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Mediators of behaviour change maintenance in physical activity interventions for young and middle aged adults: a systematic review

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Mediators of behaviour change maintenance in physical activity interventions for young and middle aged adults: a systematic review.

Abstract

Background: Regular physical activity is important for maintaining physical and mental health. Benefits are optimised when physical activity is maintained. Understanding causal mechanisms is important to inform future interventions.

Purpose: To investigate mediators of physical activity maintenance.

Methods: Six databases were searched (Medline, EMBASE, PsycINFO, CINAHL, Cochrane Database of Systematic Reviews, Web of Science). Eligibility criteria included: Adult non-clinical populations; validated measure of physical activity behaviour at baseline and at least six months post-baseline; control/comparison group(s); reported mediators of physical activity behaviour change. Mediators were examined according to: i) formal mediation tests; ii) mediator association with physical activity outcome; iii) intervention effects on mediators.

Results: There were few formal mediation tests conducted (n=12/39 included studies), and various other methodological limitations were identified. There was some evidence that effective mediators in formal mediation tests at six months and later included the 'Behavioural processes of change' (n=5/6). Many of the included interventions were not effective for changing targeted mediators (only 34% of 413 tests of mediator changes were significant).

Conclusions: There were a number of methodological and statistical limitations in the evidence base. In future, pre-specified formal mediation tests should be carried out and could be aided by a formal framework. Social and environmental variables should be considered in addition to intrapersonal variables. Improving knowledge of how to change hypothesised mediators, based on theory and evidence, will reveal how physical activity behaviour change maintenance can be achieved. Maintenance research would be enhanced by establishing a formal definition of behaviour change 'maintenance'.

Keywords: Physical activity; Maintenance; Mediator; Behaviour change; Intervention; Systematic review

PROSPERO registration: PROSPERO 2015:CRD42015025462

Introduction

Regular physical activity is important for maintaining physical and mental health, and in the prevention and control of chronic diseases [1–3]. In addition, the economic burden attributable to physical inactivity is substantial [4]. Health benefits are more pronounced when physical activity is maintained [5]. Despite this, studies of physical activity interventions are frequently charged with neglecting to report longer-term intervention effects [6–15]. For those studies reporting longer-term outcomes there is little evidence regarding what factors influence longer-term behaviour change [12,15–18]. Consequently, little is known about what causes behaviour to be maintained [19,20], and how interventions should facilitate these factors. Identification of effective mediators would help inform future physical activity interventions. Given this, the present review of physical activity interventions will examine the analyses on mediators of behaviour change maintenance, extending and enhancing of the findings reported in a recent systematic review and meta-analysis [15].

Mediators have been defined as intervening variables in the causal process or pathway between the intervention and effect [21]. Research into mediators of physical activity behaviour contributes to understanding why some people change their levels of physical activity and can lead to improvements in public health interventions, as they will target factors known to cause these changes. Although research on short-term mediators is helpful in identifying how to help people initiate changes, there is an emerging body of literature arguing that processes underlying initiation and maintenance of behaviour change are fundamentally different [14,22,23] and research should consider them separately.

Maintenance research has been hindered by differing perspectives on what constitutes behaviour change maintenance. For example, it has been defined in terms of a timeframe over which the behaviour is carried out [24], how automatic it is [25] or the likelihood of enacting the correct behavioural response at different times and in different contexts [14]. A previous review of adult physical activity interventions employed a two-fold definition of behaviour change ‘maintenance’, requiring significant intervention effects (i.e. any increase in physical activity for intervention versus controls) post-intervention and after a period of no-intervention [6]. However, this definition may restrict the inclusion of interventions relevant for maintenance (e.g. longer-term community-based interventions with ongoing contact or interventions with built environment components which have no defined end period). This is disadvantageous given that several recent reviews emphasise the importance of considering social and environmental influences on physical

activity behaviour to achieve maintenance [14,26–28]. Applying a threshold-based maintenance criterion is also difficult as studies do not always report the magnitude of behaviour changes post-intervention [6].

The current review adopts the operational definition of ‘maintenance’ as existing when changes in physical activity are present at six months post-baseline. This represents a relatively lenient definition of behaviour change maintenance in line with the Transtheoretical Model of behaviour change [24]. People who maintain an increase in physical activity for six months are also usually viewed as successful maintainers in the literature [29] and research shows that the risk for relapse is highest within six months of starting a physical activity programme [30]. Finally, physical activity studies usually target inactive participants, aiming to achieve any increase in physical activity, and government guidelines acknowledge there are benefits to getting at least some physical activity rather than none [31].

The current lack of knowledge regarding what causes behaviour change maintenance or which intervention characteristics are most appropriate for different populations calls for an up-to-date review of potential causal mechanisms operating at individual, social and environmental levels in physical activity interventions with a particular focus on maintenance.

Therefore specific objectives included:

- I. To determine results of formal mediation tests, mediator effects on physical activity outcomes and intervention effects on putative mediators of physical activity behaviour change maintenance
- II. To examine methodological approaches of analysing mediators in physical activity maintenance studies.

Methods

Search Strategy

Six electronic databases were searched: Medline; EMBASE; PsycINFO; Cochrane Database of Systematic Reviews; CINAHL; Web of Science. The search strategy included ‘physical activity’, ‘study design’, ‘behaviour change’ and ‘maintenance’ terms, and was based on previously used strategies [6,15,26,32] (Supplementary file 1). Reference lists of included studies, and relevant systematic reviews were searched for additional references.

Studies were included if they met the following criteria:

- I. Primary aim of the study was to increase physical activity behaviour (interventions targeting multiple health behaviours were excluded)

- II. Adult, non-clinical population (mean age $\geq 18-64$ years). Populations with diagnosed clinical conditions (e.g. Diabetes, Cancer, Cardiovascular disease) were excluded
- III. Physical activity measured at baseline and at least six months post-baseline
- IV. Prospective study design: Randomised controlled trials, cluster randomised controlled trials or quasi-experiments (controlled pre-post trials). Interventions of any duration were considered as some relevant interventions do not actively end (e.g. interventions altering the built environment). Physical activity measurements may have taken place during interventions, directly post-intervention, or after a period of no-intervention
- V. Validated objective or self-report measurement of physical activity (i.e. at least one appropriate validation study could be identified for the target population)
- VI. Control group receiving no intervention or on a waiting list, or a comparison group receiving usual care, minimal intervention or participating in activities unrelated to physical activity
- VII. Performed at least one of the following: (a) formal mediation tests (with physical activity outcomes measured at six months or later), (b) examined association of putative mediators (or mediator changes) with physical activity outcomes (or physical activity changes) which were measured at six months or later, (c) examined intervention effects on putative mediators.

Studies were considered to have conducted formal mediation tests if they reported the significance of the indirect effect using statistical methods such as variants of the causal steps approach [21,33], difference-in-coefficients approach [34–36], product-of-coefficients approach [37,38] or causal inference approach [39,40]. Arguably, studies merely carrying out steps VII.b. or VII.c. above (i.e. analyses other than formal mediation tests), may not be viewed as contributing concrete evidence on mediators of physical activity behaviour change maintenance. However, these were included in the eligibility criteria (and reported distinctly from the results of formal tests) as they can provide important information on putative mediators. A common criticism is that whilst studies measure and report mediators, formal tests are not always carried out [41–43]. Given the dearth of published research on this key issue, we are currently in the position of needing to extract as much information as possible from existing studies. In line with this reasoning, according to MacKinnon and colleagues [44], the most commonly cited method of ‘formal’ mediation analysis in the psychological literature is the Baron and Kenny (1986) [21] causal steps approach. Yet this method is more concerned with establishing conditions necessary for mediation (e.g. VII.b. and VII.c.) than testing the indirect effect or making causal

inferences. Mediation analyses are often carried out based on cross-sectional data [45]. Therefore, studies were included if they examined cross-sectional associations of mediators with physical activity outcomes, or if they examined the association of mediator changes with changes in physical activity. Research has yet to provide a consensus on how such questions should be answered and in the absence of a formal framework all available evidence has been considered, with limitations acknowledged.

For abstracts initially identified, all titles/abstracts were screened by JM with 25% independently screened by RH, and all full texts were independently screened by two reviewers (JM, RH, SB). Consensus was achieved by discussion with a third reviewer in the case of disagreement at both stages of screening. For screening of titles and abstracts, percentage agreement was 90%, Cohen's kappa was 0.62. For screening of full texts, percentage agreement was 86%, Cohen's kappa was 0.71, indicating an adequate level of agreement [46,47]. Data were independently extracted by JM and cross-checked by RH and SB, and disagreements were resolved by discussion with a third reviewer (see Supplementary file 3).

Evidence Synthesis and Analyses

Mediator outcomes were summarised narratively. Due to substantial heterogeneity between studies (e.g. duration of follow-up, variation in measurement instruments used), the wide range of constructs examined as mediators (i.e. some mediators were only examined in one study and most took part in relatively few tests) and variation in analytical approaches used (e.g. some studies carried out formal mediation tests whilst some studies merely examined intervention effects on mediators or examined the association of mediator outcomes with physical activity, some studies analysed cross-sectional data whilst some controlled for baseline values of the mediator), it was inappropriate to combine results quantitatively [48]. Furthermore, previous reviews have observed the tendency for studies not to report effect sizes for non-significant findings [49]. Thus pooled effect size estimates would be biased towards larger effects. Results were categorised according to whether or not studies (i) conducted formal mediation tests, (ii) examined association of putative mediators with physical activity outcomes, (iii) examined intervention effects on putative mediators.

Mediators were categorised according to the 14 domains of the Theoretical Domains Framework (Tables 2-3) [50]. Definitions of all putative mediators are provided in Supplementary file 2. Mediators were summarised according to number of studies testing each construct, number of tests of each construct and proportion of times a significant effect was found and further separated according to the time-point at which they were measured; before six months post-baseline (i.e. <6 months), or six months or later (i.e. ≥6 months).

Therefore it was possible for a single study to contribute more than one test (e.g. for different intervention arms, time-points or if they conducted more than one type of test). Although the focus of this review was maintenance of physical activity behaviour change beyond six months, mediators measured before six months have been examined since temporal precedence is a necessary condition for causal inferences [51]. Based on previous systematic reviews examining the correlates and predictors of physical activity, constructs were categorised as showing 'evidence' if significant in greater than 59% of tests, 'inconclusive' if 34%-59% of tests were significant, and 'no evidence' if significant in less than 34% of tests [49,52].

Methods employed in formal mediation analyses were extracted, specifically: Statistical methods of formal mediation analyses and computing standard errors/confidence intervals; whether studies were powered to detect mediator changes; whether formal mediation analyses were pre-specified in published study protocols; whether mediators were measured prior to physical activity outcomes; whether studies examined changes in mediators and physical activity outcomes from baseline; how 'maintenance' was operationalised in the included studies. This reflected what the literature currently tells us about common limitations of mediation analyses in intervention studies. For example, some methods of computing confidence intervals have been criticised for violating distributional assumptions, leading to under-powered tests [53], and mediation analyses are often under-powered [54,55], data-driven rather than pre-specified and based on theory [56], or over-reliant on cross-sectional data with limitations for causal inference [45].

The Cochrane Risk of Bias tool [57] was used to categorise studies as 'high', 'low' or 'unclear' risk of bias for each domain. Quality of studies for mediation analysis was also assessed using the tool developed by Lubans and colleagues [58] with the three additional items employed by Rhodes and Pfaeffli [43] and Cerin and colleagues [59]. The tool includes 11 items (1='yes', 0='no') and enables studies to be classified as 'high quality' (score 9-11), 'moderate quality' (score 5-8) or 'low quality' (score of 0-4) [43]. The overall quality of studies for mediation analysis was reported to summarise the state of research on the topic [60] and a sensitivity analysis was carried out to include only those studies classified as 'moderate' or 'high' quality [57].

This review adheres to a registered protocol (PROSPERO 2015:CRD42015025462) [61].

Results

Search Results

Searches were conducted up to 10th October 2017 with no lower date boundary. From 6,327 individual records, the full texts of 435 studies were examined, resulting in 39 distinct studies being included (Figure 1). A broad summary of the characteristics and findings of each study is provided in Supplementary file 3. A detailed breakdown of studies carrying out formal mediation tests is provided in Supplementary file 4.

Study Characteristics

Study characteristics are outlined in Table 1. Of the 39 studies examining mediators, 12 studies carried out formal mediation tests and 52 putative mediating constructs were identified. The majority of studies had randomised controlled trial or cluster randomised controlled trial designs (n=33) and included 32,930 participants (mean age 53 years). Intervention duration varied from a single mailing of material to a 24 month intensive multicomponent intervention (mean=7 months; median=6 months). The duration of follow-up ranged between six and 36 months (mean=12 months; median=11 months). Most of the included studies were underpinned by two theories of behaviour change (n=21 Transtheoretical Model; n=19 Social Cognitive Theory). These were also the most commonly examined in studies conducting formal mediation tests (n=8 Transtheoretical Model; n=9 Social Cognitive Theory). Thirteen studies had an objective physical activity measure and 38 included self-report physical activity measures. The majority of studies measured mediators using self-report measures.

Assessments of the risk of bias and quality of studies for mediation analysis are provided in Supplementary file 5. In terms of the quality rating of studies for mediation analyses, three studies were classified as 'high' quality, 25 were classified as 'moderate' quality and 11 were classified as 'low' quality. All 12 studies conducting formal mediation tests were classified as 'high' or 'moderate' quality. There was little difference between the results of the sensitivity analysis including 'high' and 'moderate' quality studies only (Supplementary file 5), and the analysis is presented below with all included studies.

Mediators of Physical Activity Maintenance

Tables 2 and 3 show the number of studies testing mediators, number of times mediators were investigated and percentage of times a significant ($P<0.05$) effect was found for mediators measured before six months post-baseline, or six months and later. In the following paragraphs, information is presented on: the results of formal mediation tests (VII.a.), the results of tests of the association between mediators and physical activity (VII.b.), the results of tests of intervention effects on putative mediators (VII.c.).

Mediators Measured before Six Months Post-Baseline

Twenty two studies examined mediators before six months post-baseline, three of which conducted formal mediation tests, four examined the association of mediators with physical activity outcomes, and 22 examined the mediator for significant intervention effects. In these studies, 30 variables (grouped in 11 categories) were examined with 14 variables being used in formal mediation tests, 18 being examined for an association with physical activity, and 30 being tested for whether the intervention significantly changed the variables. All studies conducting formal mediation tests or examining the association of mediators with physical activity outcomes were classified as 'high' or 'moderate' quality. Fourteen of the 22 studies examining mediators for significant intervention effects were classified as 'high' or 'moderate' quality.

Results of formal mediation tests before six months post-baseline.

Before six months post-baseline, the majority of mediators focused on intrapersonal (e.g. psychological) processes. The only variable for which there was evidence as a mediator in formal mediation tests included 'Behavioural processes of change' (significant findings for 1/1 tests; $n=1/1$, 100%). There was inconclusive evidence for 'Competence' as a mediator ($n=1/2$, 50%). There was no evidence that any of the other intrapersonal variables mediated intervention effects on physical activity in formal mediation tests (significant in 0% of tests). There was no evidence that any socio-environmental variables mediated intervention effects (significant in 0% of tests).

Results of tests of the association between mediators and physical activity before six months post-baseline.

The only intrapersonal variable for which there was evidence of having an association with physical activity outcomes before six months post-baseline was 'Behavioural processes of change' ($n=1/1$, 100%). Tests of 'Physical activity self-efficacy' ($n=2/4$, 50%), 'Awareness of physical activity level/benefits' ($n=1/2$, 50%) and 'Competence' ($n=1/2$, 50%) were inconclusive for showing an association with physical activity. There was no evidence that any of the other intrapersonal variables were associated with physical activity outcomes (significant in 0% of tests). The only socio-environmental variable which was significant in any tests of an association with physical activity outcomes included 'Sports partner', but overall results were inconclusive ($n=1/2$, 50%).

Results of tests of intervention effects on putative mediators before six months post-baseline.

Intrapersonal variables for which there was evidence of significant intervention effects before six months post-baseline included 'Self-regulatory skill use for physical activity' ($n=3/3$, 100%), 'Competence'

(n=2/2, 100%), 'Identified regulation' (n=1/1, 100%), 'Self-determined behaviour beliefs' (n=1/1, 100%), 'Total needs satisfaction' (n=1/1, 100%), 'Behavioural processes of change' (n=5/6, 83%) and 'Stage of change for physical activity/Motivational readiness for physical activity' (n=6/8, 75%). Tests of 'Experiential/Cognitive processes of change' (n=3/6, 50%), 'Enjoyment' (n=1/2, 50%) and 'Autonomy/Perceived choice' (n=1/2, 50%) were inconclusive. There was no evidence for significant intervention effects of any of the other intrapersonal variables (significant in less than 34% of tests). The only socio-environmental variable for which there was evidence of having significant intervention effects was 'Descriptive norms/Social modelling' (n=2/2, 100%). Tests of 'Social support (family)' (n=1/2, 50%) were inconclusive.

Mediators Measured at Six Months or Later

Thirty eight studies examined mediators at six months or later, 11 of which conducted formal mediation tests, 17 tested for an association with physical activity outcomes, and 37 examined the mediator for significant intervention effects. In these studies, 49 variables (grouped in 13 categories) were examined with 29 variables being used in formal mediation tests, 34 being examined for an association with physical activity, and 49 being tested for whether the intervention significantly changed the variables. All studies conducting formal mediation tests were classified as 'high' or 'moderate' quality. Fourteen of the 17 studies examining the association of mediators with physical activity outcomes and 26 of the 37 studies examining mediators for significant intervention effects were classified as 'high' or 'moderate' quality.

Results of formal mediation tests at six months or later.

The majority of variables tested at six months or later focused on intrapersonal processes. Variables for which there was evidence as mediators in formal mediation tests at six months or later included 'Revitalisation' (n=4/4, 100%), 'Autonomy/Perceived choice' (n=2/2, 100%), 'Competence' (n=2/2, 100%), 'Total needs satisfaction' (n=2/2, 100%), 'Self-regulatory skill use for physical activity' (n=1/1, 100%), 'Physical activity integrated in the self-concept' (n=1/1, 100%) and 'Behavioural processes of change' (n=5/6, 83%). Tests of 'Awareness of physical activity level/benefits' (n=2/4, 50%), 'Intention to change physical activity' (n=2/4, 50%) and 'Enjoyment' (n=1/2, 50%) were inconclusive. There was no evidence that any of the other intrapersonal variables mediated intervention effects on physical activity in formal mediation tests (significant in less than 34% of tests). There was no evidence that any of the socio-environmental variables mediated intervention effects (significant in less than 34% of tests).

Results of tests of the association between mediators and physical activity at six months or later.

Intrapersonal variables for which there was evidence of having an association with physical activity outcomes at six months or later included 'Competence' (n=2/2, 100%), 'Planning (Strategic)' (n=2/2, 100%), 'Self-regulatory skill use for physical activity' (n=1/1, 100%), 'Pros' (n=1/1, 100%), 'Revitalisation' (n=1/1, 100%), 'Goal setting' (n=3/4, 75%), 'Awareness of physical activity level/benefits' (n=2/3, 67%), 'Behavioural processes of change' (n=3/5, 60%) and 'Planning (Action)' (n=3/5, 60%). Tests of 'Physical activity integrated in the self-concept' (n=1/2, 50%), 'Stage of change for physical activity/Motivational readiness for physical activity' (n=1/2, 50%), 'Enjoyment' (n=1/2, 50%), 'Mood' (n=1/2, 50%), 'Autonomy/Perceived choice' (n=1/2, 50%), 'Total needs satisfaction' (n=1/2, 50%), 'Intention to change physical activity' (n=2/5, 40%) and 'Physical activity self-efficacy' (n=5/13, 38%) were inconclusive. There was no evidence that any of the other intrapersonal variables were associated with physical activity outcomes (significant in less than 34% of tests). The only socio-environmental variable with evidence of having an association with physical activity outcomes included 'Perceived barriers to physical activity/Barrier self-efficacy' (n=5/7, 71%). Tests of 'Social support (family)' (n=4/8, 50%) and 'Social support (friends/community)' (n=4/9, 44%) were inconclusive.

Results of tests of intervention effects on putative mediators at six months or later.

Intrapersonal variables for which there was evidence of having significant intervention effects at six months or later included 'Revitalisation' (n=4/4, 100%), 'Physical activity integrated in the self-concept' (n=3/3, 100%), 'Self-determined motivation/behaviour beliefs' (n=1/1, 100%), 'Competence' (n=1/1, 100%), 'Total needs satisfaction' (n=1/1, 100%), 'Physical activity habit' (n=1/1, 100%), 'Awareness of physical activity level/benefits' (n=3/4, 75%) and 'Self-regulatory skill use for physical activity' (n=3/4, 75%). Tests of 'Stage of change for physical activity/Motivational readiness for physical activity' (n=6/11, 55%), 'Tranquility' (n=2/4, 50%), 'Physical exhaustion' (n=2/4, 50%), 'Pros' (n=1/2, 50%), 'Experiential/Cognitive processes of change' (n=13/29, 45%), 'Decisional balance (pros/cons)' (n=5/12, 42%), 'Behavioural processes of change' (n=11/29, 38%) and 'Intention to change physical activity' (n=3/8, 38%) were inconclusive. There was no evidence for significant intervention effects of any of the other intrapersonal variables (significant in less than 34% of tests). The only socio-environmental variable for which there was some evidence of having a significant intervention effect included 'Perceived environment (home)' (n=1/1, 100%). Tests of 'Social support (rewards and punishment)' (n=2/4, 50%), 'Social support (family)' (n=7/15, 47%), 'Social support (unspecified)/Social influences' (n=4/9, 44%) and 'Social support (friends/community)' (n=6/16, 38%) were inconclusive.

Methods of Mediation Analysis

Formal mediation analyses were conducted in 12 studies [62–73]. A further two studies reported having had the intention to conduct mediation analyses which were subsequently not carried out due to lack of variability in outcomes or non-significant treatment effects for maintenance outcomes [74,75]. Eight studies used the product-of-coefficients method [37], with bootstrapped standard errors (n=5) [38], standard errors based on a first-order delta method (n=2) [76], or asymmetric confidence intervals based on the distribution of the product (n=1) [77]. Two studies employed a linear regression method with the following steps i) physical activity change regressed on treatment group; ii) mediator change regressed on treatment group; iii) physical activity change regressed on mediator change and treatment group. Other methods included structural equation modelling (n=1), and the Baron and Kenny (1986) regression-based approach [21] with Sobel standard errors [76] (n=1).

Three of the 12 studies [65,70,71] conducting formal mediation tests reported adequate power to detect mediator outcomes, one of which was specifically powered to detect mediation [65]. Six studies had published study protocols but did not report the intention to conduct formal mediation analyses [63,67–69,72,73]. Three studies measured mediators prior to the physical activity outcome [63,65,72], and all 12 of the studies examined changes in physical activity and mediator outcomes from baseline, or controlled for baseline values.

Mediators were measured using a range of self-report measures. Nineteen of the 39 included studies in this review investigated whether the intervention had a significant effect on the mediating variable without examining the association with physical activity or conducting formal mediation tests. Seven studies examined whether the putative mediator was predictive of physical activity without testing for mediation formally.

The included studies typically did not state an aim to assess maintenance. For those which did include the aim to assess maintenance, it was poorly defined (e.g. mediators and physical activity outcomes were measured at successive six month time intervals, which is typical in behaviour change interventions [78]).

Discussion

Due to several methodological limitations to how mediation analyses of behaviour change maintenance are conducted in the included studies, as evidenced by our quality assessment for mediation analysis, there are limited definitive conclusions that we can draw from the current evidence base. The majority of mediators examined in this review focused on intrapersonal factors such as psychological processes, emotions or use of skills. Eight different aspects of social support were examined and only four

constructs looked at the influence of the perceived or built environment. For mediators measured before six months post-baseline, most formal mediation tests were non-significant although there was some evidence that 'Self-regulatory skill use for physical activity', 'Behavioural processes of change' and 'Stage of change for physical activity/Motivational readiness for physical activity' showed significant intervention effects (i.e. for intervention versus controls). At six months or later, there was some evidence that 'Behavioural processes of change' and 'Revitalisation' were important mediators in formal mediation tests.

Comparison with Results of Previous Reviews

The present review contributes further evidence of the deficit of formal mediation tests in studies of physical activity interventions. For example, the reviews by Rhodes and Pfaeffli [43], Teixeira and colleagues [42] and Brown and colleagues [41] found that only 16 out of 88 (i.e. 18%) included studies conducted formal mediation tests overall.

Methodological Considerations

The lack of attention to mediation analysis in published protocols of the included studies could suggest that mediation analyses have been carried out on the basis of available data, without having been grounded explicitly in theory [56]. This calls into question whether the included interventions were designed to change the tested mediators. Our assessment of the quality of studies for mediation analyses showed that for ten of the 39 included studies, there was no evidence that interventions were explicitly designed to influence the tested mediating variables. For example, 'Physical activity self-efficacy' has been shown to be important for physical activity behaviour change in previous reviews [42,79,80] but is significant in only 12 of 41 tests of intervention effect at six months or later. Many of the included interventions were not effective for changing targeted mediators (e.g. only 34% of 413 tests of mediator changes were significant) suggesting that current behaviour change techniques may not be appropriate for changing these constructs. Furthermore, our quality assessment reveals that studies have neglected to conduct pilot studies to test the effectiveness of their intervention strategies for changing hypothesised mediators prior to launching full-scale trials. This is an important stage of the research process given that some researchers would advocate that interventions should target mediators and mechanisms rather than physical activity behaviour directly [81–83]. Increased effect may be achieved by refinement of intervention components which target a particular mechanism known to represent a pathway from intervention to effect [84].

Self-report measures, used by the majority of included studies to measure putative mediators (and our quality assessment showed that 29 of the 39 included studies used self-report physical activity measurements only) in this review, are often charged with social desirability bias [85] and most of the included studies were not powered to detect mediator outcomes. Therefore, sample sizes may have been too small to detect real effects [86]. It is apparent that a non-significant result for tests of mediators in the included studies could have been observed for one of five reasons: (1) the tested construct is not an important mediator of physical activity behaviour change maintenance; (2) the intervention was not designed to change the mediator; (3) poor intervention design has left the mediator unchanged; (4) inadequate power to detect mediator changes; (5) inadequate measurement tools.

Most of the studies used a randomised controlled trial design with single randomisation. There is an emerging body of evidence suggesting that robust causal inference and clarification of mediators requires more rigorous study designs (e.g. double randomisation in which there is randomisation of both treatment and mediator; blockage designs where the effects of the mediator are blocked so that mediating processes can be detected only in the unblocked condition; enhancement or randomisation to varying levels of the mediator; purification designs which identify and select components activating the most relevant mechanisms and; pattern matching which examines mediation effects in varying samples and contexts at different times and using different outcome measures) [37,87]. Growing consensus of the need to study causal mechanisms may mean that such designs are more widely adopted in future.

Less than one-third of the studies in the present review used formal mediation analysis techniques. When formal mediation tests are conducted, the literature highlights that their statistical methodology is potentially flawed. Methods of formal mediation analysis such as the Baron and Kenny causal steps approach [21], and other methods which rely on non-experimental data have been criticised as potentially yielding biased results [88]. Regression-based techniques typically rely on assumptions of normality which may be violated due to the typical non-normal distribution of physical activity data [89]. When computing standard errors or confidence intervals for significance testing methods such as the multivariate delta method [76], employed in two studies in this review, impose the usually violated assumption of normality on the distribution of the indirect effect. Resampling methods (e.g. bootstrap), employed in five studies, are usually recommended as being more accurate [53]. Even when carried out on the basis of robust statistical methodology, a study-design flaw of mediation analyses is that causal inferences are frequently made on the

basis of cross-sectional analyses which do not capture the causal process of behaviour change [45]. Our quality assessment showed that only 18 of the 39 included studies adjusted their analyses for baseline physical activity, and only four determined whether changes in mediators preceded changes in physical activity.

Theoretical Considerations

Given the current review's focus on maintenance of behaviour change, it is encouraging that the behavioural processes of change were frequently tested and showed some evidence in formal mediation tests, as the Transtheoretical Model advocates that these are more often utilised in the later stages of change [24]. However, this may be due to the fact that the Transtheoretical Model was the most frequently referenced behaviour change theory in intervention design in this review.

Examination of several constructs proposed by behaviour change theories as being critical for maintenance of behaviour change was scarce. Habit formation, for which there is theoretical [25,90] and empirical [91–94] evidence of association with physical activity behaviour, was examined only once in these studies. Outcome satisfaction, central to Rothman's behavioural maintenance framework [22] was also examined only once. Studies were poor at making the distinction between action and maintenance self-efficacy, proposed by maintenance theories like the Health Action Process Approach and receiving increasing empirical support [95,96]. Therefore, findings of physical activity maintenance may be by happenstance rather than being due to the fact that specific behaviour change maintenance techniques are 'designed-in' from the outset [15,29].

The large number of non-significant findings for mediators tested in the present review suggests that we still have much to learn about how to induce behaviour change maintenance. If we are to uncover the mechanisms underlying maintenance of behaviour change it is important that studies test mediators which theory tells us are specific to those stages. Since the development of theory for behaviour change has focused on initiation, physical activity researchers have traditionally been limited in the range and depth of theories on which to base interventions. Notably, in this review the Transtheoretical Model and Social Cognitive Theory were predominant. More recently, behaviour change theories have been developed with a focus on maintenance [22,97]. However, studies which claim that an intervention is based on a specific theory frequently do not make extensive use of the theory in intervention development [98].

Of the 39 studies included in this review, 18 examined aspects of social support and 15 examined environmental constructs. This is reflective of the prevailing state of physical activity research, and the studies

included in this review, which have tended to focus on altering psychological processes at the intrapersonal level. Whilst research could benefit from examination of multilevel designs [14] it is difficult to objectively quantify changes in the physical environment, and therefore to assess their role as mediators of physical activity behaviour. Prins and colleagues were among the first to examine the mechanisms through which changes to the built environment may lead to changes in physical activity behaviour in a recent Socio-ecological based study [28]. Maintenance may be more effectively achieved by the additional consideration of social and environmental factors and several recent reviews point to their potential to promote physical activity behaviour change [14,26–28]. The results of the present review remain largely inconclusive regarding the potential of social and environmental factors to cause maintenance of physical activity behaviour change. Theory has yet to tell us exactly how maintenance of behaviour change should occur, and until it does, studies may provide measurements of physical activity maintenance without making clear how it is achieved.

Strengths and Limitations

We believe that the current review is the first to investigate mediating variables reported in physical activity interventions with a particular focus on maintenance. It is the most comprehensive review of mechanisms of behaviour change maintenance, as previous reviews have typically focused on single theories. The categorisation of results according to the type of analysis carried out permitted us to focus on studies providing the strongest evidence of mediating effects. The results of formal mediation analyses yield a similar pattern to the results of analyses examining the association of mediators with physical activity or intervention effects on mediators (e.g. for both types of analysis, behavioural processes of change are important mediators before six months post-baseline, revitalisation and behavioural processes of change are important mediators at greater than six months). This indicates that consideration of analyses that can inform about mediation in addition to formal mediation tests was a sensible approach to partially account for the limitations of the evidence base.

Heterogeneity in terms of study design, self-report measures and the range of variables investigated in these studies complicated the matter of summarising effects across studies and a quantitative synthesis was not possible. In general, the issue of addressing heterogeneity in the research literature is made challenging by inconsistencies in reporting of study methods and results. Due to the range of variables tested as putative mediators, results are based on a small number of tests per variable or multiple tests carried out within the

same study. Poor reporting of mediators, potentially due to publication bias, makes it unclear whether there is a lack of evidence or lack of effect for variables with no significant mediating effect.

Recommendations for Future Research

There is a clear need for established guidelines outlining how mediation testing should be approached, deciding which constructs should be measured, how and when these should be measured, appropriate statistical approaches (with particular reference to the nature of the data), experimental conditions facilitating causal inference and quality assessment. It is vital for research to answer the question of how interventions can change targeted mediators before we can draw definitive conclusions regarding which are the most effective mediators for achieving physical activity behaviour change maintenance and interventionists should conduct pilot studies testing their mediation hypotheses prior to conducting full-scale trials. For example, several reviews have been published highlighting the most effective techniques for changing 'Physical activity self-efficacy' and future studies attempting to achieve behaviour change via changes in this construct should make use of this evidence [79,80,99]. There is also a need for evidence regarding the most effective techniques for altering other potentially effective mediators.

Hypothesised mediators of physical activity maintenance should be measured prior to physical activity outcomes, at time-points reflecting the process of behaviour change to allow causal inferences about mediation to be made. Future studies should specify mediation tests *a priori* in published protocols, ensuring that variables are selected with reference to theory. Theoretical developments should address the dynamic and time varying nature of behaviour change and its implication for maintenance. When referencing a theory in intervention design, researchers should make extensive use of the theory in intervention development and test mediators accordingly. Consideration of the interplay between mediators and moderators within the same analysis could also contribute to advancements in theory [100]. Since physical activity is a complex behaviour with multiple levels of influence [101], mediation analyses should incorporate multiple mediators and embrace intrapersonal, social and built environmental influences. Competitive tests of relevant behaviour change theories could help move this field of research forward.

Lack of consensus regarding how maintenance should be defined (including mid-term maintenance and long-term maintenance) and measured remains an issue for clarification but should reflect a dynamic rather than linear, static process. More frequent measures of mediators and outcomes (at longer time-points) would increase understanding of the behaviour change process, from initiation to maintenance. Real-time

monitoring of behaviour with reference to a criterion (i.e. threshold level of physical activity established by research as sufficient for maintenance) would enable identification of periods of relapse and recovery, and prompt measurement of putative mediators (when we know a lapse has occurred) to help better understand these dynamic processes.

Implications for Practice

Several implications for future practice are proposed based on the findings for significant mediators in the present review. However, owing to the methodological limitations of the evidence base and the fact that results generally relied on relatively few tests of each construct (e.g. 'Revitalisation' was tested in one study only [67]), these recommendations are made tentatively. For example, future interventions could promote maintenance by encouraging participants to experience revitalisation from physical activity (e.g. by allowing participants to self-select their physical activity intensity level [102], or by encouraging them to structure their workouts so that intensity is gradually ramped down [103,104]), or to implement the behavioural processes of change (e.g. forming helping relationships supportive of physical activity, substituting physical activity in the place of unhealthy behaviours, restructuring the environment to include cues to physical activity, use of reinforcement management to reward physical activity, observing societal and environmental changes supportive of physical activity) [24].

Conclusions

The present review has shown that there are methodological limitations to mediation analyses of behaviour change maintenance in physical activity intervention studies. Formal mediation tests are rarely conducted or are often based on poor methodology. Formal tests of mediation should be carried out with explicit theoretical rationale and could be aided by establishment of a formal framework. Mediation analyses investigating mediators of physical activity maintenance should be carried out with reference to relevant behaviour change theories for maintenance [22,25,105]. Future studies should include evidence-based techniques for changing hypothesised mediators and investigate constructs with particular relevance for maintenance (e.g. habit formation, outcome satisfaction, social and environmental variables). Further research is also required investigating which behaviour change techniques are most effective for changing hypothesised mediators. Refinement of behaviour change theory and the establishment of a formal definition of behaviour change 'maintenance' should tell us how physical activity behaviour change maintenance can be achieved by interventions.

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Figure 1

Flow of studies through the systematic review process

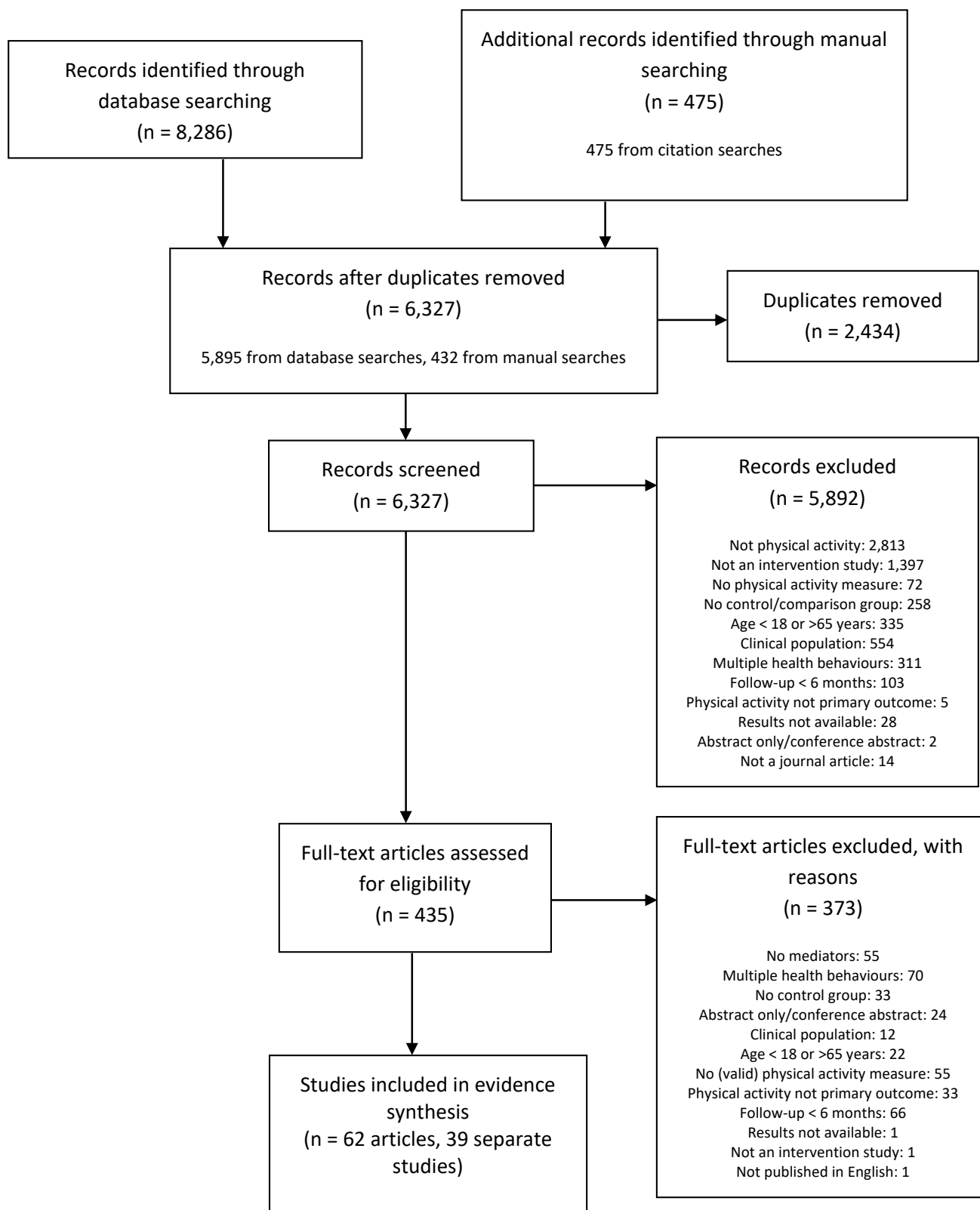


Table 1*Characteristics of 39 included studies*

Characteristics	N (%)
Location	
North America (USA and Canada)	23 (59)
UK	6 (15)
Europe (not UK)	6 (15)
Canada	2 (5)
Asia/Australia	4 (10)
Study design	
Randomised controlled trial	27 (69)
Cluster randomised controlled trial	6 (15)
Quasi-experiment (controlled pre-post)	4 (10)
Non-equivalent control group design	1 (3)
Stepped wedge cluster randomised controlled trial	1 (3)
Participant population	
Mean age ≤53 years	27 (69)
Mean age >53 years	12 (31)
All female participants	8 (21)
All male participants	1 (3)
Male and female participants	30 (77)
Setting	
Community	22 (56)
Work/University	9 (23)
Primary care	8 (21)
Theory	
Transtheoretical Model	21 (54)
Social Cognitive Theory	19 (49)
Self-Determination Theory	4 (10)
Theory of Planned Behaviour	3 (8)
Social-ecological model	2 (5)
Other	11 (28)
Unclear	4 (10)
N.B. several studies employed more than one behaviour change theory	
Physical activity measures	
Objective measures	13 (33)
Subjective measures	38 (97)
International Physical Activity Questionnaire	5 (13)
2-week/7-day physical activity recall	15 (38)
Community Healthy Activities Model Program for Seniors	3 (8)
Behavioral Risk Factor Surveillance System	2 (5)
Pedometer	2 (5)
Accelerometer	9 (23)

Other	14 (36)
N.B. several studies employed more than one form of measurement	
<i>Intervention duration and follow-up</i>	
Intervention duration (months): median (range)	6 (0-24)
Duration of follow-up (months): median (range)	11 (6-36)
<i>Mediator measures</i>	
Intrapersonal	39 (100)
Social	18 (46)
Environmental	15 (38)

NB. Results are n (%) unless otherwise stated.

Table 2

Putative mediators of physical activity behaviour change measured before six months post-baseline (i.e. <6 months) in 22 studies

Putative Mediators (change)	Studies testing formally for a mediation effect			Studies testing whether there is an association between putative mediator and physical activity			Studies testing whether there is an intervention effect on putative mediator		
	No. of studies	Times tested	Significant effect (%)	No. of studies	Times tested	Significant effect (%)	No. of studies	Times tested	Significant effect (%)
Knowledge									
Awareness of physical activity level/benefits	1	4	0	1	2	50	2	3	0
Skills									
Self-regulatory skill use for physical activity	-	-	-	-	-	-	3	3	100
Beliefs about capabilities									
Physical activity self-efficacy	2	5	0	3	4	50	16	21	24
Optimism									
Attitude to physical activity (e.g. instrumental/affective)	-	-	-	-	-	-	1	1	0
Beliefs about consequences									
Outcome expectancies	-	-	-	1	1	0	4	4	25
Outcome satisfaction	-	-	-	-	-	-	1	1	0
Perceived benefits of physical activity/Response efficacy	-	-	-	-	-	-	2	4	25
Intentions									
Intention to change physical activity	-	-	-	-	-	-	2	2	0
Stage of change for physical activity/Motivational readiness for physical activity	-	-	-	-	-	-	6	8	75
Experiential/Cognitive processes of Change	1	1	0	1	1	0	4	6	50
Behavioural processes of Change	1	1	100	1	1	100	4	6	83
Intrinsic motivation for physical activity	2	6	0	2	4	0	2	3	33
Identified regulation	1	2	0	1	2	0	1	1	100
Self-determined behaviour beliefs	-	-	-	-	-	-	1	1	100
Goals									
Goal setting	-	-	-	-	-	-	1	1	0
Memory, attention and decision processes									
Decisional balance (pros/cons)	1	1	0	1	1	0	3	5	20

Pros	1	4	0	1	2	0	1	2	0
Cons	1	4	0	1	2	0	1	2	0
Environmental context and resources									
Perceived barriers to physical activity/Barrier self-efficacy	-	-	-	1	1	0	5	8	13
Social influences									
Social support (unspecified)/Social influences	1	4	0	1	2	0	2	3	0
Social support (friends/community)	-	-	-	1	1	0	1	2	0
Social support (family)	-	-	-	1	1	0	1	2	50
Social support (instrumental/institutional)	-	-	-	-	-	-	1	1	0
Sports partner	1	4	0	1	2	50	1	2	0
Descriptive norms/Social modelling	1	4	0	1	2	0	1	2	100
Emotion									
Enjoyment	-	-	-	-	-	-	1	2	50
Autonomy/Perceived choice	1	2	0	1	2	0	2	2	50
Competence	1	2	50	1	2	50	2	2	100
Relatedness	-	-	-	-	-	-	1	1	0
Total needs satisfaction	-	-	-	-	-	-	1	1	100

A single study may contribute to more than one of the three columns in this table.

Planning (Action)	2	5	20	2	5	60	3	5	20
Planning (Strategic)	1	4	0	1	2	100	1	2	0
Coping planning	1	4	0	1	2	0	1	2	0
Physical activity habit	-	-	-	-	-	-	1	1	100

A single study may contribute to more than one of the three columns in this table.