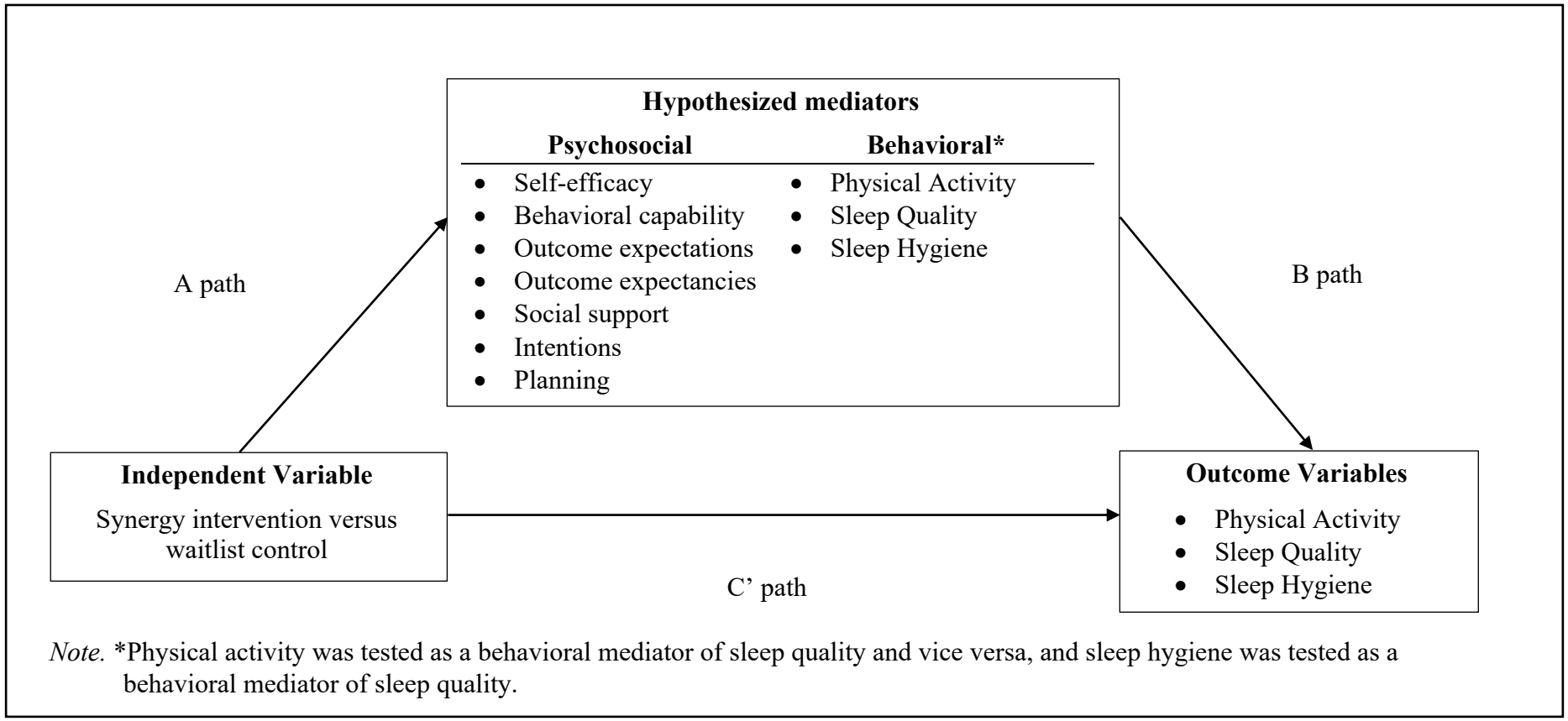


Figure 2. Overview of variables tested in simple mediation models using single mediators.

Table S1.
Results from mediation analyses based on complete cases (CC), baseline carried forward (BCF) and expectation maximization (EM).

DV = Physical activity		**A path (IV on MV)**		**B path (MV on DV)**		**C' path (IV on DV)**		**A*B (Mediated effect)**		
Psychosocial mediators		**a (SE)**	***p***	**b (SE)**	***p***	**c' (SE)**	***p***	**ab (SE)**	**95% CI**	**R^2**
Barrier self-efficacy	CC	-2.92 (1.46)	**0.048**	14.20 (3.45)	**<0.001**	108.14 (56.04)	0.056	-41.39 (23.72)	**-98.36 to -3.04**	0.23
	BCF	-2.04 (1.17)	**0.084**	10.67 (3.12)	**<0.001**	58.58 (46.11)	0.206	-21.71 (13.84)	**-57.16 to -0.21**	0.21
	EM	-3.04 (1.16)	**0.010**	14.55 (2.95)	**<0.001**	103.24 (43.66)	**0.019**	-44.23 (20.28)	**-94.21 to -13.37**	0.22
Perceived capability	CC	-0.67 (0.45)	0.139	38.86 (11.62)	**0.001**	84.09 (57.52)	0.146	-25.88 (20.76)	-82.05 to 3.30	0.19
	BCF	-0.45 (0.36)	0.221	28.84 (10.32)	**0.006**	41.77 (46.98)	0.375	-12.86 (12.37)	-46.14 to 4.17	0.18
	EM	-0.69 (0.36)	0.056	39.57 (9.81)	**<0.001**	77.77 (44.72)	0.084	-27.47 (17.24)	**-73.88 to -2.43**	0.19
Outcome expectations	CC	-1.08 (0.73)	0.146	11.79 (7.36)	0.112	79.97 (59.77)	0.183	-12.69 (10.97)	-42.84 to 2.79	0.12
	BCF	-0.90 (0.61)	0.140	9.39 (6.27)	0.136	45.64 (47.75)	0.341	-8.43 (6.96)	-29.30 to 0.79	0.15
	EM	-1.00 (0.58)	0.083	12.12 (6.39)	0.060	72.91 (46.39)	0.118	-12.17 (9.04)	-35.82 to 0.55	0.11
Outcome expectancies	CC	-0.37 (0.35)	0.286	22.29 (15.72)	0.159	85.76 (59.77)	0.154	-8.25 (12.87)	-51.63 to 3.83	0.12
	BCF	-0.15 (0.27)	0.588	14.68 (13.94)	0.294	44.44 (47.62)	0.352	-2.18 (6.88)	-26.22 to 4.52	0.14
	EM	-0.60 (0.28)	**0.034**	21.39 (13.06)	0.104	77.89 (46.57)	0.097	-12.87 (12.64)	-50.70 to 1.74	0.11
Environment	CC	-1.20 (0.38)	**0.002**	26.58 (14.10)	0.062	103.78 (61.40)	0.094	-31.84 (18.19)	**-77.65 to -5.62**	0.12
	BCF	-0.88 (0.31)	**0.005**	18.87 (12.49)	0.133	59.42 (48.92)	0.226	-16.54 (11.39)	**-47.39 to -0.78**	0.14
	EM	-1.25 (.32)	**<0.001**	22.91 (11.53)	**0.049**	92.22 (48.28)	0.058	-28.57 (15.46)	**-69.42 to -5.84**	0.11
Social support	CC	-0.85 (0.61)	0.170	24.51 (8.59)	**0.005**	91.03 (58.21)	0.121	-20.79 (19.06)	-76.65 to 2.95	0.16
	BCF	-0.34 (0.51)	0.501	18.67 (7.41)	**0.013**	48.68 (46.95)	0.302	-6.37 (11.29)	-40.32 to 9.27	0.17

	EM	-1.04 (0.48)	**0.033**	23.75 (7.46)	**0.002**	87.85 (45.71)	0.057	-24.66 (16.51)	**-71.98 to -2.51**	0.14
Intention	CC	0.41 (0.26)	0.112	65.36 (20.36)	**0.002**	41.42 (57.65)	0.474	26.78 (19.38)	-2.92 to 77.43	0.18
	BCF	0.34 (0.21)	0.105	52.46 (17.92)	**0.004**	21.17 (46.87)	0.652	17.78 (13.17)	-1.88 to 52.37	0.18
	EM	0.39 (0.20)	0.052	64.67 (17.70)	**<0.001**	34.40 (44.82)	0.444	25.38 (15.81)	**1.83 to 63.92**	0.17
Planning	CC	2.22 (1.33)	0.098	9.22 (4.01)	**0.023**	49.80 (59.09)	0.401	20.47 (15.02)	**0.36 to 65.52**	0.14
	BCF	1.73 (1.11)	0.121	9.21 (3.35)	**0.007**	24.65 (46.99)	0.601	15.98 (12.01)	-2.04 to 45.61	0.17
	EM	1.99 (1.04)	0.056	9.44 (3.51)	**0.008**	43.70 (45.88)	0.342	18.80 (12.29)	**2.14 to 54.07**	0.13
Behavioral mediators										
Sleep quality	CC	-1.31 (0.49)	**0.008**	-8.00 (11.12)	0.473	56.54 (61.46)	0.359	10.52 (14.97)	-13.43 to 48.36	0.10
	BCF	-0.88 (0.40)	**0.030**	-15.56 (9.38)	0.099	26.41 (48.04)	0.583	13.74 (10.82)	-0.17 to 43.31	0.15
	EM	-1.35 (0.40)	**0.001**	-7.61 (9.17)	0.408	52.19 (47.91)	0.278	10.25 (13.26)	-12.89 to 40.83	0.09

DV = Sleep quality		**A path (IV on MV)**		**B path (MV on DV)**		**C' path (IV on DV)**		**A*B (Mediated effect)**		
Psychosocial mediators		**a (SE)**	***p***	**b (SE)**	***p***	**c' (SE)**	***p***	**ab (SE)**	**95% CI**	**R^2**
Self-efficacy	CC	-0.14 (0.74)	0.848	-0.02 (0.06)	0.714	-1.22 (0.49)	**0.014**	0.00 (0.05)	-0.08 to 0.15	0.44
	BCF	-0.10 (0.64)	0.876	0.02 (0.05)	0.686	-0.78 (0.40)	0.054	0.00 (0.04)	-0.10 to 0.05	0.50
	EM	-0.48 (0.66)	0.472	-0.04 (0.05)	0.396	-1.25 (0.40)	**0.002**	0.02 (0.06)	-0.04 to 0.22	0.36
Perceived capability	CC	-0.74 (.85)	0.389	-0.10 (0.05)	0.060	-1.19 (0.48)	**0.015**	0.07 (0.10)	-0.05 to 0.49	0.46
	BCF	-0.71 (0.71)	0.318	-0.08 (0.04)	0.084	-0.78 (0.40)	0.051	0.06 (0.08)	-0.03 to 0.31	0.52
	EM	-0.71 (0.71)	0.322	-0.10 (0.04)	**0.030**	-1.26 (0.40)	**0.002**	0.07 (0.10)	-0.04 to 0.36	0.38
Outcome expectations	CC	0.18 (1.51)	0.903	0.04 (0.03)	0.205	-1.14 (0.50)	**0.024**	0.01 (0.08)	-0.12 to 0.23	0.44
	BCF	0.33 (1.19)	0.784	0.02 (0.03)	0.378	-0.80 (0.40)	**0.049**	0.01 (0.05)	-0.06 to 0.19	0.51

	EM	-1.24 (1.22)	0.313	0.06 (0.03)	**0.029**	-1.22 (0.40)	**0.003**	-0.07 (0.09)	-0.34 to 0.04	0.36
Outcome expectancies	CC	0.44 (0.75)	0.552	0.04 (0.06)	0.539	-1.22 (0.50)	**0.015**	0.02 (0.06)	-0.04 to 0.26	0.43
	BCF	0.37 (0.61)	0.551	0.03 (0.05)	0.629	-0.87 (0.40)	**0.034**	0.01 (0.04)	-0.04 to 0.17	0.50
	EM	-0.03 (0.61)	0.959	0.05 (0.05)	0.329	-1.30 (0.40)	**0.002**	0.00 (0.05)	-0.12 to 0.08	0.36
Environment	CC	-0.04 (0.08)	0.655	0.10 (0.54)	**0.015**	-1.24 (0.50)	**0.015**	0.00 (0.05)	-0.15 to 0.07	0.42
	BCF	-0.02 (0.07)	0.802	0.13 (0.49)	0.796	-0.84 (0.41)	**0.040**	0.00 (0.04)	-0.10 to 0.06	0.50
	EM	0.02 (0.07)	0.758	-0.23 (0.44)	0.607	-1.31 (0.41)	**0.002**	-0.01 (0.04)	-0.13 to 0.05	0.34
Social support	CC	0.07 (1.10)	0.951	0.06 (0.04)	0.165	-1.21 (0.49)	**0.014**	0.00 (0.08)	-0.14 to 0.20	0.44
	BCF	0.31 (0.88)	0.725	0.08 (0.04)	**0.031**	-0.92 (0.39)	**0.022**	0.02 (0.08)	-0.11 to 0.22	0.52
	EM	-0.79 (0.91)	0.386	0.05 (0.04)	0.138	-1.31 (0.40)	**0.001**	-0.04 (0.07)	-0.27 to 0.04	0.37
Intention	CC	1.20 (1.57)	0.448	0.02 (0.03)	0.588	-1.28 (0.50)	**0.011**	0.02 (0.06)	-0.05 to 0.24	0.42
	BCF	1.14 (1.28)	0.375	0.03 (0.03)	0.211	-0.89 (0.40)	**0.028**	0.04 (0.06)	-0.04 to 0.25	0.50
	EM	0.58 (1.27)	0.650	0.02 (0.03)	0.515	-1.32 (0.41)	**0.001**	0.01 (0.05)	-0.04 to 0.17	0.34
Planning	CC	0.18 (2.41)	0.942	-0.02 (0.02)	0.423	-1.26 (0.49)	**0.012**	0.00 (0.07)	-0.18 to 0.11	0.43
	BCF	-0.63 (1.95)	0.749	-0.02 (0.02)	0.359	-0.87 (0.40)	**0.032**	0.01 (0.05)	-0.05 to 0.19	0.50
	EM	0.21 (1.97)	0.916	-0.01 (0.02)	0.524	-1.31 (0.40)	**0.001**	0.00 (0.05)	-0.14 to 0.07	0.35
Behavioral mediators										
Physical activity	CC	67.06 (59.57)	0.263	-0.001 (0.001)	0.473	-1.28 (0.49)	**0.011**	-0.04 (0.07)	-0.29 to 0.04	0.43
	BCF	40.15 (47.58)	0.400	-0.001 (0.001)	0.099	-0.84 (0.40)	**0.039**	-0.05 (0.06)	-0.25 to 0.04	0.50
	EM	62.44 (46.24)	0.179	-0.001 (0.001)	0.408	-1.31 (0.41)	**0.002**	-0.04 (0.06)	-0.23 to 0.04	0.35
Sleep hygiene	CC	-1.41 (0.69)	**0.042**	0.13 (0.06)	**0.050**	-1.05 (0.49)	**0.036**	-0.18 (0.15)	**-0.62 to -0.003**	0.44
	BCF	-1.14 (0.60)	0.060	0.15 (0.05)	**0.005**	-0.69 (0.40)	0.083	-0.17 (0.11)	**-0.46 to -0.01**	0.52
	EM	-2.26 (0.71)	**0.002**	0.11 (0.04)	**0.020**	-1.08 (0.41)	**0.009**	-0.24 (0.13)	**-0.58 to -0.05**	0.37

DV = Sleep hygiene		A path (IV on MV)		B path (MV on DV)		C' path (IV on DV)		A*B (Mediated effect)		
Psychosocial mediators		**a (SE)**	***p***	**b (SE)**	***p***	**c' (SE)**	***p***	**ab (SE)**	**95% CI**	**R^2**
Self-efficacy	CC	-0.40 (0.80)	0.617	-0.03 (0.09)	0.753	-1.69 (0.76)	**0.028**	0.01 (0.13)	-0.17 to 0.46	0.60
	BCF	-0.09 (0.64)	0.892	0.00 (0.08)	0.999	-1.07 (0.61)	0.078	0.00 (0.10)	-0.19 to 0.25	0.71
	EM	-0.47 (0.66)	0.477	-0.14 (0.09)	0.104	-2.25 (0.71)	**0.002**	0.07 (0.14)	-0.10 to 0.55	0.42
Perceived capability	CC	-0.91 (0.88)	0.301	-0.14 (0.08)	0.075	-1.80 (0.76)	**0.019**	0.13 (0.19)	-0.10 to 0.73	0.61
	BCF	-0.67 (0.70)	0.343	-0.12 (0.07)	0.081	-1.17 (0.60)	0.055	0.08 (0.14)	-0.10 to 0.54	0.72
	EM	-0.68 (0.71)	0.341	-0.24 (0.08)	**0.003**	-2.37 (0.70)	**0.001**	0.16 (0.19)	-0.13 to 0.66	0.44
Outcome expectations	CC	-0.19 (1.53)	0.900	0.00 (0.05)	0.962	-1.82 (0.77)	**0.020**	0.00 (0.08)	-0.16 to 0.18	0.60
	BCF	0.31 (1.20)	0.796	0.00 (0.04)	0.973	-1.17 (0.61)	0.056	0.00 (0.06)	-0.14 to 0.12	0.71
	EM	-1.24 (1.23)	0.314	-0.03 (0.05)	0.517	-2.32 (0.72)	**0.002**	0.04 (0.10)	-0.06 to 0.39	0.41
Outcome expectancies	CC	0.18 (0.76)	0.814	0.02 (0.09)	0.842	-1.86 (0.74)	**0.014**	0.00 (0.08)	-0.12 to 0.22	0.62
	BCF	0.36 (0.61)	0.556	0.05 (0.08)	0.492	-1.19 (0.59)	**0.046**	0.02 (0.08)	-0.06 to 0.32	0.72
	EM	-0.04 (0.61)	0.951	-0.04 (0.09)	0.640	-2.30 (0.71)	**0.001**	0.00 (0.07)	-0.12 to 0.18	0.42
Environment	CC	-0.03 (0.08)	0.733	-0.03 (0.82)	0.974	-1.67 (0.76)	**0.030**	0.00 (0.09)	-0.15 to 0.22	0.60
	BCF	-0.02 (0.07)	0.802	0.18 (0.73)	0.807	-1.10 (0.61)	0.072	0.00 (0.07)	-0.17 to 0.12	0.71
	EM	0.02 (0.07)	0.754	-0.85 (0.78)	0.276	-2.19 (0.71)	**0.003**	-0.02 (0.09)	-0.35 to 0.08	0.41
Social support	CC	-0.17 (0.11)	0.882	-0.02 (0.06)	0.723	-1.82 (0.75)	**0.017**	0.00 (0.09)	-0.15 to 0.23	0.61
	BCF	0.31 (0.88)	0.723	0.01 (0.05)	0.797	-1.11 (0.60)	0.065	0.00 (0.06)	-0.08 to 0.21	0.72
	EM	-0.79 (0.90)	0.385	-0.06 (0.06)	0.304	-2.27 (0.70)	**0.002**	0.05 (0.10)	-0.06 to 0.41	0.42
Intention	CC	0.83 (1.60)	0.604	0.01 (0.04)	0.802	-1.74 (0.75)	**0.022**	0.01 (0.08)	-0.08 to 0.27	0.61
	BCF	1.14 (1.28)	0.376	0.03 (0.04)	0.502	-1.12 (0.60)	0.065	0.03 (0.08)	-0.06 to 0.30	0.72
	EM	0.57 (1.27)	0.652	-0.02 (0.04)	0.651	-2.21 (0.71)	**0.002**	-0.01 (0.07)	-0.21 to 0.08	0.41

Planning	CC	-0.26 (2.44)	0.916	-0.00 (0.03)	0.874	-1.72 (0.76)	**0.025**	0.00 (0.081)	-0.17 to 0.18	0.60
	BCF	-0.63 (1.95)	0.746	-0.01 (0.02)	0.715	-1.14 (0.60)	0.060	0.01 (0.07)	-0.10 to 0.18	0.71
	EM	0.21 (1.97)	0.913	-0.02 (0.03)	0.471	-2.25 (0.71)	**0.002**	0.00 (0.08)	-0.21 to 0.13	0.41

Note. CC = Complete case analysis; BCF = missing values replaced using baseline carried forward; DV = Dependent variable; EM = missing values imputed using estimation maximization; IV = Independent variable; MV = Mediating variable; $(100*R^2)$ = % variance explained; numbers in bold font indicate a statistically significant effect.

Table S2.

Mean (SD) values of outcome and mediator variables at 3 months based on complete case, baseline carried forward and imputed data

	Complete cases		Baseline carried forward		Expectation maximization	
	IG (n = 59)	**WLC (n = 66)**	**IG (n = 80)**	**WLC (n = 80)**	**IG (n = 80)**	**WLC (n = 80)**
Outcomes						
Physical activity	363.9 (348.80)	312.4 (336.34)	316.12 (323.66)	290.8 (315.86)	363.9 (298.86)	312.4 (305.09)
Sleep quality	6.7 (3.81)	8.0 (3.16)	7.5 (3.85)	8.4 (3.20)	6.7 (3.26)	8.0 (2.85)
Sleep hygiene	29.7 (6.37)	32.0 (6.52)	30.7 (7.21)	31.9 (6.81)	29.7 (5.46)	32.0 (5.87)
Mediators						
Physical Activity						
Self-efficacy	14.3 (9.08)	17.2 (8.91)	15.5 (9.17)	17.3 (8.42)	14.3 (7.78)	17.3 (8.03)
Behavioral capability	6.1 (3.19)	6.5 (2.63)	6.3 (3.02)	6.3 (2.87)	6.1 (2.73)	6.6 (2.38)
Outcome expectations	17.3 (4.79)	18.2 (3.66)	17.3 (4.77)	17.9 (4.06)	17.3 (4.10)	18.2 (3.30)
Outcome expectancies	12.3 (2.59)	13.0 (1.97)	12.6 (2.53)	12.9 (2.09)	12.3 (2.22)	13.0 (1.77)
Environment	7.8 (2.88)	8.8 (2.73)	8.2 (2.80)	8.7 (2.78)	7.8 (2.47)	8.8 (2.46)
Social support	5.8 (3.72)	6.7 (3.66)	6.3 (3.78)	6.5 (3.71)	5.7 (3.19)	6.7 (3.30)
Intention	4.4 (1.47)	4.0 (1.55)	4.5 (1.51)	4.1 (1.51)	4.4 (1.26)	4.0 (1.39)
Planning	12.7 (7.52)	10.8 (7.92)	12.1 (7.78)	10.5 (8.04)	12.7 (6.44)	10.9 (7.16)
Sleep						
Self-efficacy	23.5 (4.87)	23.4 (5.74)	24.0 (5.64)	23.2 (5.60)	23.5 (4.17)	23.4 (5.17)
Behavioral capability	26.0 (5.75)	26.1 (5.43)	26.0 (5.73)	25.7 (5.46)	26.0 (4.93)	26.1 (4.89)
Outcome expectations	40.9 (9.45)	43.0 (10.27)	41.4 (10.03)	42.6 (10.00)	40.8 (8.09)	43.0 (9.24)
Outcome expectancies	20.4 (4.43)	20.5 (5.20)	20.5 (4.80)	20.3 (5.15)	20.4 (3.80)	20.5 (4.68)
Environment	4.0 (0.75)	3.9 (0.83)	4.0 (0.71)	3.9 (0.78)	4.0 (0.65)	3.9 (0.75)
Social support	24.5 (6.70)	25.1 (8.16)	25.8 (6.81)	25.2 (7.83)	24.5 (5.75)	25.1 (7.35)
Intention	42.5 (7.70)	41.6 (11.22)	43.5 (8.10)	41.9 (10.77)	42.5 (6.59)	41.6 (10.10)
Planning	28.0 (15.26)	27.9 (16.26)	27.2 (16.40)	28.1 (15.74)	28.0 (13.07)	28.0 (14.64)